Columbia River Project Water Use Plan

Lower Columbia River

Reference: CLBMON #29 (Year 6 and Year 7)

Lower Columbia River Juvenile Sturgeon Detection Program: 2013 and 2014 Investigations Data Report

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EXECUTIVE SUMMARY

The population of White Sturgeon (*Acipenser transmontanus*) in the lower Columbia River (LCR) Canada was listed as one of four endangered populations under the Species at Risk Act (SARA) in 2006. 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 to become functionally extinct by 2044 in the absence of effective recovery. Recovery measures were initiated in 2000, with the release of hatchery-reared juveniles occurring annually from 2001 to present. 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, passive sampling was conducted using drift nets in order to determine the distribution of White Sturgeon yolk-sac larvae (YSL) in the LCR and assist in identifying spawning locations. In 2013, drift net sampling was conducted at monitoring sites downstream of Arrow Lakes Generating Station (ALH; rkm 0.1) and Kinnaird (rkm 14.5 – 18.2). Unlike previous years, no drift net sampling was completed at Waneta. Based on development stages of captured YSL, spawning was estimated to have occurred on July 16 and 17 at Kinnaird. No samples were collected at ALH. In 2014, drift net sampling occurred at ALH, Kinnaird, and Waneta. Spawning was not estimated at any of the monitoring sites since live YSL were not sacrificed for preservation and all larvae dead upon capture were in too poor of a condition to developmentally stage. All YSL samples captured during 2013 and 2014 were at an early developmental stage suggesting habitat is not suitable for YSL hiding causing early drift dispersal. Finally, a common garden experiment was designed and implemented to investigate the effects of temperature on development of larvae and morphology. Results from this experiment are important to understanding recruitment processes and natural adaptability in altered systems and can be used as a management tool to increase understanding of White Sturgeon reproductive ecology.

A 2011-2012 genetic study determined the number of adults spawning in the LCR was more than 10-fold the number used in 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 eggs collected in the LCR. Hatched larvae were transported to the Kootenay Trout Hatchery and reared for release in the following spring. While implemented concurrently with the broodstock program, this program was initiated to increase number of adults contributing to stocked offspring, increase effective breeding number, and maintain genetic diversity within the population.

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. In 2013, this was continued 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. To determine distribution of fish throughout the Canadian portion of the LCR, sampling effort was randomly distributed with equal probability within and across each of 5 zones (11.2 rkm in length) ensuring a spatially balanced sampling design. Juvenile captures were predominantly hatchery-released fish with wild juveniles representing <4% of the total catch. High habitat use was documented in the Robson stretch, Kinnaird, and Waneta, with juveniles selecting primarily slow, deep sections of habitat (e.g., deep runs and eddy habitats). Generally, older ages (i.e., 2001 and 2002 year class) represented larger proportions of the total catch but all hatchery release ages of ≥4 years were represented within the high use areas (i.e., Robson Reach and Waneta). Annual growth in length was faster for younger fish (fish released from 2006 -2011) compared to older aged juveniles (fish released 2001-2005). Conversely, older aged juveniles put on more weight per year compared to younger ones. A significant amount of work was conducted to describe the diet of juveniles of all ages and is presented in this report.

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: Additional data pertaining to timing, locations, and frequency of spawning in the lower Columbia River (LCR) are needed to address this question at the larval stage. 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 (1-3 days post hatch) individuals, suggesting early dispersal from spawning locations possibly due to habitat suitability or other factors. Given challenges in sampling for larval sturgeon, it will not be possible to evaluate survival at this early life stage. - Juvenile Stage: Distribution of juveniles has been assessed throughout the LCR, and is restricted primarily to slower moving habitats like eddy's and deeper runs. While these habitats are available primarily in the upper (Robson to Genelle) or lower (Beaver Creek to Waneta) sections of the river, juveniles of hatchery origin are captured throughout the entire LCR. With continued sampling in the coming years, abundance and survival rates will be able to be estimated.
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, the spawning habitat throughout the LCR is presumed to be poor for hiding after hatching from the egg. Further work is needed to address current habitat conditions.

Management Question	Status
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. Additional data will help to further address this question over a longer time period that includes more operational scenarios.

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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).

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., egg 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 determines the location of yolk-sac larvae (YSL) 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 YSL rearing habitats.

Estimating the White Sturgeon spawning period within the LCR using staged eggs has been the primary measure of spawning activity for many years and the best available metric describing the duration of spawning activity. Including staged YSL could improve estimates representing possible spawning days that were not represented by egg samples. Therefore, a study was conducted to quantify the developmental response of White Sturgeon YSL to different temperatures experienced during incubation and the time period leading up to first feeding. Additionally, thermal induced responses in seven larval morphological traits were examined to determine the effects of temperature on growth and resource allocation. Describing thermal induced responses in the development of YSL is important to understanding recruitment processes and natural adaptability in altered systems, and will be used as a management tool to increase understanding of White Sturgeon reproductive ecology.

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). The Conservation Aquaculture Program has been successful in releasing 136,942 hatchery reared juvenile sturgeon into the LCR; 103,362 of which were released in the Canadian portion (as of the spring of 2014).

For conservation aquaculture programs that rely on wild caught broodstock, factors such as number of spawning adults, limited access to spawning adults, and life history characteristics (i.e., intermittent spawning, delayed maturity, skew sex ratios) can lead to management practices that reduce offspring levels of genetic diversity relative to levels represented in the natural spawning population Allendorf and Phelps 1980, Ryman 1991; Crossman et al. 2011). Based on research conducted on White Sturgeon and other species, offspring of naturally produced eggs and larvae are less related and produce greater effective breeding numbers compared to offspring produced from direct gamete collection from adults (Crossman et al. 2011; Jay et al. 2014), as practiced in the LCR Conservation Aquaculture Program. Jay et al. (2014) estimated 121.5 ± 23.7 adults contributing to offspring annually within the LCR. Based on these results, 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. Developing this facility in Canada also aligns with the US portion of the LCR white Sturgeon population, as collections of wild origin larvae serve as the basis for hatchery releases.

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. In addition to growth and survival, it is important to track information on the diet of juvenile White Sturgeon in order to help identify what resources they are using as well as to determine when older juveniles might start switching to consuming other fish. An important objective of this monitoring program was to examine diet composition and prey selectivity of hatchery-reared juveniles. Sturgeon of different ages, size-classes, and from different habitat types were collected to account for important dietary aspects of the species biology. Further, the efficacy nonlethal gastric lavage and lethal removal of the stomach and contents, two methods used to describe the diet of juvenile sturgeon, were evaluated to directly compare field assessments across evaluated factors. These results will expand our knowledge on the feeding ecology of juvenile White Sturgeon, and provide new information on how habitat use and site fidelity influence dietary overlap in a regulated river.

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 YSL and young-of-year life stages, and to understand underlying mechanisms resulting in recruitment failure.

This report describes the sixth (2013) and seventh (2014) years of ongoing 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 and growth of early life stages.

2. Look at the distribution, growth, and survival of both wild and hatchery origin juvenile White Sturgeon.

3. Quantify developmental and morphological responses of YSL to different temperature regimes between incubation and first feeding.

4. Describe juvenile White Sturgeon diet including overall composition and prey selectivity.

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 2013 and 2014 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 YSL and juvenile sturgeon are assessed with sufficient consistency to describe annual trends.

2. Early life stage distributions over time, including location and parameters of YSL and juvenile rearing habitats, are adequately defined.

3. Relationships between YSL 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 YSL 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. Adult Broodstock: Provide eight to ten late-vitellogenic female and eight to ten mature males for induced spawning at the Kootenay Sturgeon Hatchery (KSH) to provide offspring towards an annual objective of 8 genetically distinct families or secondary families.

2. Hatchery Rearing: The successful incubation and rearing of approximately equal numbers of healthy juveniles from each family or subfamily bred in a given year targeting an annual release of 12,000 sub-yearling sturgeon into both the LCR and Mid-Columbia Rivers.

3. Wild Progeny: Collect naturally produced eggs and larvae for streamside incubation and KSH rearing for stocking purposes.

1.3.2 Larval Stage

1.3.2.1 Yolk-sac Larval Assessment

1. Identify timing and frequency of annual spawning days at Waneta, ALH, and Kinnaird sites using drift nets to collect White Sturgeon YSL.

2. Identify specific locations of unknown spawning grounds and describe YSL rearing habitat.

3. Assess YSL development, condition, behaviour, and survival.

4. Determine effects of current operations on YSL survival and rearing habitats.

1.3.2.2 Larval Development and Morphology

1. Quantify thermal induced responses of YSL reared at varying temperatures.

2. Provide an index of YSL development as a tool for estimating fertilization date of wild caught YSL.

3. Examine temperature effects on resource allocation and development of morphological traits.

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.

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.

1.3.3.2 Diet Assessment

1. Evaluate and describe the composition and prey selectivity in the diet of juveniles of different habitats.

2. Determine if site fidelity is a function of food availability or composition.

3. Describe reliability of non-lethal gastric lavage compared to lethal sampling in describing the diet to increase confidence when assessing seasonal or annual diet trends.

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.

1.4 Study Area and Study Period

The study area for the 2013/2014 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.

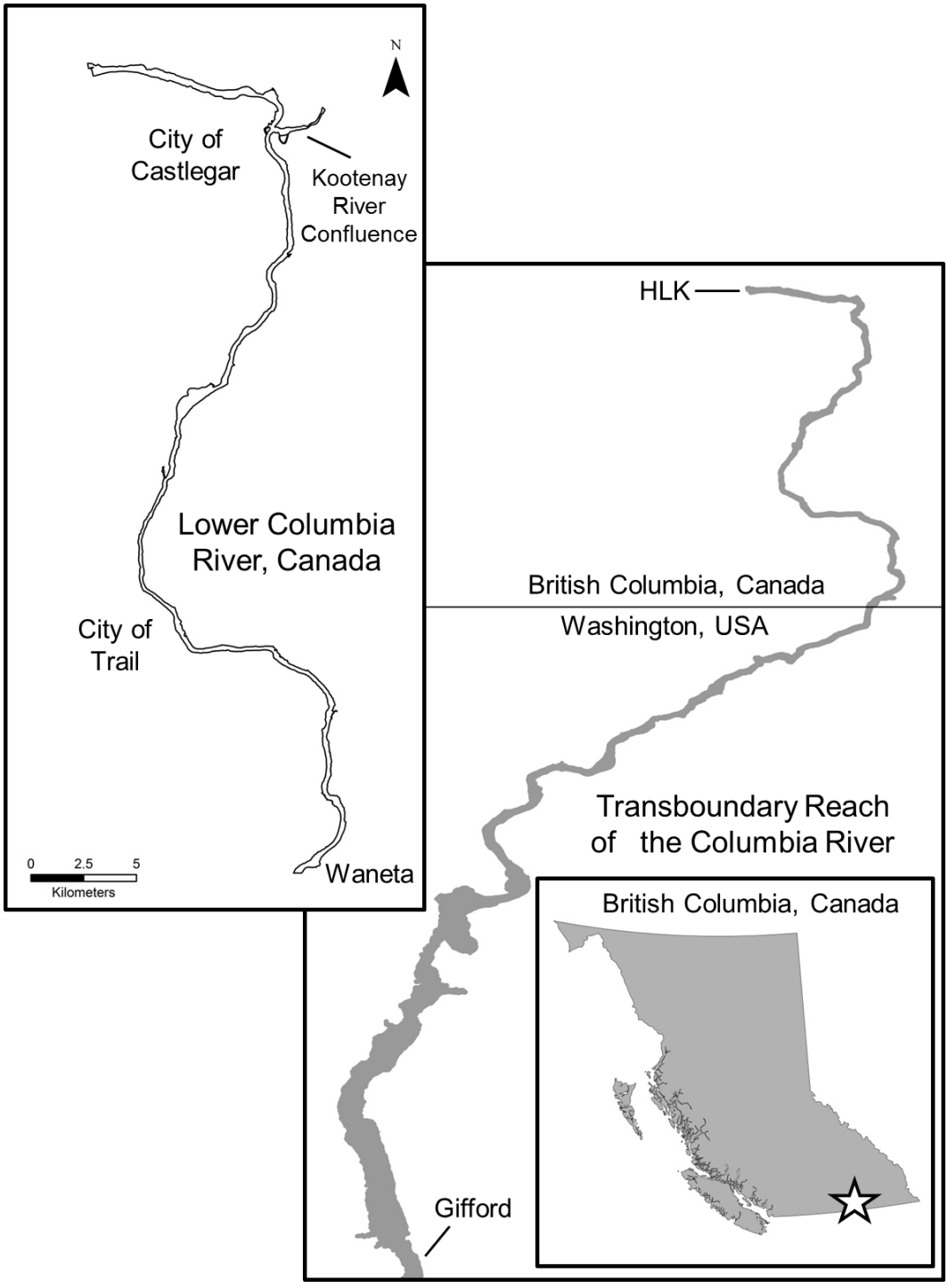


Figure 1. Overview of the study area between HLK (rkm 0.1) and the Canada/US border (rkm 57.0).

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, YSL and juvenile assessments, and a suite of population characteristics including diet composition, and population size estimation. These are described separately below.

2.1 Physical Parameters

2.1.1 Discharge

In 2013/2014, 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 2013/2014 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 Yolk Sac Larval Assessment

2.2.1.1 Study Design

Sampling was conducted at several sites to determine the relative abundance

and distribution of White Sturgeon YSL 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 2013, egg mats were the sole sampling method at Waneta (BC Hydro 2015a), therefore no spawn monitoring data is presented in this report. Drift net sampling was conducted at Waneta in 2014 and results are presented below. In 2013 and 2014, sampling occurred immediately downstream of ALH tailraces as described by Terraquatic Resource Management (2011). Sampling was also conducted downstream of Kinnaird (rkm 14.5 to rkm 18.2) based on previous studies (Golder 2009a), however location of exact egg deposition remains unknown. To address this issue, number of sampling locations at Kinnaird was increased in 2014.

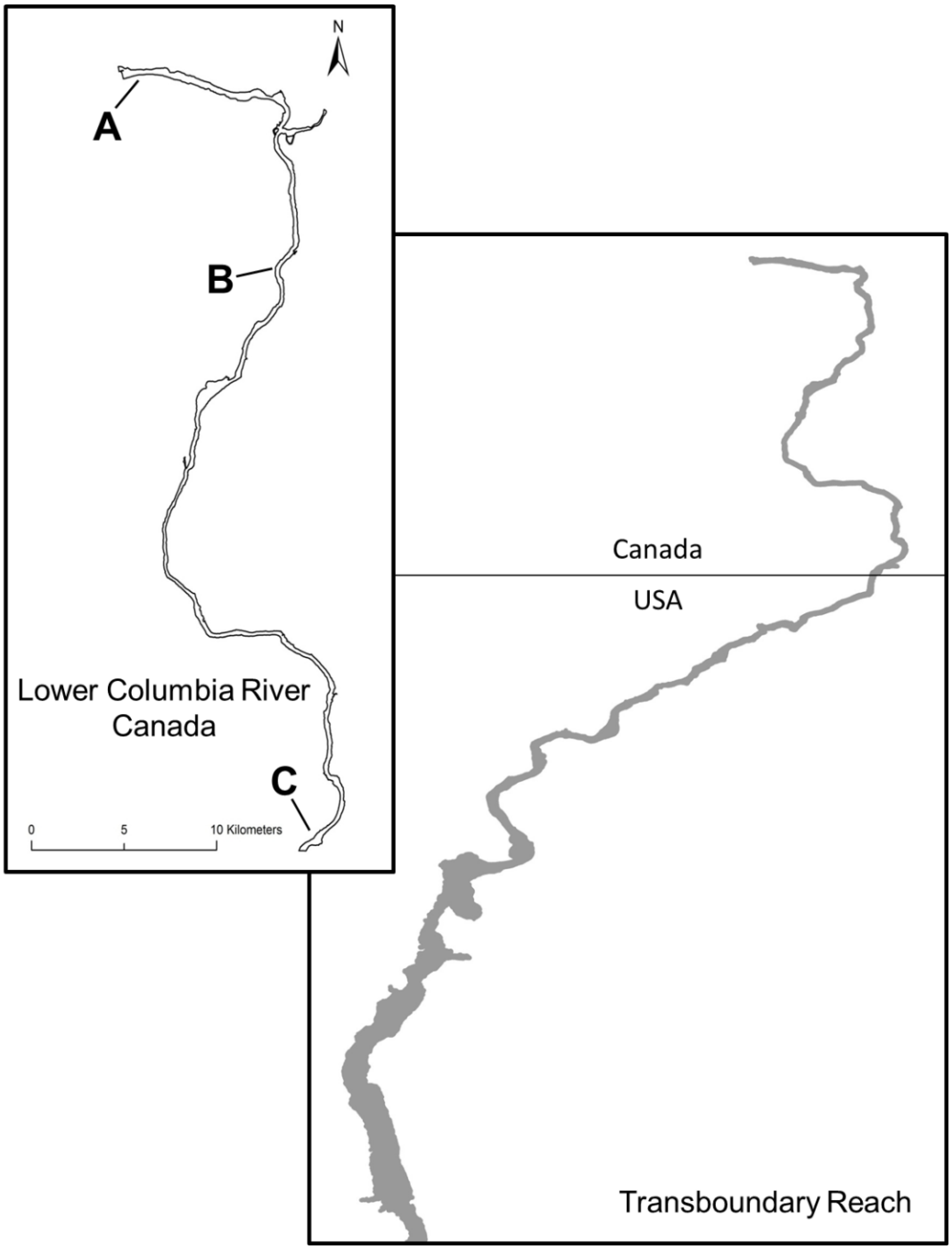


Figure 2. Drift net deployment sites in the LCR including: A) ALH (rkm 0.1), B) downstream of Kinnaird (rkm 14.5 to rkm 18.2), and C) Waneta (rkm 56.0). In 2013, drift net sampling occurred at ALH and downstream of Kinnaird. In 2014, sampling was conducted at all sites using drift nets.

2.2.1.2 Sampling Methods

Drift net sampling has been used successfully to capture passively dispersing YSL for many sturgeon species including White Sturgeon in the LCR (Golder 2009a), 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). In 2013, drift nets were deployed at ALH (n=6), rkm 14.5 (n=2), rkm 18.2 (n=4). In 2014, drift nets were deployed at Waneta (n=2), ALH (n=4), rkm 14.5 (n=2), rkm 15.0 (n=2), rkm 15.6 (n=2), rkm 16.9 (n=1), rkm 17.3 (n=1) and rkm 18.2 (n=4). Catch per unit effort (CPUE) was calculated for each site across years.

Drift net deployment and anchor system specifications were consistent among sampling locations and between sampling years in the LCR. In 2013, drift nets used during the sampling period were of standard design. Standard 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. In 2013, standard drift nets were deployed for 24 hours. In 2014, an altered drift net design was also added to the sampling procedure to prohibit adult and juvenile White Sturgeon from entering the drift net. Altered drift nets included 1.3 cm rolled stainless steel bars welded vertically across the standard drift net frame at 15 cm intervals to prohibit adult and juvenile White Sturgeon from entering the drift net. In 2014, standard and altered drift nets were deployed for 2 to 4 hour (short-set) and 24-hour (long-set) periods, respectively.

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 Larvae Preservation

In 2013, a random subsample of YSL (~20%) collected at Waneta and all YSL collected at the upstream locations were preserved in 95% ethanol for developmental staging and possible future genetic analysis. The disparity of sample preservation between locations is due to the large number of YSL collected at Waneta and relatively few samples obtained at the upstream locations. Samples were collected for developmental staging and estimation of fertilization date (see Section 2.2.1.4). In 2014, all live 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 the upstream locations (ALH and Kinnaird) were preserved for possible future genetic analyses.

2.2.1.4 Developmental Staging and Estimation of Fertilization Date

Preserved YSL 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 YSL classification by Dettlaff et al. (1993), including stages 36 (hatch) through 45 (exogenous feeding). Each developmental stage was associated with the appearance of at least one new feature therefore stages were not determined strictly by quantitative changes. No preserved samples had developed beyond stage 45.

Fertilization dates for collected YSL were estimated by back-calculation from the recorded date and time of preservation based on developmental stage and mean incubation water temperature. The estimated age (hours; see Section 2.2.2) 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, YSL maturation rates, and more importantly, the fluctuation in daily thermal regimes (Parsley et al. 2010).

2.2.2 Temperature Effects on YSL Development

Estimates of White Sturgeon spawning duration and number of spawning events is possible by back calculating fertilization dates based on time and date of capture, developmental stages of eggs and mean water temperatures during incubation (Golder 2009a). Prior to 2011, estimating White Sturgeon spawning period within the LCR using developmentally staged eggs was the best available metric describing spawning duration and has been used as the primary measure of spawning activity for many years. These methods could also be applied to developmentally staged YSL to provide a better representation of all spawning

days, however, data describing the effects of temperature on the development of YSL is required to ensure confidence in these estimates.

Experiments were conducted to quantify the developmental response of White Sturgeon YSL to different temperatures experienced during incubation and the time period leading up to first feeding. Additionally, we examined thermal induced responses in seven larval morphological traits to determine the effects of temperature on growth and resource allocation. Describing thermal induced responses in the development of White Sturgeon is important to understanding recruitment processes and natural adaptability in altered systems, and can be used as a management tool to increase understanding of White Sturgeon reproductive ecology.

2.2.2.1 Gamete Collection and Fertilization

Mature adult White Sturgeon were captured from the LCR in June 2012,and transported to be held at the Kootenay Trout Hatchery, Forte Steele, British Columbia. Females (n=2) were held in tanks maintained at a constant temperature of 15°C throughout captivity. Males (n=2) were initially held at an ambient temperature of 10°C and temperature was increased to 15°C after administration of Luteinizing Hormone – Releasing Hormone analogue (LHRHa; des-Gly10, [D-Ala6] LH-RH Ethylamide). Changes in water temperature were made at 2°C hourly increments to improve acclimation. Females were injected intramuscularly with LHRHa dissolved saline to induce ovulation with a loading dose of 5 µg/kg (10%) and a resolving dose of 45 µg/kg (90%) administered 12 hours apart. Males were intramuscularly injected with a single bolus dose of LHRHa dissolved in saline (10 µg/kg) concurrently with the initial female injection. Females began ovulation and released eggs approximately 24 hours after the resolving injection. Approximately 12,000 eggs (estimated by subsampling a known volume of eggs) were collected from each female using manual expression through the uro-genital opening. Pressure was applied from the anterior section of the abdomen to the posterior in order to extrude eggs. Milt from each male was collected through the uro-genital opening by inserting tygon tubing attached to a 20-cc plastic syringe and applying pressure anterior to the uro-genital opening (Conte et al. 1988). Milt was stored in the syringe at 4°C until required for fertilization or up to 12 hours. Immediately following egg extraction, fertilization and de-adhesion of eggs were completed and fertilized eggs were transferred to hatching jars (MacDonald Type; J30, Dynamic Aqua-Supply Ltd., Surrey, BC) for incubation following methods as described by Conte et al. (1988). The process from egg collection to incubation continued for 90 minutes. Each female was crossed with one male to produce two full-sibling families (F1 and F2). Adult fish were held for three days following spawning to assure they were in suitable condition before release into the LCR.

2.2.2.2 Experimental Treatments

The experimental treatments were constant water temperatures (± 0.2°C) held at 12.5°C, 14.0°C, 15.5°C and 17.0°C during the egg incubation and YSL stages. Temperature treatments were developed based on conditions during White Sturgeon spawning, egg incubation, and YSL stages within the Columbia River (AMEC 2014; Terraquatic 2011; Golder Associates Ltd. 2009a) and other White

Sturgeon inhabited river systems (Fraser River, Perrin et al. 2003; Kootenai River, Paragamian et al. 2001). Both ambient (10.0°C) and heated (17.0°C) groundwater was supplied to each treatment with adjustable valves to maintain the aforementioned temperatures throughout the duration of the experiment. Temperatures were manually measured 4 times per day using a thermometer and necessary adjustments to the water valves were made. Temperature was also recorded hourly (VEMCO Minilog-II-T, Bedford, Nova Scotia) throughout the experiment.

Using family as a replicate, 3,000 eggs were incubated for each temperature treatment. When placed in the hatching jars, eggs were acclimated to the temperature treatments at a rate of 1°C h^{-1}. To ensure adequate egg separation and oxygenation, water flow was maintained at 5 L min^{-1} and raised to 15 L min^{-1} before and after neutralization, respectively. Survival to neutralization was estimated by randomly sampling 100 eggs in each hatching jar.

Upon hatching, YSL were flushed from the hatching jars directly into treatment and family specific rearing troughs (152.4 x 76.2 x 20.3 cm; L x W X H) with water levels of 10 cm depth. Following 100% hatch, water flows were reduced (10 L min^{-1}) to exchange water at least twice per hour but not disturb larvae causing them to swim. YSL exhibit negative phototaxis (Conte et al. 1988), therefore all rearing troughs were covered with dark plastic sheets to eliminate effects of overhead light. Additionally, troughs were supplied with artificial substrate (1" diameter sinking Bio-Spheres; Dynamic Aqua-Supply Ltd. Surrey, BC) allowing YSL to burrow into interstitial spaces preventing an increase in energy consumption among YSL searching for cover that can reduce growth (McAdam 2011, Boucher et al. 2014) or development. YSL were not provided a food source during the duration of the experiment to prevent confounding effects on development across the different temperature ranges.

2.2.2.3 Sampling and Developmental Staging

Ten YSL per treatment were sampled when observations of 50% of eggs had hatched within a hatching jar (time zero) and every 12 hours thereafter until complete yolk-sac absorption. Specimens were euthanized by an overdose of MS-222 (tricaine methanesulfonate) and preserved in Prefer buffer (solution of glyoxcal, buffer and alcohol). Preserved samples were examined using a digital compound microscope (Nikon SMZ-745t Stereo Microscope with 10X eyepiece) and assigned a developmental stage. Enumeration of stages corresponded to the classification by Dettlaff et al. (1993), as follows: stage 36 – hatch; 37 – pectoral fin rudiment, opening of mouth; 38 – gill filament rudiments; 39 – digestive system rudiment divides into stomach and intestine; 40 – ventral fin rudiment; 41 – liver subdivided; 42 – complete liver division, pyloric appendage rudiment; 43 – ventral fin extends to preanal fin fold margin; 44 – complete yolk-sac absorption, discharge of pigment plug from spiral valve. Based on previous studies (Wang et al. 1985; Beer 1981; Dettlaff et al. 1993), 12 hours was assumed to be sufficient sampling intervals to record all developmental stages.

Time (h) and accumulated thermal units (ATU; °C□d; Rombough 1985) were used to measure the initial occurrence of each developmental stage. One thermal unit is accumulated by a specimen held in water of 1°C for 24 h and is

additive for every additional 24 h period. Both units were measured from 50% of observed hatching (t_0 = 0 h; ATU_0 = 0) specific for each temperature treatment. The relative time (RT_i) of each developmental stage was estimated following the formula (Klimogianni et al. 2004):

$$RT_i = (t_i/Tsd)*100\%$$

where RT_i is the relative time of developmental stage *i*, t_i is the time interval (h) from t_0 to developmental stage *i,* and Tsd is total duration of the YSL period (h; development from stage 36 to 44). Since RT_i is a proportional measurement, the same results are given when calculated using ATU.

2.2.2.4 Morphological Traits

Photographs of preserved YSL (n=10) were taken from the time of hatch to the end of the experiment at 24-hour intervals for analysis of seven morphological traits. Due to the volume of individual photographs required to assess multiple traits, we only included temperatures treatments of 12.5^{o}C and 17.0^{o}C in this part of the study. Additionally, there was uncertainty as not all measured traits have been compared for this species, and we expected an increased probability of finding differences in YSL development when comparing the upper and lower temperature treatments. Photographs were taken using a camera adaptor (DS-2Mv colour non-cooled digital camera head) on a digital compound microscope of consistent magnification. A ruler (mm) was placed in the camera's field of view and morphological traits were measured to the nearest 0.01 mm using ImageJ (Rasband, 2010, version 1.43r, Bethesda). Traits included total length (TL; mm), body area (BA; mm^2), yolk sac area (YSA; mm^2), head area (HA; mm^2), mouth area (MA; mm^2), pectoral fin area (PFA; mm^2), and gill filament area (GFA; mm^2). TL, BA, and YSA are common traits measured for sturgeon (*Acipenser transmontanus*, Boucher et al. 2014; *A. fulvescens*, Hastings et al. 2013; *A. brevirostrum*, *A. oxyrhynchus,* Hardy and Litvak 2004) and other fish species (*Danio rerio*, Jardine and Litvak 2003; *Pomacentrus amboinensis*, McCormick 1999; *Morone saxatillis,* Brown et al. 1988) during early life stages. HA was measured as the lateral area of the head from tip of snout to posterior margin of operculum (Figure 3A). MA was measured following the inner margin of the mouth opening (Figure 3B). PFA measured the ventral surface area of the right pectoral fin (Figure 3C). GFA measured the lateral area of all developed gill filaments (Figure 3D). Measurements of TL, BA, HA, PA, GFA and YSA were measured parallel to the sagittal (longitudinal) axis of the body, and MA was measured perpendicular to this axis. Each trait was measured twice for each specimen by a single technician and the mean was used. If the examined morphological trait was damaged, the photograph was discarded.

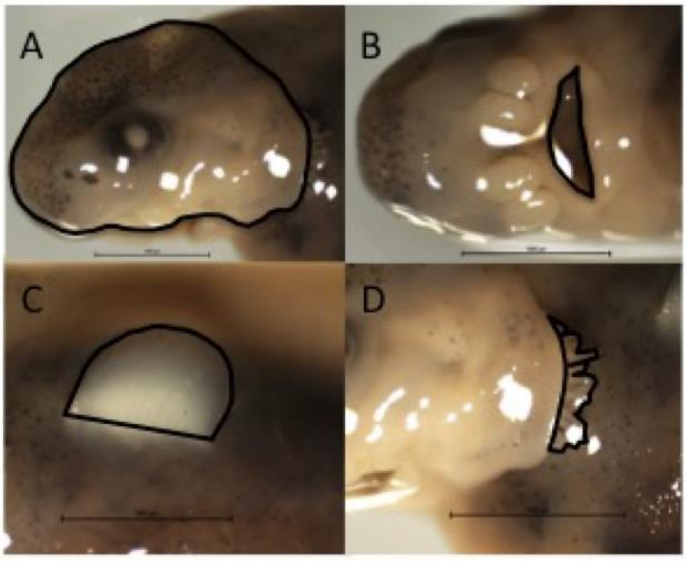


Figure 3. Morphological traits measured to the nearest 0.01 mm including: A – head area (HA; mm^2); B – mouth area (MZ; mm^2); C – pectoral fin area (PFA; mm^2); and D – gill filament area (GFA; mm^2). HA was measured as the lateral area of the head from tip of snout to posterior margin of operculum. MA was measured following the inner margin of the mouth opening. PFA was measured the ventral surface area of the right pectoral fin. GFA was measured the lateral area of all developed gill filaments.

2.2.2.5 Statistical Analysis

All analyses were performed using the statistical software "R" (version 3.0.3, R Development Core Team 2012, http://www.r-project.org). As a function of temperature, the relationship between developmental stage *i*, and initial occurrence of developmental stage *i*, was fitted by a least squares regression. This relationship was calculated for time, ATU and RT_i. Analysis of variance (ANOVA) was used to test for differences in developmental rate among all temperature treatments measured in time, ATU and RT_i. A Student's T-test was applied to test for any difference in size of the morphological traits between the temperatures treatments of 12.5°C and 17.0°C at each 24-hour period, and each developmental stage. Morphological traits could not be compared using ATU since measurements were not recorded based on specific ATU values.

2.3 Juvenile Stage

2.3.1 Conservation Aquaculture Program

Conservation aquaculture has become a critical component of the UCWSRI since 2001 and supports the work conducted under this program through the release of hatchery-reared juveniles. Adult White Sturgeon were acquired from the LCR for broodstock purposes through the Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON 28). Specific capture, handling, induced

spawning, and adult release methodology are described by BC Hydro (2015a, 2015b). Offspring were reared at the KSH for approximately 9 months and released into the LCR during the following spring. Rearing conditions are provided by FFSBC (2014; 2015). Prior to release, fish were measured for fork length (FL; cm), and weight (g). All individuals were administered a Passive Integrated Transponder (PIT) tag from Biosonics Inc. (400 kHz PIT tag or 134.2 kHz ISO PIT tag). PIT tags were inserted into the dorsal musculature at the midpoint between the dorsal and lateral scute lines inferior to the anterior margin of the dorsal crest scute line. Each individual was also marked externally by removal of three left lateral scutes according to a prescribed coding formula corresponding to year class (see FFSBC 2014, 2015, for details). LCR release location was recorded for each individual.

2.3.2 Juvenile Population Monitoring, Abundance, and Characteristics

Starting in 2013, 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. The design of the stock assessment includes two annual surveys, one in the spring and one in the fall, and will continue for five years, ending in 2017. Results presented here only include data collected in the Canadian portion of the LCR. Future reports will include both Canada and USA data.

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 4). 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 (R Core Team 2013; 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 4. Study area for White Sturgeon stock assessment survey occurring from 2013-2017 in the transboundary reach of the Columbia River. Upstream extent of the study area is Hugh Keenleyside Dam (HLK) 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 2.3.3). 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 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 a manner consistent with the marking strategy employed by WDFW and ODFW.

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 captured via the caudal vein to determine ploidy levels (see BC Hydro 2015b for details). Fish were held ventral side up in the stretcher and a blood sample was taken midline just posterior of anal fin. A hypodermic needle (25 gauge) was inserted into the musculature perpendicular to the ventral surface until the spine was reached or blood entered the syringe. Blood was extracted until a sufficient amount was collected (approximately 2 ml) and a blood smear was made immediately after extraction. For each blood smear, a drop of blood was placed on an untreated slide and smeared by placing the end of another slide at an angle and dragging the blood toward the end of the sample slide. Slides were labeled with the fish ID number, air dried, and stored for later analyses by the FFSBC Fish Health Lab. For autopolyploidy assessment see FFSBC (2014, 2015).

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 in 2011 and 2012, as well as previous years including 2009 and 2010 (BC Hydro 2013a), 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).

Statistical analyses were performed using JMP (Version 12.0.1; SAS Institute Inc. 2015). The relationship between year class (including wild fish as a factor) and data on FL, weight, and W_r were each examined. The influence of sampling zone on each of FL, weight, and W_r was also examined. Where normal distributions were present, an Analysis of Variance (ANOVA) and Tukey-Kramer HSD tests were used to determine differences. When nonnormal distributions were identified, data transformations were conducted followed by an ANOVA and Tuky-Kramer HSD test. If transformations resulted in a poor goodness of fit (Shapriro-Wilk test for normality), a Wilcoxon's rank-sum test was used to test for differences.

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).

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 Diet Assessment

Reliable methods to describe diet composition of fish are needed to identify potential changes in food availability (Correa and Winemiller 2014) and to determine prey selection in aquatic systems where population sizes are changing (Schindler et al. 1997) or there are other changes at the com- munity level (e.g., invasive species, Vander Zanden et al. 1999). Studies focused on describing the diet help to inform foraging ecology (Mittelbach 2002) and contribute to under- standing ecological interactions in the aquatic community (Krebs 1998). Annual differences in food availability may represent a selective factor leading to differences in growth rates and indirectly influence survival (Osenberg et al. 1988). In particular, knowledge of dietary preferences, along with food availability, has important implications for the conservation of threatened species by helping to identify problems, such as growth limitations due to inadequate food resources that may arise as recovery programs are implemented.

Describing the diet or prey selection can be challenging, especially when studying threatened or endangered species, where sacrificing individuals is either logistically difficult (e.g., limited numbers of individuals available) or not possible due to the species protection status (e.g., permits that restrict lethal sampling). Nonlethal methods to assess diet have been in use for decades and typically involve gut content analysis using stomach suction or flushing (e.g., gastric lavage [GL]) techniques (Bowen 1996; Kamler and Pope 2001). However, field evaluations are needed to validate the efficiency of nonlethal methods compared with lethal sampling, which provides more robust data on which to assess fish diets (Heupel and Simpfendorfer 2010). Identifying shifts in diet in response to various measures implemented through recovery programs for threatened or endangered species (e.g., stocking rates, locations, size at release) is important, and baseline data on how and what prey are selected needs to be established.

Sturgeon species worldwide are threatened (Birstein 1993) and there is a need to evaluate the reliability of results obtained from nonlethal sampling in order to ensure confidence in data used for conservation and recovery planning. Diets of sturgeon have been generally described using stomach contents (SC) obtained from mortalities, GL (Wanner 2006; Brosse et al. 2002), or from assigning trophic status using stable isotopes (Gu et al. 2001). Nonlethal GL is commonly used in the field (e.g., Guilbard et al. 2007), but evacuation rates are generally unknown, though laboratory testing demonstrates some reliability in the technique (Brosse et al. 2002; Wanner 2006). Most studies focused on sturgeon diets have relied on a single method and research is needed to compare the efficacy of different methods available and thereby assure confidence in designing recovery programs for threatened or endangered species for which diet data are lacking.

Information on juvenile sturgeon diets in populations that have been supplemented with hatchery progeny is important when refining recovery programs and long-term population targets. White Sturgeon in the lower Columbia River, Canada, are suffering from recruitment failure (Hildebrand and Parsley 2013) and were listed as endangered under the Species at Risk Act (SARA) in Canada in 2006 (Fisheries and Oceans Canada 2014). Juvenile age-classes have been absent from the LCR White Sturgeon population in recent decades and conservation aquaculture has been a critical component of the recovery program. Supplementation with hatchery juveniles (6–9 months of age) has occurred annually since 2001 and has been successful in re-establishing a strong juvenile component that consists of numerous age-classes (Hildebrand and Parsley 2013). Limited knowledge exists regarding the relationship between the habitats selected for rearing and the feeding ecology of juvenile White Sturgeon, especially as they relate to the regulated LCR, because changes have occurred to both habitat and the aquatic community (e.g., invasive species) since wild juvenile age-classes were last present in the river.

Our study examined diet composition and prey selectivity in juvenile hatchery origin White Sturgeon stocked into the LCR. We collected juvenile White Sturgeon of different ages, size-classes, and from different habitat types to account for important dietary aspects of the species biology. Further, we evaluated the efficacy of two methods, nonlethal GL and lethal removal of the stomach and contents that are used to describe the diet of juvenile sturgeon but have not been directly compared in field assessments across factors evaluated in this study.

2.3.3.1 Study Design

In 2012 and 2013, sampling was conducted within three river sections: (1) rkm 0.1 to 12.0 including the Kootenay/LCR confluence, (2) rkm 13.0 to 26.0, and (3) rkm 45.0 to 57.0 (Figure 5). The relative availability and suitability of juvenile White Sturgeon habitat differed among river sections. Section 1 is predominantly deep (averaging 20 m in the thalweg) and slow moving (<1 m/s), whereas the more downstream sections 2 and 3 are typified by shallower thalweg depths (<10 m) and faster flows (>1 m/s), with slow water habitats limited to occasional large, deep eddies. Juvenile White Sturgeon are distributed throughout all of river section 1 but tend to concentrate in eddy habitats in river sections 2 and 3.

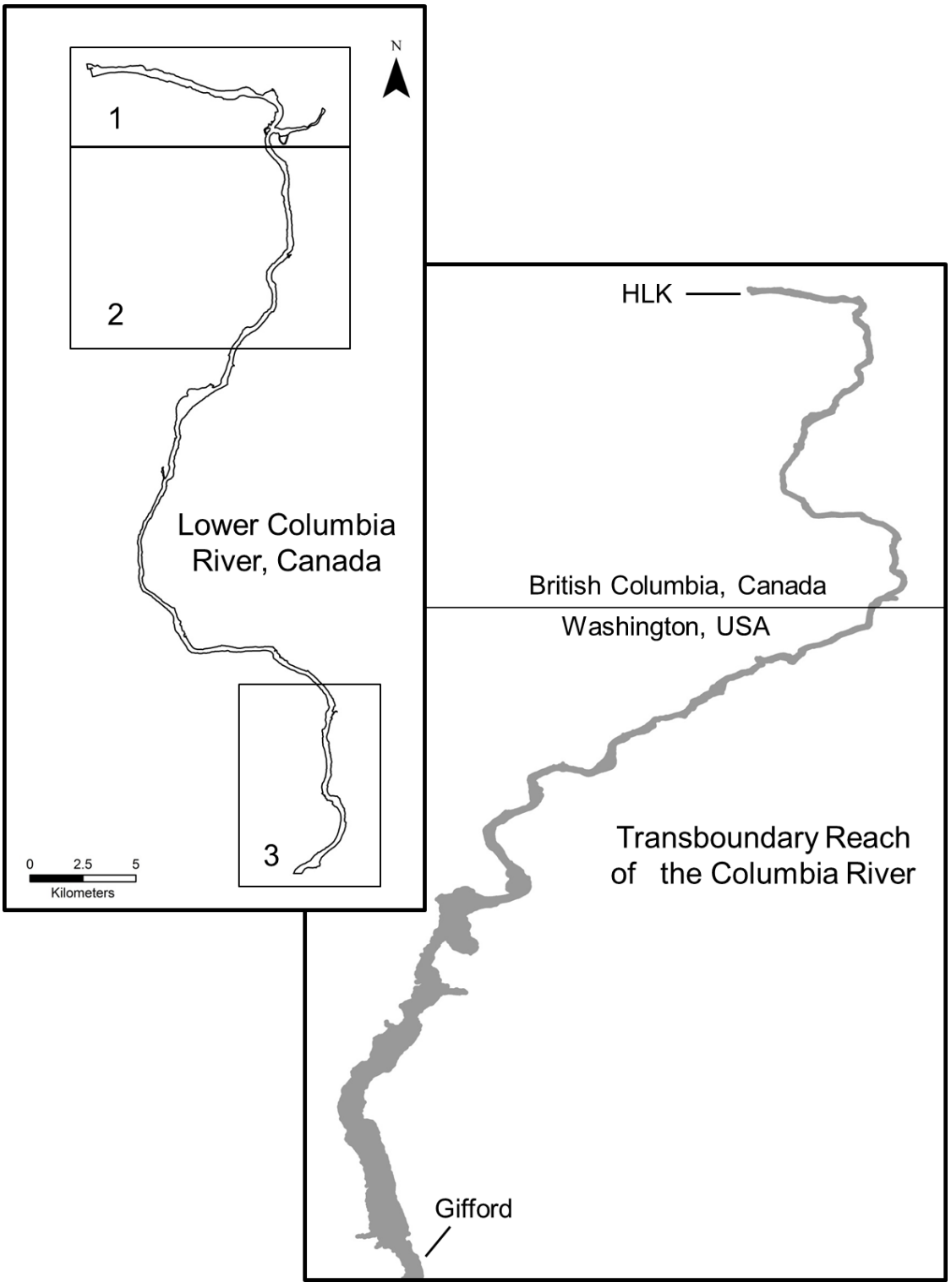


Figure 5. Tranboundary reach of the Columbia River showing the three sections of river where juvenile White Sturgeon were sampled from in 2012 and 2013 for diet assessment.

2.3.3.2 Experimental Design

Due to the listed status of White Sturgeon in Canada, permitting restrictions resulted in the ability to only evaluate lethal methods in one of the two study years. In year 1 (2012), juvenile White Sturgeon of hatchery origin were collected from river sections 1 and 3 in the LCR (Figure 5). We focused on the upstream and downstream-most river sections because fidelity to these specific areas has been shown to be high and observed differences in growth rates (slower growth in river section 3) between the two areas is hypothesized as being a function of diet or resource availability (Van Poorten and McAdam 2010; Hildebrand and Parsley 2013). We attempted to collect 25 individuals including at least three juveniles from each of eight age-classes (ages 4–11) from each river section. The ages of captured juveniles were known because all fish were of hatchery origin and were each marked individually with PIT tags prior to being stocked into the LCR. Further, in an attempt to acknowledge the documented variability in juvenile length at age, as described in Hildebrand and Parsley (2013), we aimed to collect individuals within each age-class from each of three size-classes (40–70 cm, 71–100 cm, >100 cm FL). All fish captured in 2012 were sacrificed, and sampling continued until juveniles from all age-class and size-class criteria were collected from both river sections or when >2 weeks of effort was expended in a specific river section. In year 2 (2013), sampling was expanded to also include section 2. We attempted to collect 50 individuals from each river section representing 11 age-classes (ages 2–12) and 3 size-classes (40–70 cm, 71–100 cm, >100 cm FL). Sampling was terminated when this sample size was reached or when >2 weeks of effort was expended in a specific river section. No individuals were sacrificed in 2013. We used a generalized random-tessellation stratified sample design developed by Stevens and Olsen (2004) to randomly assign sampling locations with equal probability within each river section. This was conducted with the statistical package R (R Core Team 2013) using the library packages spsurvey and sp, provided by the U.S. Environmental Protection Agency.

2.3.3.3 Fish Capture

Angling, the sole method used to capture juvenile White Sturgeon, was conducted in the month of October in each year during daylight hours (between 0800 and 1600 hours). This method allowed the rapid collection of fish, which limited digestion and potential regurgitation of prey items. At each sampling location, angling was conducted from an anchored boat for a minimum of 0.5 h. If no juvenile White Sturgeon were captured, sampling moved to the next predetermined location. At locations where fish were captured, sampling continued for a maximum of 3 h. Angling gear consisted of a heavy action rod, 45–58-kg test braided nylon line, and barbless J-hooks (size 8/0) baited with earthworms. A lead weight (350–700 g) was attached approximately 0.3 m above the hook to ensure the bait remained on the river bottom. The time each juvenile was hooked and landed was recorded. Additionally, water depth and temperature were recorded at each sampling location.

At capture, fish were immediately measured (FL; 0.5 cm) and weighed (0.1 g) and scanned for the presence of a PIT tag to determine origin and, if hatchery origin, age. We only used hatchery-origin juveniles. In both study years,

juveniles that matched the origin, age, and size criteria described above had GL performed immediately after landing. In 2012, the fish were euthanized after GL and the SC were removed.

2.3.3.4 Gastric Lavage (GL)

Modified GL (Haley 1998; Kamler and Pope 2001; Brosse et al. 2002; Barth et al. 2013) was performed on all juvenile White Sturgeon immediately following capture. Individuals were held ventral side up, with the snout pointing downwards at a 45° angle. A small plastic tube (3.0-mm external diameter), connected to a pressurized 4-L container with regulated flow, was inserted through the mouth and into the esophagus as far as the first stomach loop following methods described by Wanner (2006). The appropriate distal location of the tubing was felt by hand through the ventral surface. Water was injected in a pulsed manner into the stomach while slowly withdrawing the tube. While the water was being flushed into the stomach, the ventral surface of the abdomen wall was massaged by hand to facilitate dislodging SC. All regurgitated water was sieved through a 100-µm mesh screen, and all SC were preserved in 10% formalin solution. If no prey items were recovered after administering 4 L of water, lavage was stopped. The time lavage started and ended was recorded. Prey from all samples were classified to the lowest taxonomic level practical (usually order) and counted.

2.3.3.5 Stomach Contents (SC)

In 2012, complete SC were taken from all collected juveniles to quantify individual diet composition and determine the efficiency of GL. Immediately following lavage, juveniles were euthanized with an overdose of tricaine methanesulfonate (MS-222) at 500 mg/mL of water, and the entire digestive system (esophagus, stomach, intestinal track) was surgically removed and preserved in a 10% formalin solution. Prior to preservation, the stomach was punctured with a scalpel to ensure preservative entry into the gut. For each juvenile, time immersed in MS-222 and time from capture to preservation of digestive system was recorded. Upon examination in the laboratory, contents of the foregut (esophagus) and midgut (stomach) sections were initially separated for taxonomic identification. The data were then pooled for analysis. Due to partial digestion, prey items in the hindgut were not included in the analysis. However, to verify that the hindgut did not contain prey taxa that were not present in the foregut and midgut, five randomly selected hindgut samples were examined and all possible prey were identified. Prey were classified to the lowest taxonomic level practical (usually order), counted, and the GL data were added for a complete measure of the SC.

2.3.3.6 Benthic Grabs (BG)

To characterize the diet of juvenile White Sturgeon in relation to available prey items in the river, benthic grabs (BG) of the substrate were collected in each year only at locations where fish were captured. Our objective was to accurately reflect the available food in the locations being selected by juvenile White Sturgeon at the time of capture rather than to specific meso or macro habitat

types. At all locations of fish capture, we collected a minimum of two grabs (1-L containers) using a Ponar sampler (15 × 20 cm). All substrate collected in each grab was preserved in a 10% formalin solution and transported to the laboratory where the samples were transferred to a 70% ethyl alcohol solution. The total volume of the sampled sediment was calculated using the depth of sediment in the sample containers and the diameter of the container. The sediments were separated from the potential food items by stirring the sample in a bucket and quickly decanting off the suspended prey items and other organic matter onto a 100-µm sieve. This was repeated until only mineral substrate remained. Prey from all grab samples were classified to the lowest taxonomic level practical (usually order) and counted.

2.3.3.7 Data Analysis

All statistical analyses were performed using R (R Core Team 2013). The numeric abundance of each prey taxon was tabulated for each juvenile White Sturgeon and sampling method (lavage, stomach removal, benthic grab). Importantly, lavage and stomach removal contents were combined to ensure a complete contents measure. To standardize across prey taxa and method, the percent frequency of occurrence (FO) of prey taxa was calculated for each sampling method as the number of samples that contained a prey taxon divided by total number of samples collected. In addition, FO was calculated for each sampling method by river section and year for the combined prey taxa comprising >95% of total prey abundance. Individual fish that did not have prey identified (e.g., empty stomach) were not included in FO calculations.

The relationship between the number of unique prey taxon identified in stomach removal samples and data on age, length, and weight were each tested using a Poisson regression model. We also tested the influence of river section on prey diversity for each SC method. Where equal variances and normal distributions were present, we used a t-test or multiple t-tests for method type with three river sections. When equal variances and nonnormal distribution were identified we used a Wilcoxon's rank-sum test with continuity correction to test for differences.

To determine the efficiency of lavage in describing the diets of individual juvenile White Sturgeon, we compared the percent of total unique prey taxa identified in the lavage and stomach removal samples. Further, we compared the abundance of total prey items collected using both SC methods as a measure of efficiency.

To further evaluate the use of lavage to describe the diet at the population level, we developed a resampling procedure in R to determine the mean number of unique prey taxa identified as sequential juveniles had lavage performed. We used a data set that included each unique prey taxon identified for each sturgeon that had prey items successfully removed during lavage. The list of prey taxa was resampled for 100 iterations, and we calculated the mean and 95% confidence interval (CI) for each cumulative sample. This was conducted to examine the accumulation of unique prey taxa captured by the incremental addition of juvenile White Sturgeon in the data set.

Many species of fish are selective foragers, with preference for specific prey types that may not be in the highest abundance (Mittelbach 2002). Using both

data for prey taxa identified in the diet (both sample methods) and those identified in the BG, we determined preferences for the predominant prey taxa in juvenile White Sturgeon diets by calculating selectivity according to the linear food selection index (L) developed by Strauss (1979):

$$L = r_i - p_i,$$

where r_i is the relative proportion of the ith prey taxon in the diet (both stomach sample methods) and p_i is the relative proportion of the ith prey taxon in the river (grab sample). The linear food index ranges between –1 (complete avoidance) and +1 (strong selection), with L = 0 suggesting that fish are selecting prey i in proportion to its abundance in the river. This method has been used with confidence to describe the selectivity of prey taxa in other species, e.g., Guppies Poecilia reticulate (Zandonà et al. 2011) and Coho Salmon Oncorhynchus kisutch (Kiffney et al. 2014). To calculate L, we assumed that lavage contents adequately described stomach removal contents, so we tested both for overall efficiency of lavage when describing stomach removal and in our resampling approach described above.

In addition, we also determined the amount of overlap in the diets of juvenile White Sturgeon between collection years (2012 versus 2013) and between river sections within each year. The proportion of dietary overlap was estimated using Schoener's (1970) similarity index:

$$\propto = 1 - 0.5\left(\sum |p_{ij} - p_{ik}|\right),$$

where α is the degree of overlap, p_{ij} is the proportion of the ith prey taxon used by group j, and p_{ik} is the proportion of the ith prey taxon used by group k. Schoener's similarity index values range from 0 to 1, where α = 0 is interpreted as the two groups sharing no prey taxa and α = 1 indicates completely identical prey selection. When overlap values exceed 0.6, they are considered to represent a biologically significant overlap in resource use (Wallace 1981). This index is typically used to compare the diets of two species that overlap in distribution but can also provide a sense of how resource use may differ between fish occupying different habitats. As discussed earlier, juvenile White Sturgeon fidelity is high to specific habitats in the LCR (Hildebrand and Parsley 2013), allowing comparison between the different river sections with the assumption that movement during this study was low.

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 YSL 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 et al. 1993). 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 2013 and 2014 study periods are presented Figure 6 and Figure 7, respectively. Minimum and maximum discharge (cms; cfs) for each location and year is given in Table 1.

Table 1. Minimum and maximum discharge (cubic meters per second, cms; cubic feet per second, cfs) at four locations on the LCR in 2013 and 2014.

Location (Year)	Minimum Discharge	Maximum Discharge
Arrow Reservoir (2013)	590 cms (20,859 cfs)	2,146 cms (75,779 cfs)
Arrow Reservoir (2014)	500 cms (17,680 cfs)	2,265 cms (79,982 cfs)
Kootenay River (2013)	448 cms (15,824 cfs)	2,420 cms (85,451 cfs)
Kootenay River (2014)	396 cms (13,995 cfs)	2,532 cms (89,433 cfs)
Birchbank (2013)	1,092 cms (38,581 cfs)	4,434 cms (156,601 cfs)
Birchbank (2014)	1,020 cms (36,009 cfs)	3,740 cms (132,080 cfs)
Border (2013)	1,343 cms (47,440 cfs)	5,720 cms (202,000 cfs)
Border (2014)	1,212 cms (42,800 cfs)	6,258 cms (221,000 cfs)

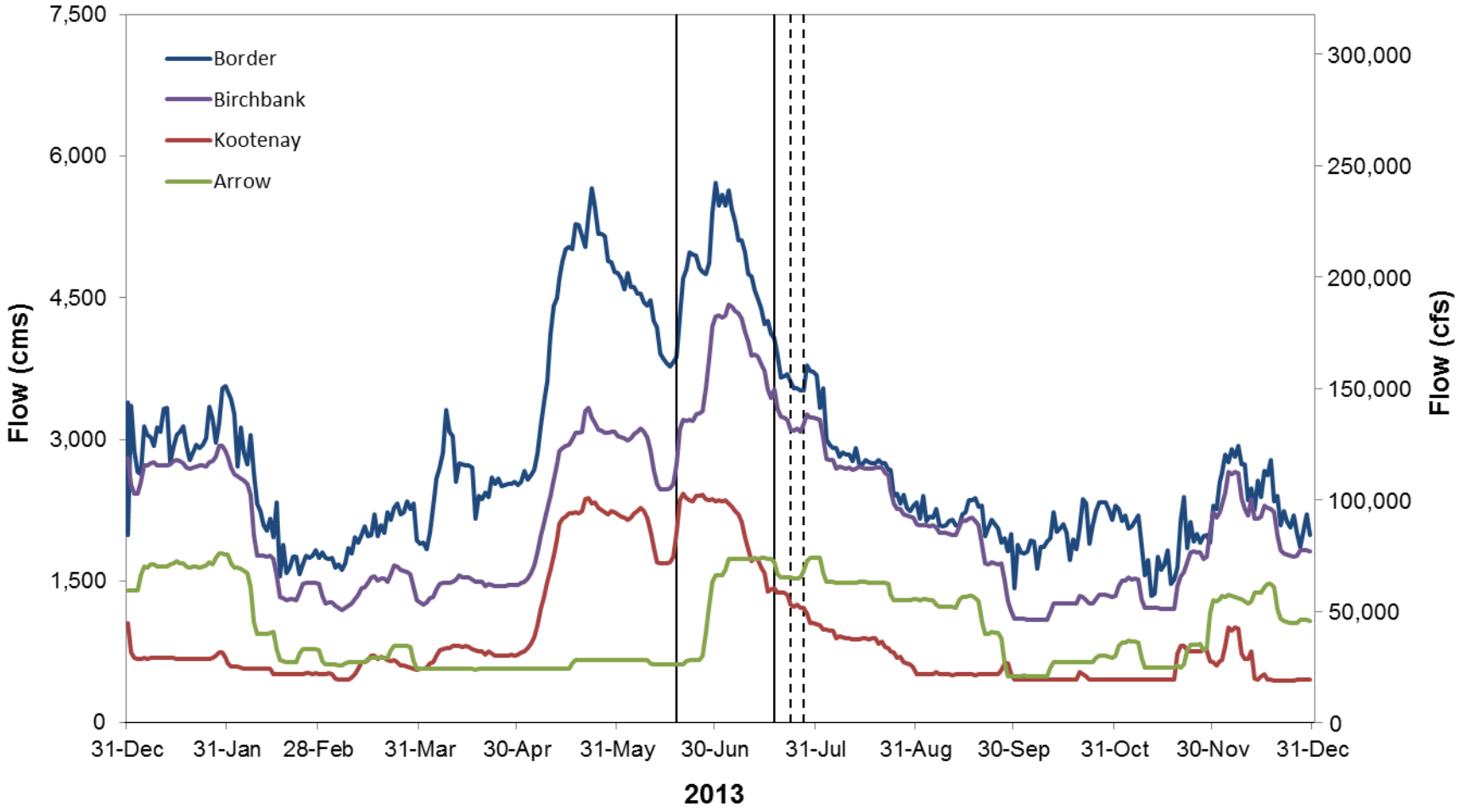


Figure 6. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada/U.S. International Border on the LCR from January 01, 2013 – December 31, 2013. The solid and dashed vertical bars represent the first and last estimated spawning dates at Waneta and Kinnaird, respectively. Estimated spawning dates are based on the developmental stage of collected eggs (BC Hydro 2015a) and/or larvae. Despite sampling effort, estimated spawning dates were not calculated for ALH due to zero captures.

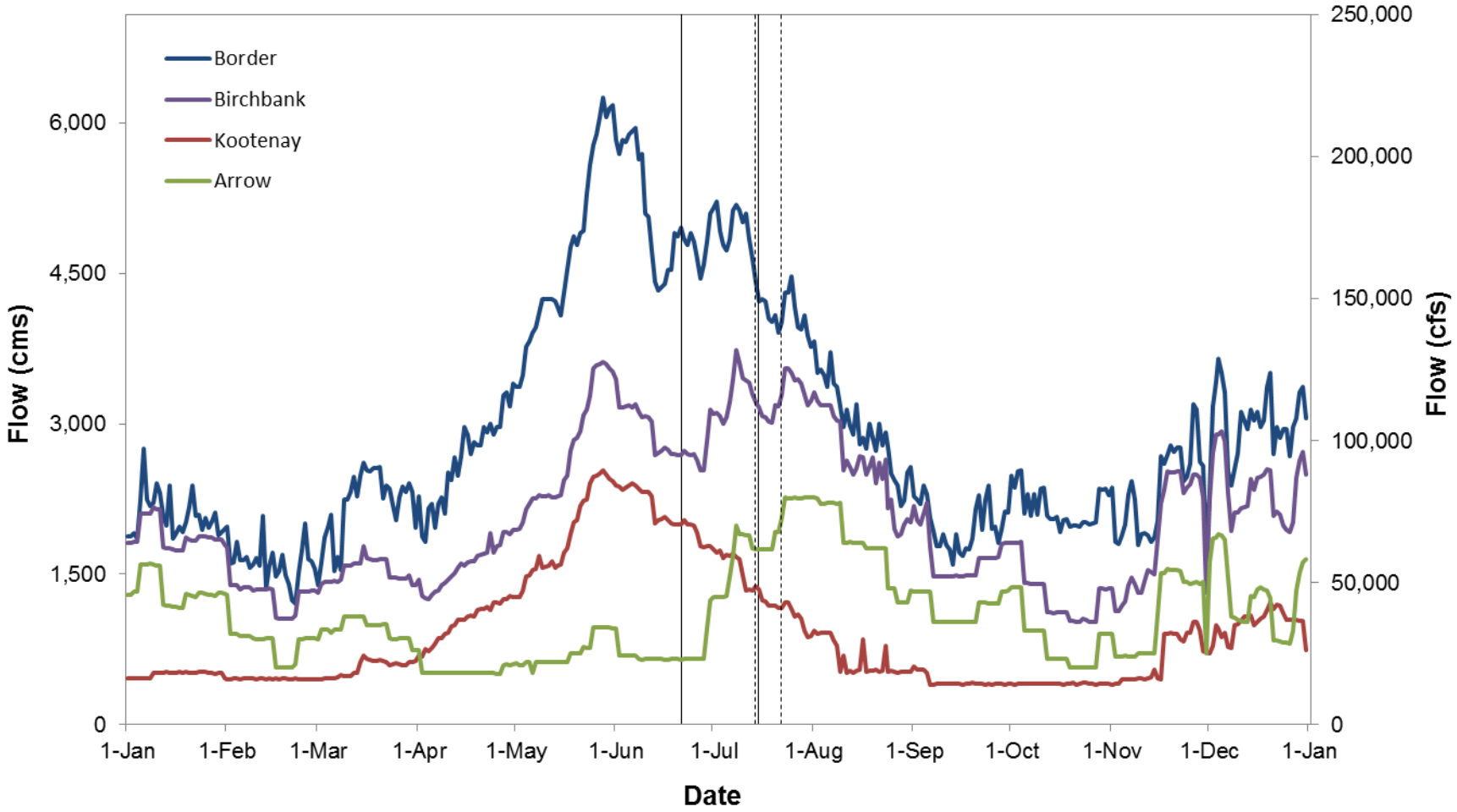


Figure 7. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada/U.S. International Border on the LCR from January 01, 2014 – December 31, 2014. The solid and dashed vertical bars represent the first and last estimated spawning dates at Waneta and Kinnaird, respectively, Estimated spawning dates are based on the developmental stage of collected eggs (BC Hydro 2015b) and/or larvae. Despite sampling effort, estimated spawning dates were not calculated for ALH.

3.1.2 Water Temperature

Mean daily river temperatures (°C) during 2013 and 2014 are illustrated in Figure 8 and Figure 9, respectively. 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), Rivervale (rkm 35.8), and Waneta Eddy (rkm 56.0) for 2013 and 2014 are summarized in Table 2. Variations in water temperatures experienced during the study period can be attributed to warm/cold water influences caused in the Arrow Reservoir system (i.e., combined HLK and ALH discharges from Arrow Lakes Reservoir), and other cold-water tributary influences.

Table 2. Mean (± SD) daily, minimum, and maximum water temperatures (^{o}C) recorded within the LCR during 2013 and 2014. Data was recorded at locations of HLK (rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle Eddy (rkm 26.0), Rivervale (rkm 35.8) and Waneta Eddy (rkm 56.0).

			Temperature			Date of Suspected Spawning Threshold (14°C)
Location	RKM	Year	Mean ± SD*	Minimum	Maximum*	
HLK	0.1	2013	10.0 ± 5.1	4.0	19.0	June 8, 2013
Kootenay	10.5	2013	N/A	3.4	N/A	N/A
Kinnaird	13.4	2013	9.8 ± 5.1	3.9	19.6	July 2, 2013
Genelle	26.0	2013	9.8 ± 5.1	3.8	19.3	July 1, 2013
Rivervale	35.8	2013	N/A	3.9	N/A	N/A
Waneta	56.0	2013	10.1 ± 6.0	2.5	20.8	June 11, 2013
HLK	0.1	2014	N/A	2.5	18.0	July 1, 2014
Kootenay	10.5	2014	9.8 ± 5.7	1.6	20.2	July 6, 2014
Kinnaird	13.4	2014	9.5 ± 5.3	2.0	19.0	July 6, 2014
Genelle	26.0	2014	9.5 ± 5.3	1.9	18.8	July 3, 2014
Waneta	56.0	2014	9.7 ± 5.9	1.3	21.1	July 1, 2014

*data not available due to lost or damaged temperature logger

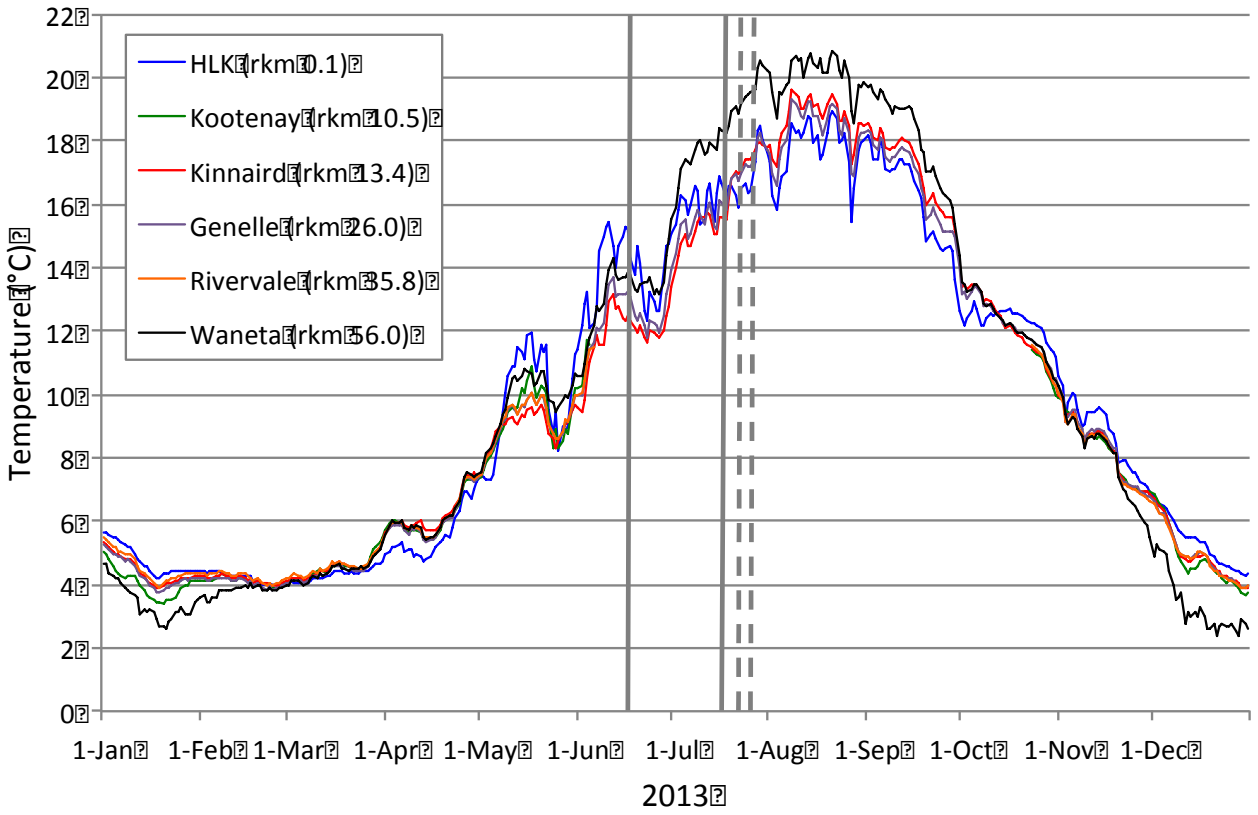


Figure 8. Mean daily water temperature (^{o}C) of the LCR in 2013. Data was recorded at locations of HLK (rkm 0.1), Kootenay (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8) and Waneta (rkm 56.0). Missing data is due to lost or damaged temperature loggers. Vertical solid and dashed lines represent estimated first and last spawning dates at Waneta and Kinnaird, respectively. Estimated spawning duration is based on the developmental stage of collected fertilized eggs (BC Hydro 2015a) and/or larvae. Despite sampling effort, spawning dates were not estimated for ALH due to zero captures.

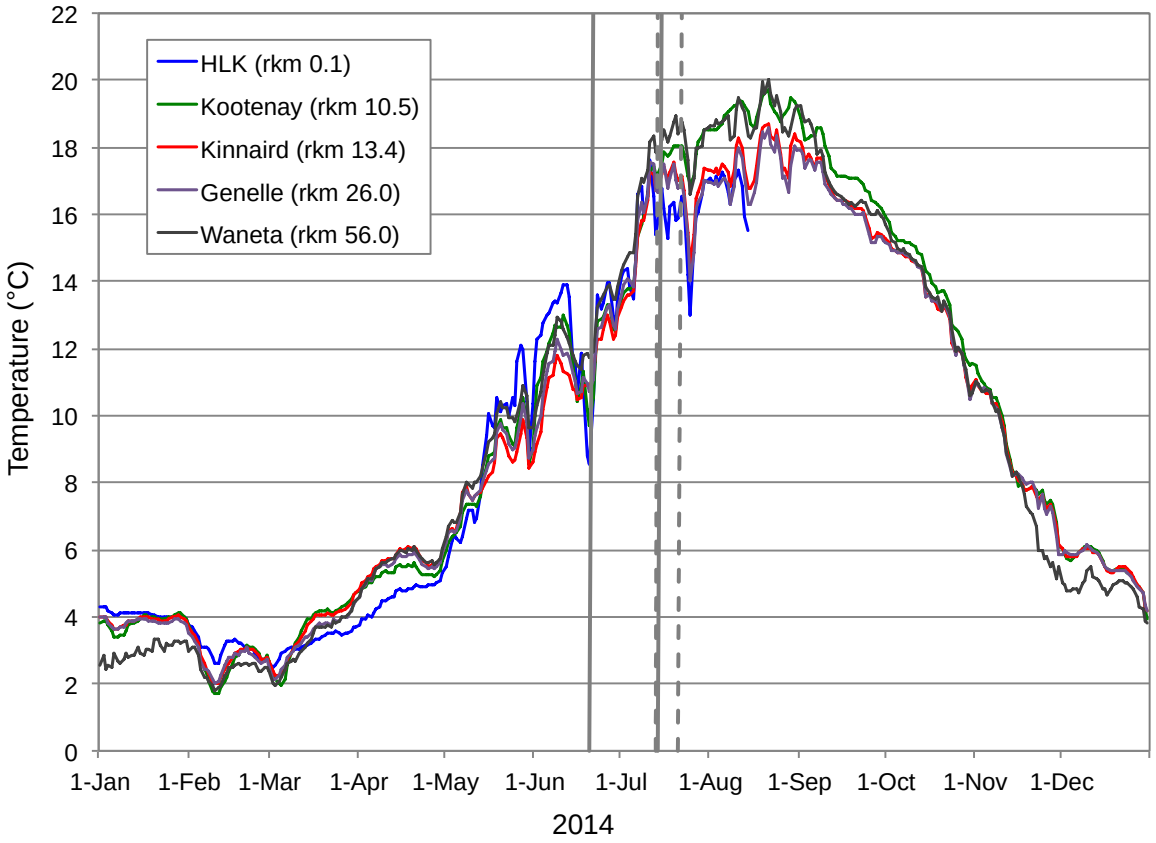


Figure 9. Mean daily water temperature (°C) of the LCR in 2014. Data was recorded at locations of HLK (rkm 0.1), Kootenay (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8) and Waneta (rkm 56.0). Missing data is due to lost or damaged temperature loggers. Vertical solid and dashed lines represent estimated first and last spawning dates at Waneta and Kinnaird, respectively. Estimated spawning duration is based on the developmental stage of collected fertilized eggs (BC Hydro 2015b) and/or larvae. Despite sampling effort, spawning dates were not estimated for ALH due to zero captures.

3.2 Larval Stage

3.2.1 Yolk Sac Larval Assessment

3.2.1.1 Larval Sampling Effort and Collection

3.2.1.1.1 2013

Downstream Location – Waneta (rkm 56.0)

Drift nets were not included in the 2013 spawn monitoring methods at the Waneta spawning site. See BC Hydro (2015a) for egg mat sampling effort and collection results.

Upstream locations

Sampling was conducted from July 11 to August 9 with water temperatures ranging from 13.9 to 19.4 °C (Figure 8). Prior to July 19, drift nets were deployed for 24 hours (long-set). After July 19, drift nets were deployed for short sets (approximately 4 hours; short-set) between the hours of 8:00 and 15:00. Across all upstream sites, the cumulative effort for entire study period was 1,197.9 hours (49.9 days; Table 3). During the long-set sampling methods, the mean (± SD) daily effort was 23.8 ± 1.3 hours. For the short-set sampling methods, drift nets were set at an average daily time of 4.4 ± 0.25 hours.

Kinnaird (rkm14.5, rkm 18.2)

Cumulative sampling effort at rkm 14.5 was 154.3 hours (6.4 days) between the dates of July 18 and August 9. The mean daily effort at rkm 14.5 was 22.3 ± 0.0 and 4.2 ± 0.7 hours for long- and short-sets, respectively. Sampling at rkm 18.2 occurred through the dates of July 15 and August 9 for a total effort of 363.2 hours (15.1 days) with a mean daily effort of 24.4 ± 1.6 and 4.2 ± 0.6 for long- and short-sets, respectively. Mean (±SD) water depth was 4.3 ± 0.6 m at rkm 14.5, and 3.9 ± 0.9 m at rkm 18.2.

A total of 5 yolk-sac larvae were collected and preserved at rkm 1.45 (n=1; CPUE=0.006) and rkm 18.2 (n=4; CPUE 0.011) between the dates of July 29 and August 2 (Table 3; Figure 10). For full results including egg collection see BC Hydro (2015a).

ALH (rkm 0.1)

Sampling at ALH occurred between July 11 and August 9. Total sampling effort conducted at ALH was 680.4 hours (28.4 days) with a mean daily effort of 24.6 ± 2.2 and 4.6 ± 0.7 hours for long- and short-sets, respectively. Mean (±SD) water depth was 6.3 ± 2.6 m. No yolk-sac larvae were collected at ALH (CPUE=0; Table 3).

3.2.1.1.2 2014

Downstream Location – Waneta (rkm 56.0)

Drift nets (n=2) were deployed on June 2 and sampling continued until July 30 with water temperatures ranging from 14.5 to 18.9°C (Figure 9). Total sampling effort was 42.9 hours (1.8 days; Table 3). Mean water depth was not recorded. For egg mat sampling effort see BC Hydro (2015b).

A total of 33 eggs and 62 YSL were captured via drift nets at Waneta between the dates of June 23 and July 23 (CPUE=2.21; Table 3). All live eggs and larvae were transported to the SIF and surviving larvae were transported to the KSH. For complete egg and larval collection see BC Hydro (2015b).

Upstream location – Kinnaird (rkm 14.5 to rkm 18.2)

Drifts were deployed at rkm 14.5 (n=2; long-set), rkm 15.0 (n=2; short-set), rkm 15.6 (n=2; short-set), rkm 16.9 (n=1; short-set), rkm 17.3 (n=1; short-set and long-set), rkm 18.2 (n=4; long-set) on July 14 and sampling continued until August 8. Water temperatures ranged from 14.6 to 17.6°C (Figure 9) and sampling water depth was 5.39 ± 1.4 m. Total sampling effort for drift nets were 2,537.5 hours (rkm 14.5, 699.7 hours; rkm 15.0, 106.2 hours; rkm 15.6, 76.9 hours; rkm 16.9, 43.0 hours; rkm 17.3, 128.1 hours; rkm 18.2, 1,513.7 hours; Table 3). Single set effort for long- and short-sets was 23.6 ± 1.5 hours and 3.1 ± 0.5 hours, respectively.

A total of 13 larvae (rkm 14.5, n=2, CPUE=0.004; rkm 16.9, n=2, CPUE=0.05; rkm 17.3, n=1, CPUE=0.01; rkm 18.2, n=8, CPUE=0.01; Table 3; Figure 10) were collected between July 16 and July 31. All larvae collected in the drift nets were dead upon capture and preserved for developmental staging. For egg collection details see BC Hydro (2015b).

Upstream Location – ALH (rkm 0.1)

Drift nets (n=4) were deployed on July 10 and sampling continued until August 8 with water temperatures ranging from 13.0 to 17.6°C (Figure 9). Total sampling effort was 857.3 hours (Table 3). Single set effort was 25.2 ± 4.7 hours and sampling water depth was 6.6 ± 1.6 m. No larvae were captured at ALH (Table 3). For egg mat sampling see BC Hydro (2015b).

Table 3. White Sturgeon egg and YSL collection and sampling effort at LCR monitoring locations of Waneta (rkm 56.0), downstream of Kinnaird (rkm 18.2, rkm 14.5), Kootenay (rkm 10.5), downstream ALH (rkm 6.0), ALH (rkm 0.1), and HLK (rkm 0.1) for years 2008 through 2012.

Year	Location	Eggs	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

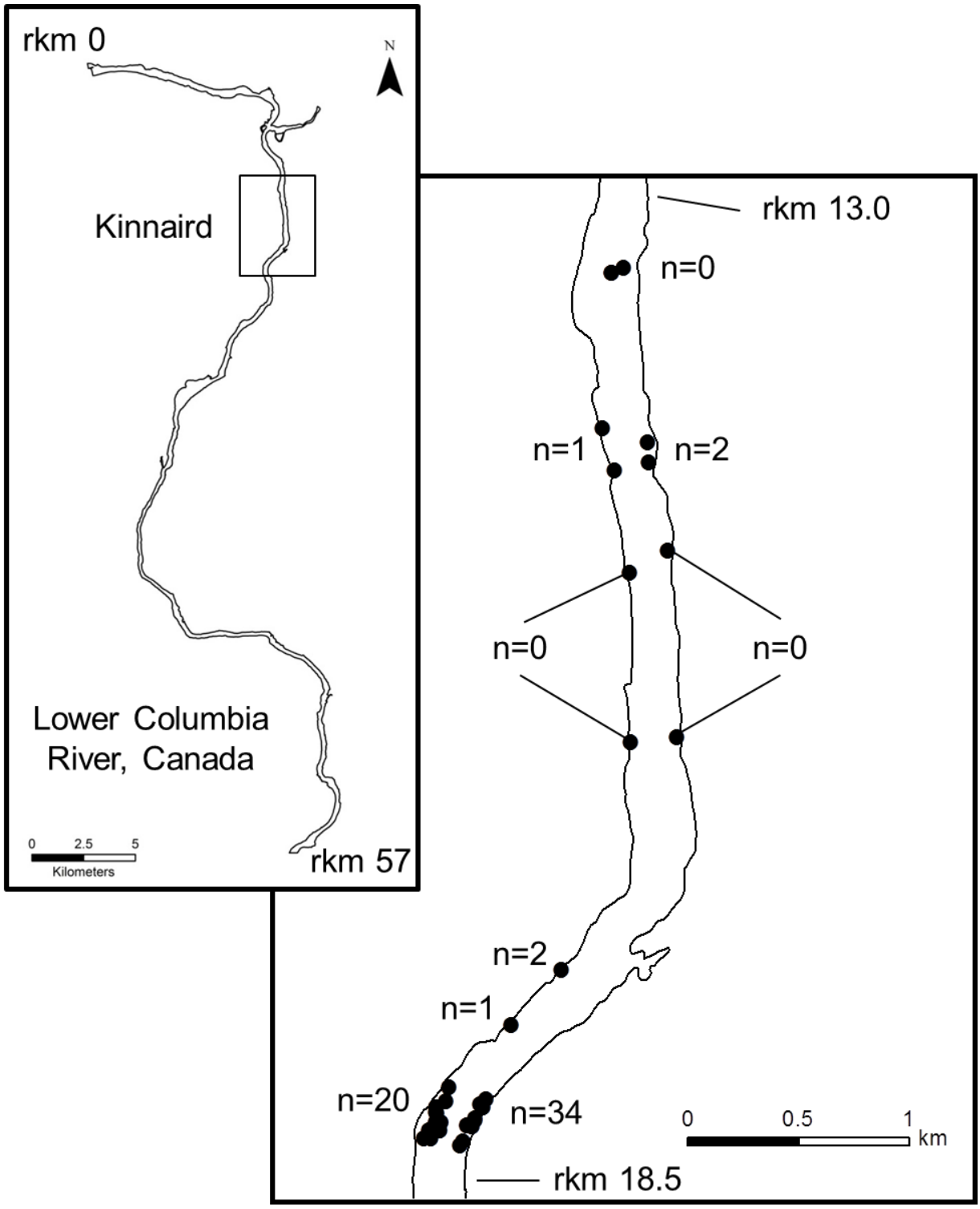


Figure 10. Drift net sample locations and number of larvae collected in the Kinnaird section (rkm 13.0 – 18.5) of the lower Columbia River from 2009 through 2014.

3.2.1.2 Developmental Staging and Estimated Spawning Dates

All preserved YSL were assigned a developmental stage based on Dettlaff et al. (1993) to calculate an estimated date of fertilization. In 2013, spawning was estimated to have occurred on July 16 and 17 at Kinnaird; with all larvae collected were 1-day post hatch (stage 37). In 2014, estimation of spawning days could not be completed since no live larvae were preserved for developmental staging and all dead larvae were in too poor of a condition to assign a developmental stage. For 2013 and 2014 estimated spawning days via developmental staging of egg samples see BC Hydro (2015a) and BC Hydro (2015b), respectively.

3.2.2 Temperature Effects on Development

3.2.2.1 Experimental Sampling

Of the 24,000 fertilized eggs, 83.5 ± 14.4% (mean ± SD) reached neurulation within each hatching jar. The number of YSL hatched was not counted, as survival across treatments was not evaluated in this study. Duration to complete yolk-sac absorption, marking the termination of the experiment, varied between treatments resulting in different total YSL samples collected by the end of the experiment to examine developmental differences between the temperature treatments of 12.5°C (F1 n = 280, F2 n = 290), 14°C (F1 n = 230, F2 n = 230), 15.5°C (F1 n = 170, F2 n = 170), and 17°C (F1 n = 150, F2 n = 140). Similarly, cold temperatures delayed development and more photographs were required at the 12.5°C treatment for the morphological traits analysis of BA (12.5°C n = 255, 17°C n = 186), GFA (12.5°C n = 206, 17°C n = 98), HA (12.5°C n = 254, 17°C n = 189), TL (12.5°C n = 255, 17°C n = 186), MA (12.5°C n = 253, 17°C n = 189), PFA (12.5°C n = 240, 17°C n = 176), and YSA (12.5°C n = 255, 17°C n = 180).

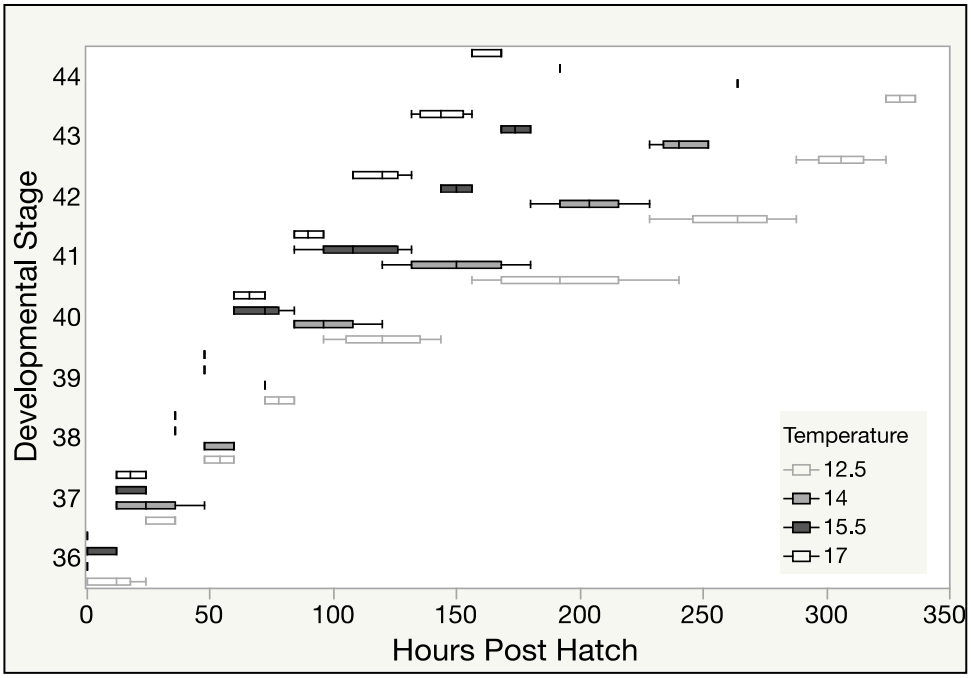
3.2.2.2 Developmental Staging

Temperature affected the chronology of development in YSL as a function of both time (h) and ATU (Table 4; Figure 11). For example, time to attain stage 44 was 324 - 336 h (169 - 175 ATU) at 12.5°C, 264 h (154 ATU) at 14.0°C, 192 h (124 ATU) at 15.5°C, and 156 - 168 h (111 - 119 ATU) at 17.0°C. In terms of RT_i, chronology of development was relatively independent of temperature treatments (Table 5). The regression analyses showed a good fit for developmental rate for each temperature treatment (17.0°C, $R^2 = 0.960$; 15.5°C, $R^2 = 0.938$; 14.0°C, $R^2 = 0.940$; 12.5°C, $R^2 = 0.916$; Table 6). The developmental rate significantly increased with increased temperatures as a function of time (17.0°C, m = 0.046; 15.5°C, m = 0.038; 14.0°C, m = 0.027; 12.5°C, m = 0.02; Tukey's HSD, $P < 0.02$; Table 6), with the exception of the 14.0°C and 12.5°C comparison (Tukey's HSD, $P = 0.08$). As a function of ATU, the developmental rate was significantly greater at higher temperatures (17.0°C, m = 0.065; 15.5°C, m = 0.059; 14.0°C, m = 0.047; 12.5°C, m = 0.040; Tukey's HSD, $P < 0.05$; Table 6), however no difference was found between 17.0°C and 15.5°C (Tukey's HSD, $P = 0.322$), or between 14.0°C and 12.5°C (Tukey's HSD, $P = 0.228$). In terms of RT_i, developmental rate was not significantly different between the temperature conditions applied (17.0°C, m = 7.471; 15.5°C, m = 7.337; 14.0°C, m = 7.184;

12.5°C, m = 0.6.790; Tukey's HSD, P > 0.05; Table 6).

Table 4. Mean time (hours) and accumulated thermal units (ATU) required to reach developmental stages of White Sturgeon YSL from time of hatch at experimental temperature regimes of 12.5°C, 14.0°C, 15.5°C, and 17.0°C.

	12.5°C	14°C	15.5°C	17°C
Stage	Hours Post Hatch			
36	0	0	0	0
37	24 - 36	12	12 - 24	12
38	48	48 - 60	36	36
39	72	72	48	48
40	96	84	60	60
41	156	120 - 132	84 - 96	84
42	228 - 252	180 - 192	144	108
43	288 - 300	228 - 240	168	132 - 144
44	324 - 336	264	192	156 - 168
	ATU Post Hatch			
36	0	0	0	0
37	13 - 19	7	8 - 16	9
38	25	28 - 35	23	26
39	38	42	31	34
40	50	49	39	43
41	81	70 - 77	54-62	60
42	119 - 131	105 - 112	93	77
43	150 - 156	133 - 140	109	94-102
44	169 - 175	154	124	111-119



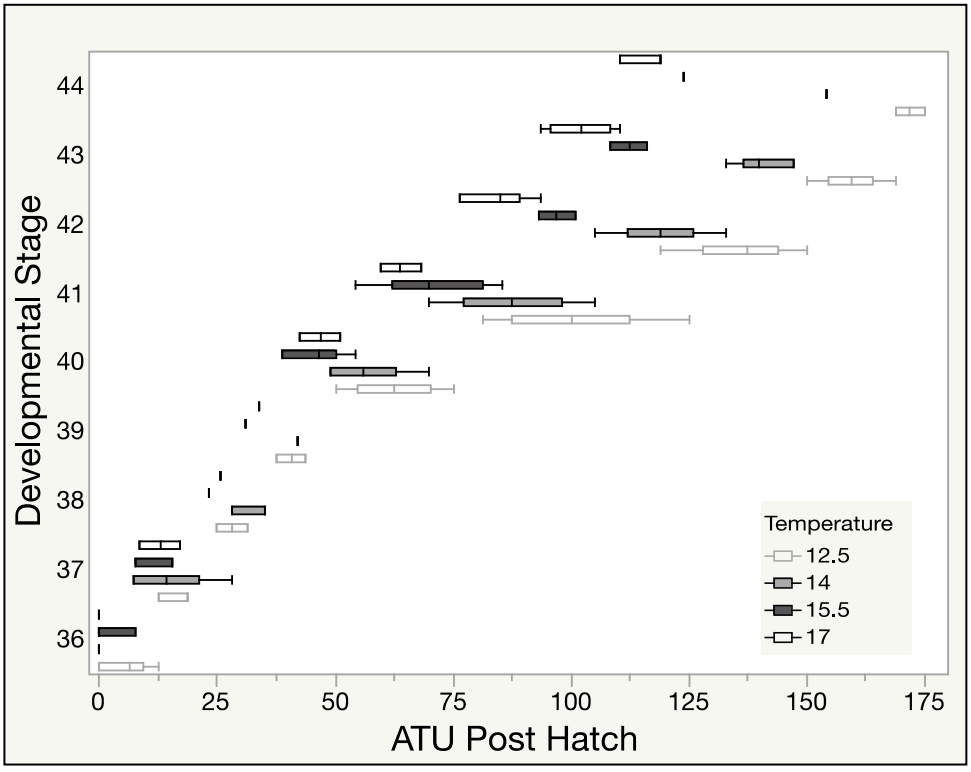


Figure 11. Relationship between developmental stage i (y), and initial occurrence of developmental stage i (x), fitted by a least squares regression following the model y = mx + b, where m is the developmental rate and b is the intercept. Occurrence of developmental stage was measured in time (hours; A) and accumulated thermal units (ATU; B) post hatch.

Table 5. White Sturgeon YSL development at conditions of 12.5°C, 14.0°C, 15.5°C, and 17.0°C. Time (h) is given as RT_i (relative measure of developmental stage *i*, as a proportion of the total duration of the YSL period).

Stage	RT_i			
	12.5°C	14°C	15.5°C	17°C
36	0.00	0.00	0.00	0.00
37	0.09	0.05	0.09	0.07
38	0.15	0.20	0.19	0.22
39	0.22	0.27	0.25	0.30
40	0.29	0.32	0.31	0.37
41	0.47	0.48	0.47	0.52
42	0.73	0.70	0.75	0.67
43	0.89	0.89	0.88	0.85
44	1.00	1.00	1.00	1.00

Table 6. Relationship between developmental stage (y) and transition measurement (hours, ATU and RT_i; x) as a function of temperature following the model y = mx+*b*, where m is the slope and *b* is the intercept. Differing superscripts within a parameter signifies differences at P < 0.05.

	m_{hours}	m_{ATU}	m_{RTi}	*b*	R^2
12.5°C	0.021^a	0.040^a	6.790^a	36.882	0.916
14.0°C	0.027^a	0.047^a	7.184^a	36.663	0.940
15.5°C	0.038^b	0.059^b	7.337^a	36.590	0.938
17.0°C	0.046^c	0.065^b	7.471^a	36.558	0.960

3.2.2.3 Morphological Traits

Effects of temperature on size differed among morphological traits. At hatch, fish reared in 12.5°C were larger, but not significantly, when compared to fish reared in 17.0°C across all morphological traits measured as a function of days post hatch (dph; t = 0; BA, P = 0.5254; GFA, P = 0.350; HA, P = 0.875; TL, P = 0.343; MA, P = 0.666; PFA, P = 0.078; YSA, P = 0.716). Similar effects were found as a function of developmental stage (stage 36) with significant differences in size of BA (P = 0.0087), HA (P = 0.039), TL (P = 0.008), and PFA (P = 0.001), and no significant difference in GFA (P = 0.658), MA (P = 0.951), and YSA (P = 0.830). Excluding YSA, morphological traits were generally larger over time (dph) in fish reared at 17.0°C than at rearing temperature of 12.5°C after 1 dph (significant difference found at: BA, 3 to 9 dph, P<0.006; GFA, 2 to 4 dph, P<0.0001; HA, 1 to 9 dph, P<0.036; TL, 1 to 9 dph, P<0.016; MA, 2 to 9 dph, P<0.0001; PFA, 2 to 9 dph, P<0.0001; Figure 12a and 12b). This pattern was inversed as a function of stage for morphological traits of BA, HA, TL, MA, and PFA with traits of fish reared at 12.5°C generally measuring larger than 17.0°C reared fish beyond stage of 38 (significant difference found at: BA, stage 41 to 44, P<0.010; HA, stage 41 to 44, P<0.005; TL, stage 42 to 44, P<0.0001; MA, stage 41 to 44, P<0.002; PFA, stage 41 to 44, P<0.002; Figure 12c). Gill filament area was larger as a function of developmental stage in 17.0°C reared YSL compared to 12.5°C reared YSL (stage 39 to 40, P<0.010; Figure 12d). YSA was found to be

smaller over time (dph) for individuals reared at 17.0°C (significant difference at 2 to 9 dph, P<0.0001), however, YSA was smaller for fish reared at 12.5°C as a function of developmental stage (significant difference at stages 39 and 43, P<0.040).

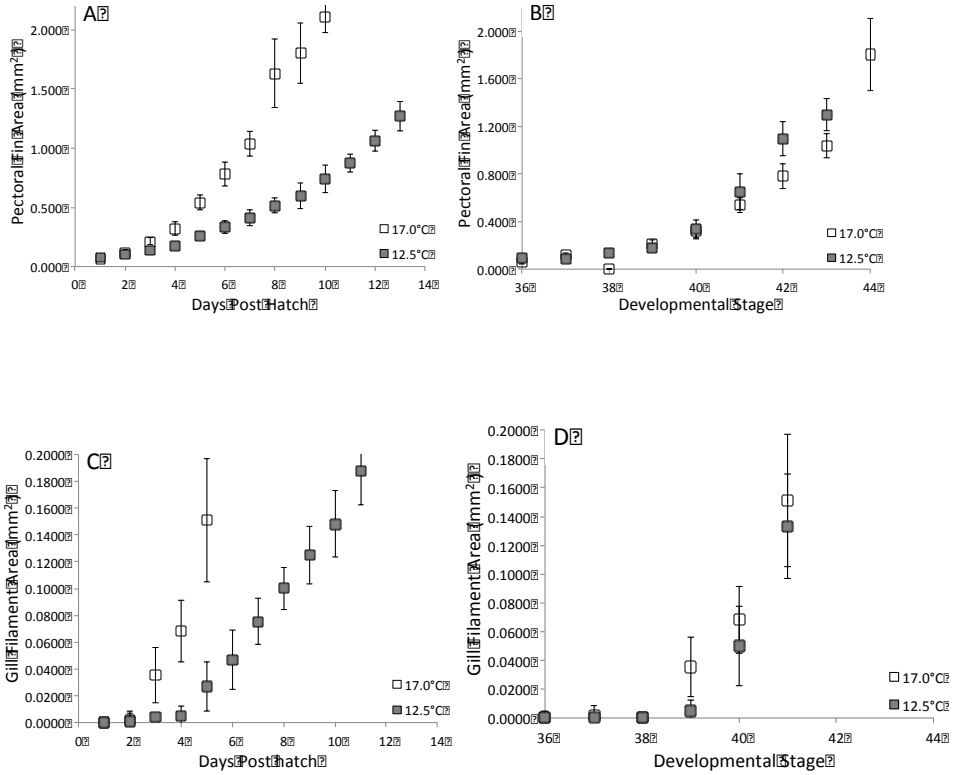


Figure 12. Morphological traits (e.g., pectoral fin area) were significantly larger following 2 days post hatch (p < 0.016; A) in fish reared at 17.0°C compared to 12.5°C. However, as a function of stage, morphological traits were generally smaller as a function of developmental stage (e.g., pectoral fin area; B) in fish reared at 17°C compared to 12.5°C. This general pattern was inversed for the morphological trait of yolk-sac area (C and D). Data is shown as mean ± SD.

3.3 Juvenile Stage

3.3.1 Conservation Aquaculture Program

The Conservation Aquaculture Program has released a total of 136,942 juvenile White Sturgeon through 2002 to 2014 (Table 7). In 2013, 4,037 hatchery-reared juveniles (year class 2012) from six maternal families were released into the Canadian portion of the LCR at locations of HLK (rkm 0.1; n=1,400), Kootenay Eddy (rkm 10.5; n=893), Genelle (rkm 24.0; n=875), and Beaver Creek (rkm 49.0; n=869) (Table 8; FFSBC 2013). FL (cm) and weight (kg) (mean ± SD) for released White Sturgeon was 22.2 ± 1.8 cm (Figure 13 and 14) and 85.0 ± 21.5 g

(Figure 15 and 16), respectively. In 2014, 1,801 hatchery-reared juveniles (year class 2013) were released into the Canadian portion of the LCR at locations of HLK (n=900), Kootenay (n=300), Genelle (n=300), and Beaver Creek (n=301) representing 6 maternal families (Table 8; FFSBC 2014). FL and weight for released White Sturgeon was 23.3 ± 2.1 cm (Figure 13 and 14) and 108.5 ± 33.6 g (Figure 15 and 16), respectively.

Table 7. Numbers of hatchery reared juvenile White Sturgeon released annually into both the LCR, Canada, and Lake Roosevelt, USA. Release numbers are presented by release year and indicated whether they occurred in the fall or spring.

Release Year	Year Class	Canada		USA		Total
		Fall	Spring	Spring	Fall/Winter	
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				3,590	3,590
2012	2011		4,000			4,000
2012	2012				302	302
2013	2012		4,037			4,037
2014	2013		1,801		657	2,458
Total		13,110	90,252	28,509	5,071	136,942

Table 8. Number of hatchery reared juvenile White Sturgeon released for year classes 2012 and 2013. Release numbers are presented by release location and family.

Release Year	Year Class	Family	River Kilometer				Total
			0.1	10.5	24.0	49.0	
2013	2012	A	280	174	175	177	806
2013	2012	B	280	175	175	176	806
2013	2012	C	280	175	175	176	806
2013	2012	D	280	184	175	170	809
2013	2012	E	280	185	175	170	810
2013	2012	All	1400	893	875	869	4037
2014	2013	F	200	67	67	66	400
2014	2013	G	200	67	66	67	400
2014	2013	H	200	67	67	67	401
2014	2013	I	100	33	33	34	200
2014	2013	J	100	33	33	34	200
2014	2013	K	100	33	34	33	200
2014	2013	All	900	300	300	301	1801

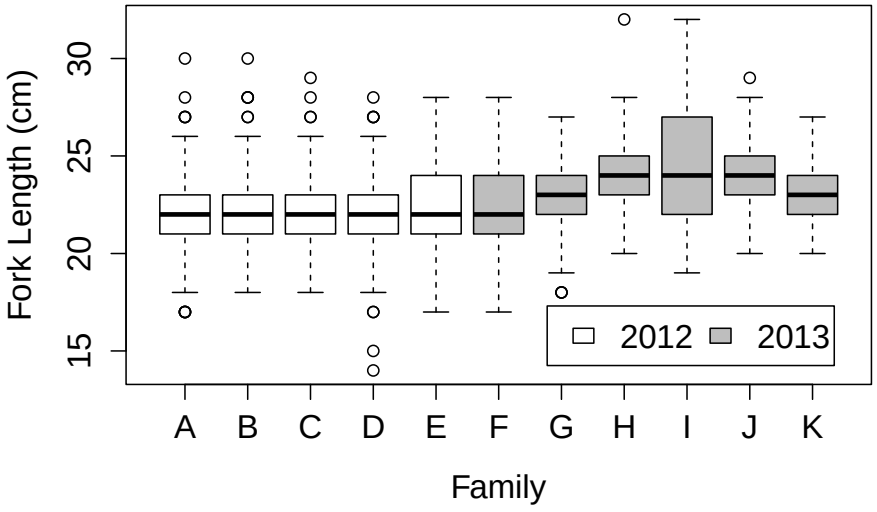


Figure 13. Fork length (cm) at release (approximately 9 months of age) of juvenile White Sturgeon year classes 2012 and 2013 by family.

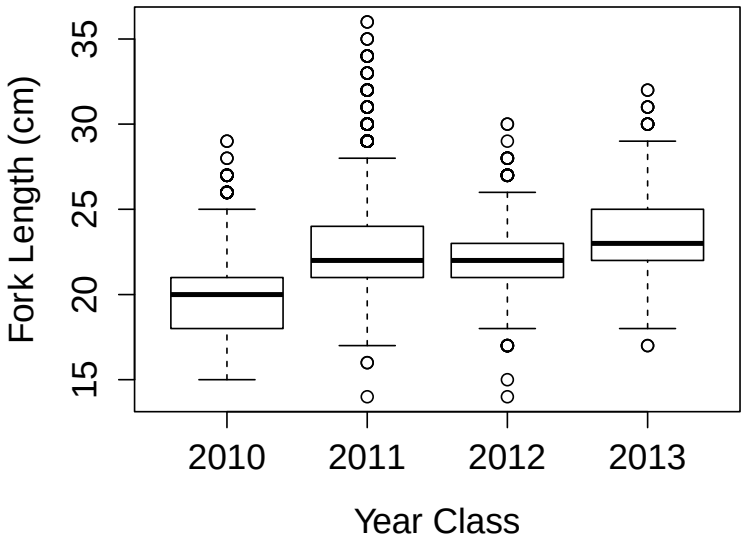


Figure 14. Fork length (cm) at release (approximately 9 months of age) of juvenile White Sturgeon year classes 2010 through 2013

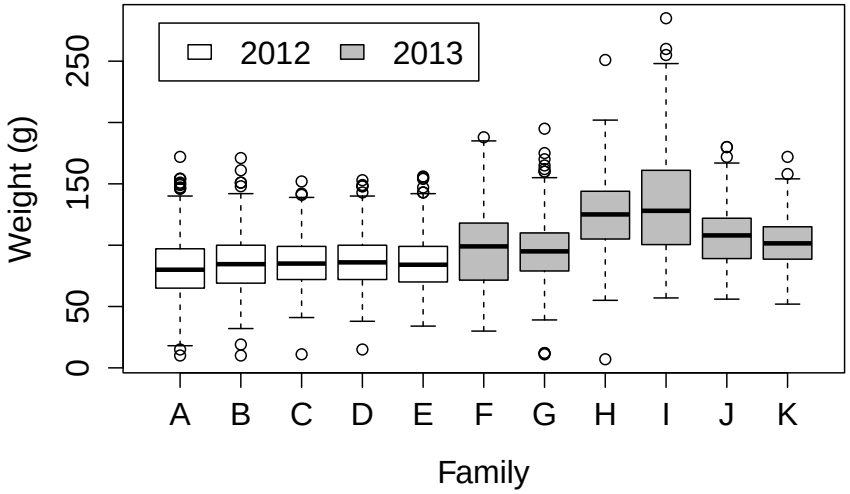


Figure 15. Weight (g) at release (approximately 9 months of age) of juvenile White Sturgeon year classes 2012 and 2013 by family.

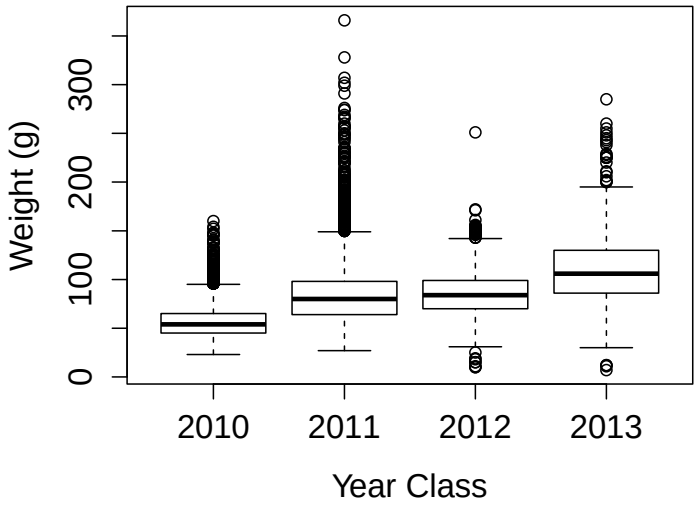


Figure 16. Weight (g) at release (approximately 9 months of age) of juvenile White Sturgeon year classes 2010 through 2013.

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 will continue twice a year (spring and fall), in both the Canadian and USA portions of the LCR, until Fall 2017. Results are presented for data collected in Canada only, and results from both USA and Canada will be combined for analyses in future years.

In 2013, spring and fall stock assessments were conducted between the dates of April 14 through May 2 (15 days) and September 16 through September 26 (11 days) with water temperatures (mean ± SD) of 6.1 ± 0.8°C and 15.9 ± 0.6°C, respectively. During the spring, 1,788 hooks were set using 149 lines. In the fall, 1,368 hooks were set using 114 lines. Sampling effort was 3,020.6 hours (125.9 days) and 2,347.6 hours (97.8 days) during the spring and fall assessments, respectively. Set line deployment during the spring and fall assessments was 20.3 ± 2.5 hours (0.8 ± 0.1 days) and 20.6 ± 2.2 hours (0.9 ± 0.1 days), respectively.

In 2014, spring and fall stock assessments were conducted between the dates of May 4 through May 15 (12 days) and September 16 through September 30 (15 days) with water temperatures of 7.5 ± 0.6°C and 15.7 ± 0.7°C, respectively. For both the spring and fall assessments, 1,440 hooks were set using 120 lines. Sampling effort for the spring and fall assessments was 2,453.2 hours and 2504.4 hours, respectively. Set line deployment during the spring and fall assessments was 20.4 ± 1.4 hours and 20.9 ± 1.5 hours at water depths of 9.8 ± 4.3 m and 15.7 ± 0.7, respectively.

Total White Sturgeon juvenile capture during the 2013 spring and fall assessments was 191 and 376, respectively (Table 9). Total juvenile capture in 2014 was 101 and 275 for the spring and fall stock assessments, respectively (Table 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 2-year sampling period, 22 captured fish were identified as wild representing a 0.04 proportion of total capture across both sampling years (Table 9; Figure 17).

Table 9. Total juvenile White Sturgeon capture during the 2013 and 2014 stock assessments in the LCR Canada. 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	Season	Hatchery Reared	Wild	Total
2013	Spring	31	3	34
2013	Fall	152	5	157
2014	Spring	99	2	101
2014	Fall	263	12	275
Total		545	22	567

Total capture and proportional data by brood year class (YrC) for sampling years 2013 and 2014 is provided in Table 10 and Figure 17, respectively. YrC 2001 and 2002 represented the largest proportions of total capture across all stock assessments (0.26 and 0.24, respectively). Year class 2001 was the highest proportion of capture in spring 2013 (0.44), spring 2014 (0.42) and fall 2014 (0.22). Year class 2002 was the highest proportion of capture in fall 2013 (0.25). Other YrC of high proportional capture across all stock assessments included 2003 (0.09), 2004 (0.09), 2005 (0.09), and 2006 (0.11). See BC Hydro (2015c) for 2009 through 2012 juvenile capture data.

Total capture across 2013 and 2014 stock assessments within each sampling zone included: zone 1, n=385; zone 2, n=75; zone 3, n=27; zone 4, n=16; and zone 5, n=64 (Table 11; Figure 18). The majority of wild fish were captured in zone 1 (n=14) representing 64% of all wild fish captured over the two years. The highest proportions of fish captured in each zone were: zone 1, YrC 2002 (0.31) and 2001 (0.27); zone 2, YrC 2001 (0.25) and 2006 (0.16); zone 3, YrC 2001 (0.33), YrC 2002 (0.22); zone 4, YrC 2001 (0.31), and equal representation of YrC 2002, 2005, 2007, and 2009 (0.13); zone 5, YrC 2003 (0.22) and 2005 (0.19) (Figure 19). Juveniles were distributed widely throughout zone 1 (Figure 20), and were caught in specific habitat types (e.g. eddies) in zone 2 (Figure 21), zone 3 (Figure 22), zone 4 (Figure 23), and zone 5 (Figure 24).

Table 10. Total juvenile White Sturgeon captured by brood year class within the LCR during sampling years 2013 through 2014. 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	2013		2014		Total
Class	Spring	Fall	Spring	Fall	
2001	15	27	42	61	145
2002	9	40	34	55	138
2003	3	19	7	24	53
2004	4	12	8	27	51
2005	0	13	5	35	53
2006	0	32	2	30	64
2007	0	6	1	13	20
2008	0	2	0	14	16
2009	0	1	0	4	5
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
Wild	3	5	2	12	22
Total	34	157	101	275	567

Table 11. Total juvenile White Sturgeon captured by brood year class within the LCR for each sampling zone during the 2013 and 2014 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 HLK Dam and moving downstream to the US Border.

Year	Zone				
Class	1	2	3	4	5
2001	104	19	9	5	8
2002	120	7	6	2	3
2003	29	10	0	0	14
2004	35	8	2	1	5
2005	27	10	2	2	12
2006	40	12	4	0	8
2007	7	1	2	2	8
2008	8	5	1	1	1
2009	1	0	0	2	2
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
Wild	14	3	1	1	3
Total	385	75	27	16	64

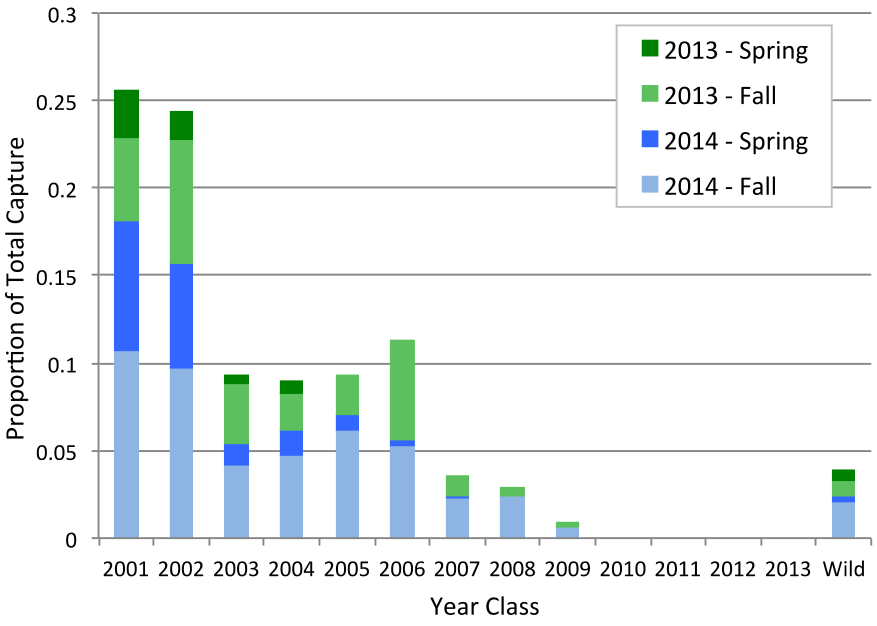


Figure 17. Proportion of total juvenile White Sturgeon capture by brood year class within the LCR during the 2013 and 2014 stock assessments. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag. Individuals with no PIT tag administered by the hatchery or lateral scutes removed were considered wild fish as a product of natural reproduction and of unknown age.

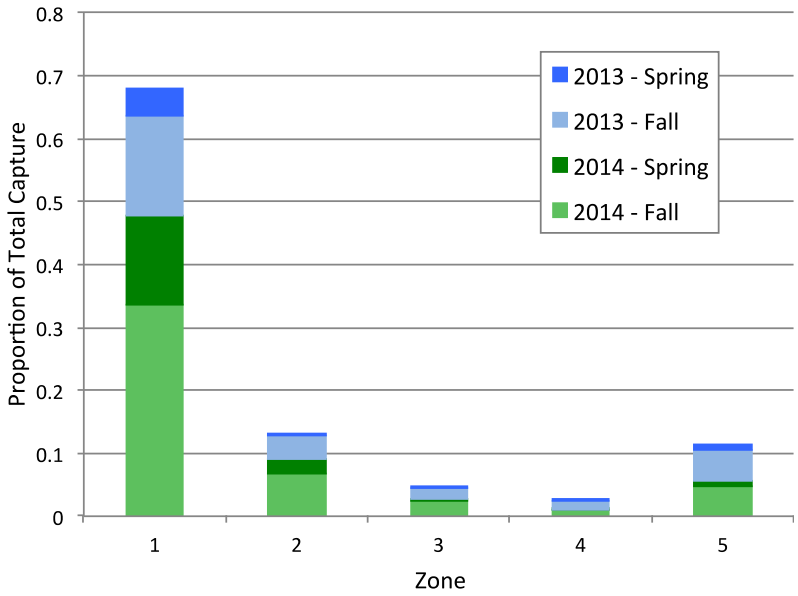


Figure 18. Proportion of total juvenile White Sturgeon capture within the LCR for each sampling zone during the 2013 and 2014 stock assessments. Sampling zones represent 11.2 km increments starting from HLK Dam and moving downstream to the US Border.

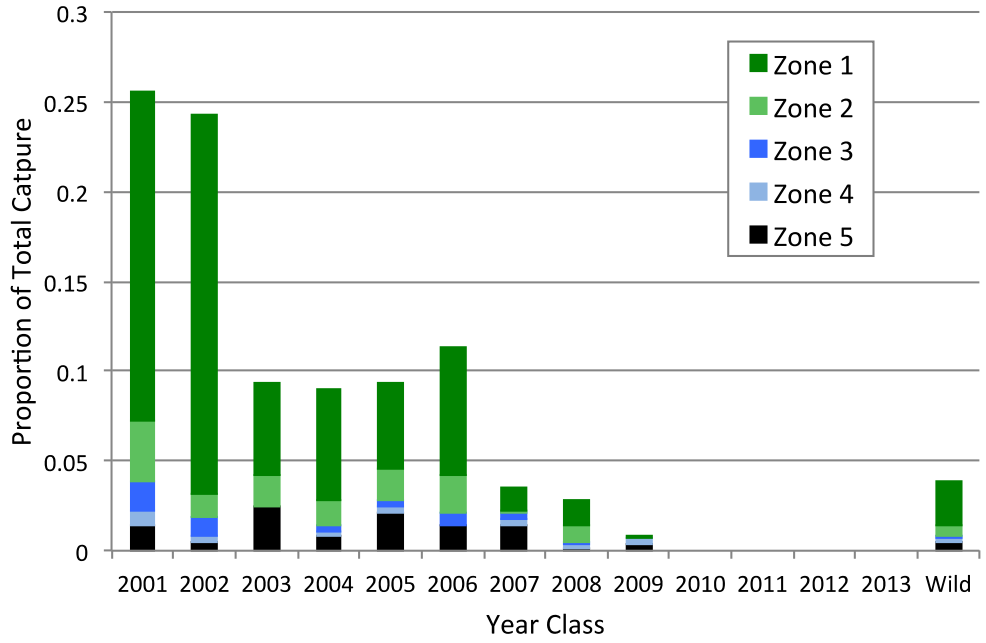


Figure 19. Proportion of total juvenile White Sturgeon capture by brood year class within the LCR for each sampling zone during the 2013 and 2014 stock assessments. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag. Individuals with no PIT tag administered 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 HLK Dam and moving downstream to the US Border.

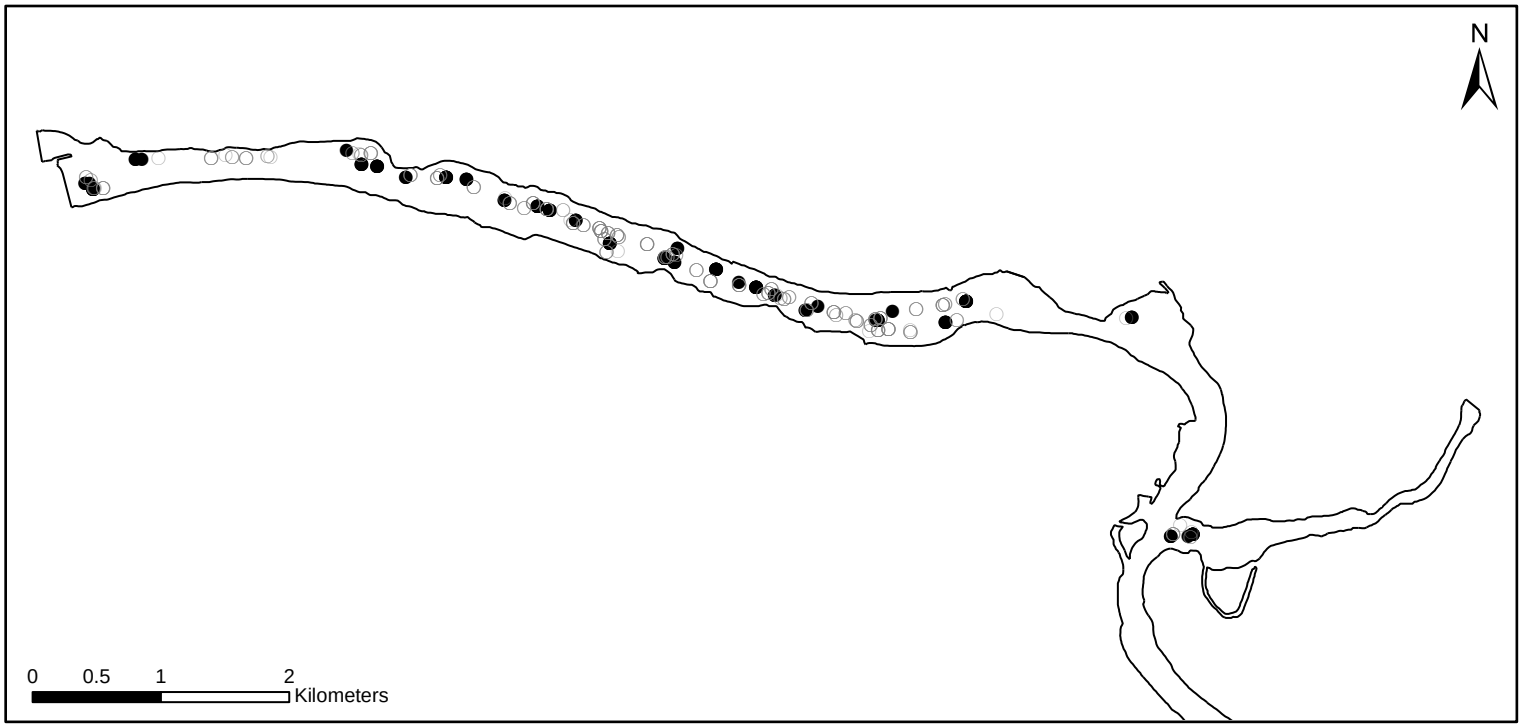


Figure 20. Juvenile White Sturgeon (<150 cm fork length) capture distribution in zone 1 2013 (black circles) and 2014 (open circles) stock assessment surveys on the lower Columbia River.

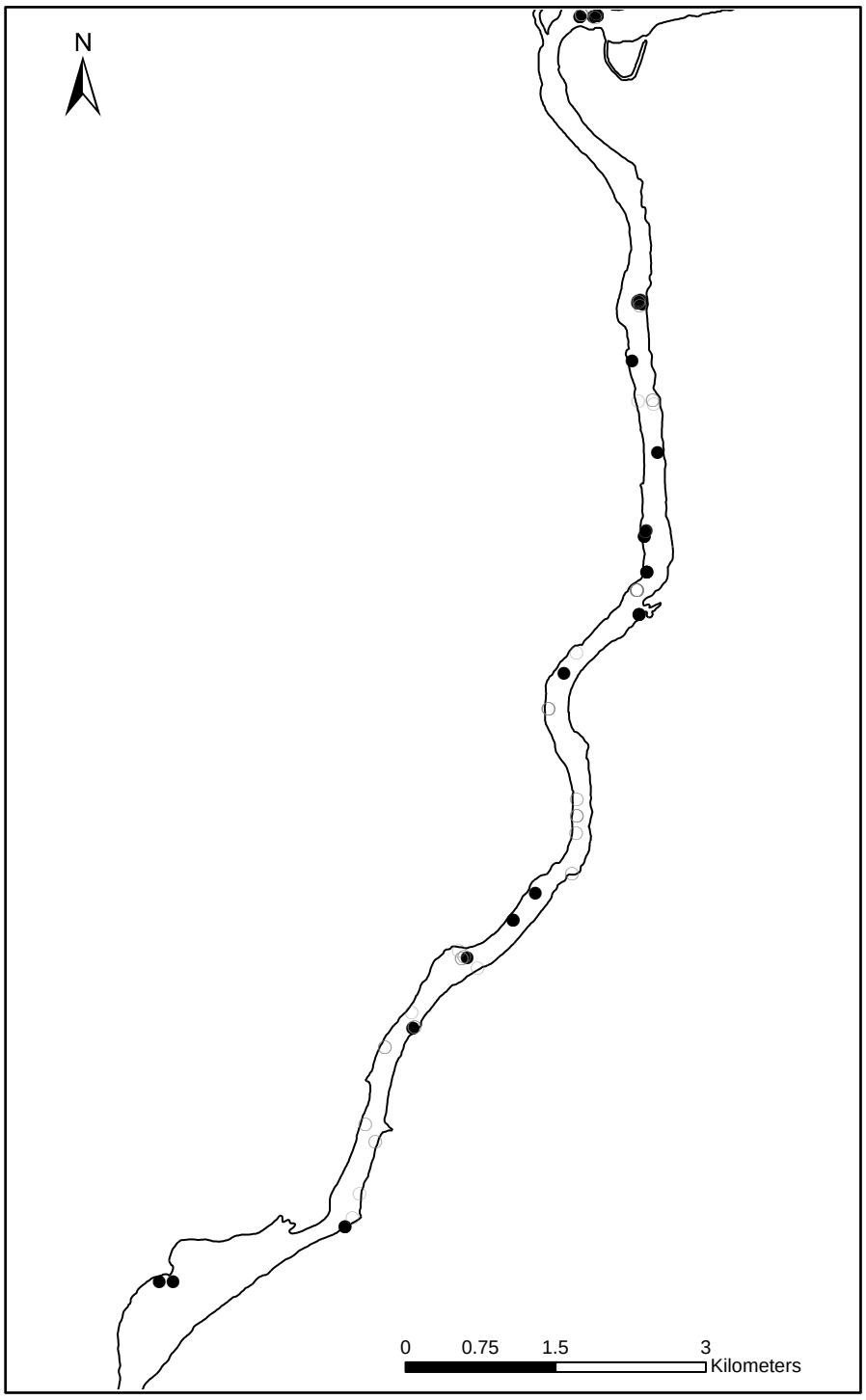


Figure 21. Juvenile White Sturgeon (<150 cm fork length) capture distribution in zone 2 2013 (black circles) and 2014 (open circles) stock assessment surveys on the lower Columbia River.

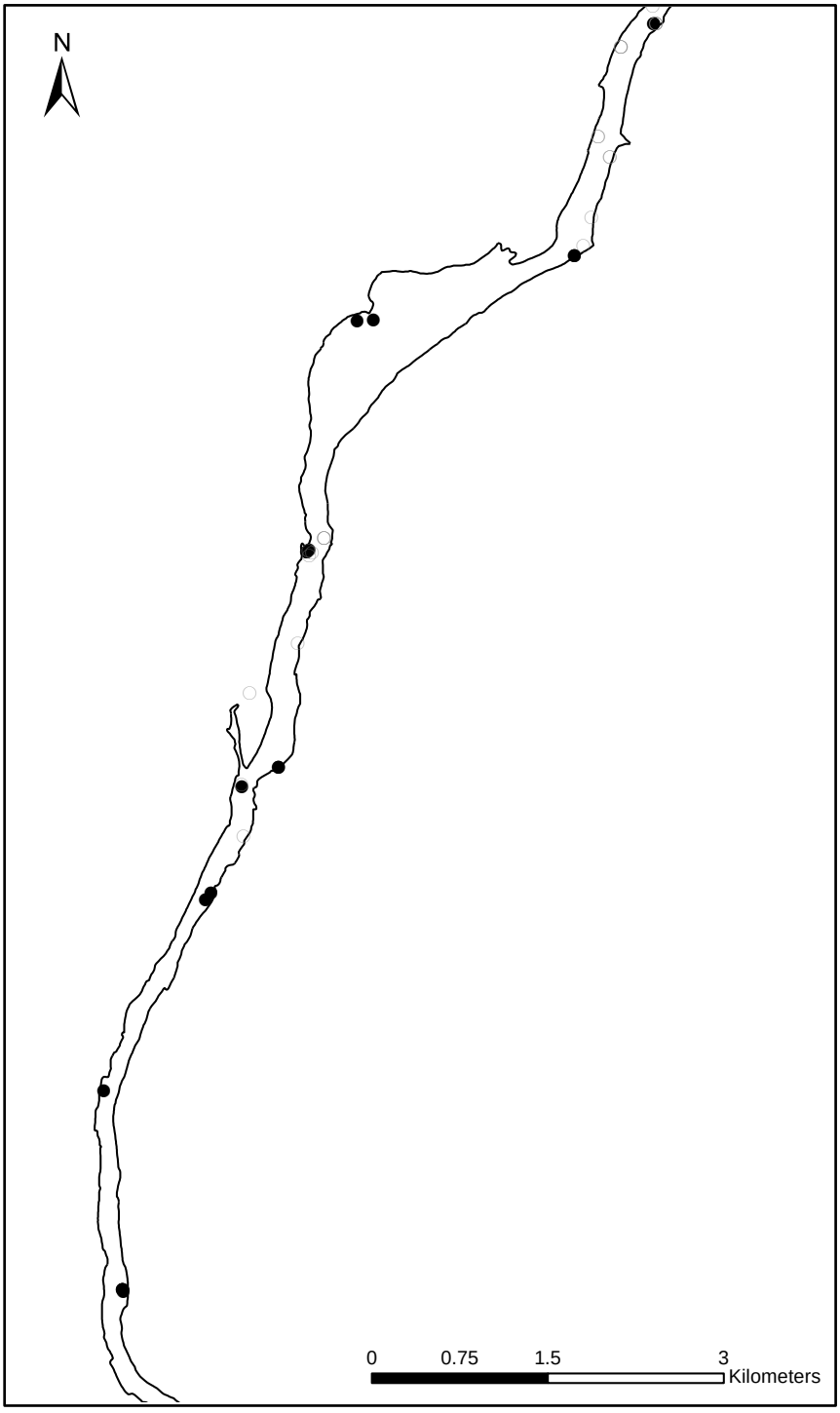


Figure 22. Juvenile White Sturgeon (<150 cm fork length) capture distribution in zone 3 2013 (black circles) and 2014 (open circles) stock assessment surveys on the lower Columbia River.

Figure 23. Juvenile White Sturgeon (<150 cm fork length) capture distribution in zone 4 2013 (black circles) and 2014 (open circles) stock assessment surveys on the lower Columbia River.

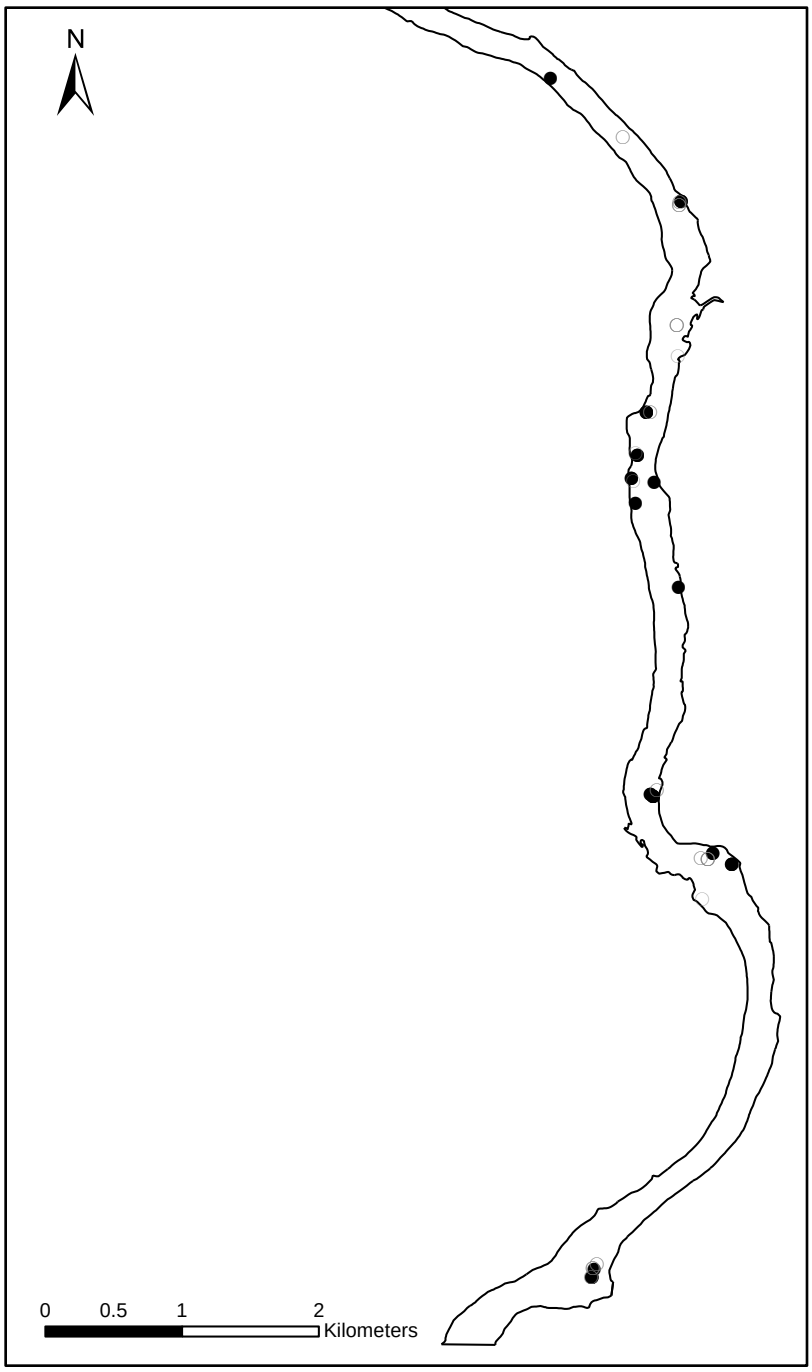


Figure 24. Juvenile White Sturgeon (<150 cm fork length) capture distribution in zone 5 2013 (black circles) and 2014 (open circles) stock assessment surveys on the lower Columbia River.

3.3.2.2 Fork Length, Weight, Relative Weight, and Growth

3.3.2.2.1 Fork Length

Mean (±SD) fork length (FL; cm) of juveniles collected in 2013 and 2014 was 98.3 ± 17.5 cm and 97.2 ± 14.7 cm, respectively (Table 12). Juvenile FL as a function of year class (Table 12; Figure 25) and sampling zone (Table 13, Figure 26) is provided below. Generally, FL decreased as a function of YrC with the exceptions of YrC 2002 (105.8 ± 9.6 cm) measuring significantly larger than YrC 2001 (102.1 ± 12.7 cm; $F_{9, 553} = 68.8096$; P=0.0454) and YrC 2008 (78.4 ± 8.3) measuring larger than YrC 2007 (77.5 ± 9.4; ns, P>0.05; Table 12). Wild juveniles were significantly larger than all hatchery-reared fish (P<0.0001; Table 12, Figure 25). Fork length of fish captured in sampling zone 1 (101.7 ± 13.6 cm) was significantly larger than fish captured in zone 2 (93.3 ± 14.8 cm), zone 3 (89.1 ± 17.0 cm), zone 4 (86.0 ± 20.4 cm), and zone 5 (84.3 ± 15.8 cm) ($F_{4,558}$=28.4287, P<0.0001). Fish captured in zone 2 were significantly larger than fish captured in zone 5 (P=0.0028; Table 13, Figure 26).

Table 12. Mean ±SD fork length (cm) by brood year class of juvenile White Sturgeon captured in the LCR during the 2013 and 2014 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 classes not connected by the same letter are significantly different in mean fork length.

Year Class	2013		2014		Total	Tukey-Kramer HSD				
	Spring	Fall	Spring	Fall						
2001	101.4 ± 11.8	102.5 ± 20.0	103.0 ± 10.7	101.3 ± 13.4	102.1 ± 12.7	A				
2002	105.1 ± 6.0	104.2 ± 14.4	110.8 ± 8.8	104.6 ± 10.3	105.8 ± 9.6	B				
2003	89.7 ± 9.0	94.2 ± 9.1	104.4 ± 15.5	98.8 ± 10.3	97.5 ± 10.9		A	C		
2004	89.5 ± 11.3	84.1 ± 8.7	93.7 ± 11.9	96.3 ± 10.5	93.9 ± 11.0			C		
2005	n/a	85.8 ± 8.1	85.3 ± 4.9	84.8 ± 8.9	85.3 ± 8.4				D	
2006	80.5 ± 0.7	85.5 ± 8.4	n/a	85.3 ± 8.4	85.2 ± 9.0				D	
2007	n/a	79.4 ± 11.1	n/a	75.1 ± 8.2	77.5 ± 9.4				D	E
2008	n/a	78.0 ± 10.9	n/a	78.8 ± 8.3	78.4 ± 8.3				D	E
2009	n/a	n/a	n/a	65.0 ± 2.3	65.0 ± 2.3					E
Wild	143.3 ± 3.5	134.0 ± 12.2	n/a	n/a	134.0 ± 12.3					F

*Comparison of all pairs is based on Total Fork Length; α=0.05

Table 13. Mean (±SD) fork length (FL; cm) of juvenile White Sturgeon captured in the 5 sampling zones of the LCR during the 2013 and 2014 stock assessments. Sampling zones represent 11.2 km increments starting from HLK Dam and moving downstream to the US Border. Fish in zones not connected by the same letter are significantly different in mean fork length.

Zone	2013		2014		Total	Tukey-Kramer HSD*	
	Spring	Fall	Spring	Fall			
1	106.5 ± 14.9	100.2 ± 14.6	107.0 ± 11.1	99.4 ± 12.9	101.7 ± 13.6	A	
2	89.8 ± 7.3	96.9 ± 17.5	91.5 ± 8.7	92.8 ± 15.7	93.3 ± 14.8	B	
3	n/a	93.3 ± 35.2	n/a	88.4 ± 13.2	89.1 ± 17.0	B	C
4	n/a	95.1 ± 34.9	96.5 ± 2.1	78.5 ± 13.3	86.0 ± 20.4	B	C
5	91.8 ± 17.9	85.3 ± 20.0	92.2 ± 11.2	80.9 ± 11.0	84.3 ± 15.8		C

*Comparison of all pairs is based on Total Fork Length; α=0.05

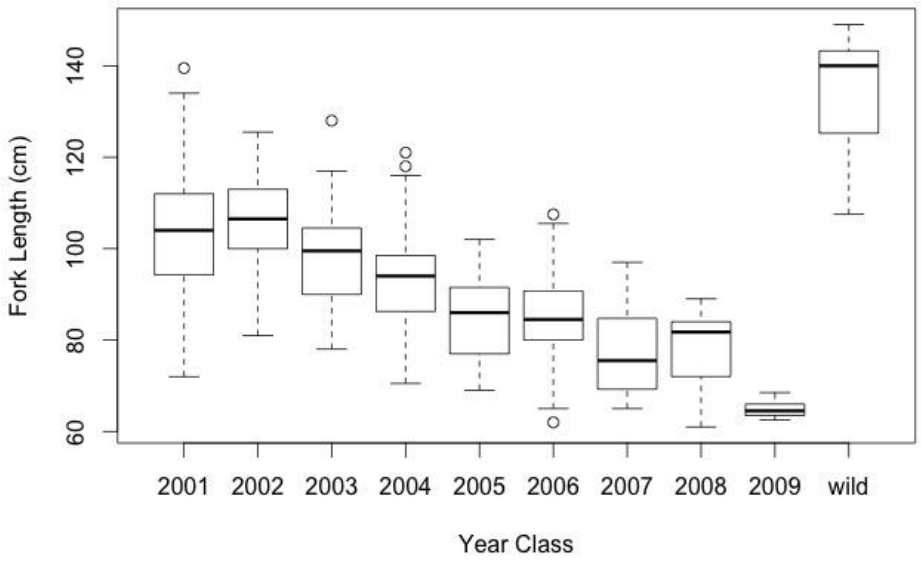


Figure 25. Fork length (cm) of juvenile White Sturgeon as a function of year class in the Canadian portion of the LCR during 2013 and 2014. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag. Individuals with no PIT tag administered by the hatchery or lateral scutes removed were considered wild fish as a product of natural reproduction and of unknown age.

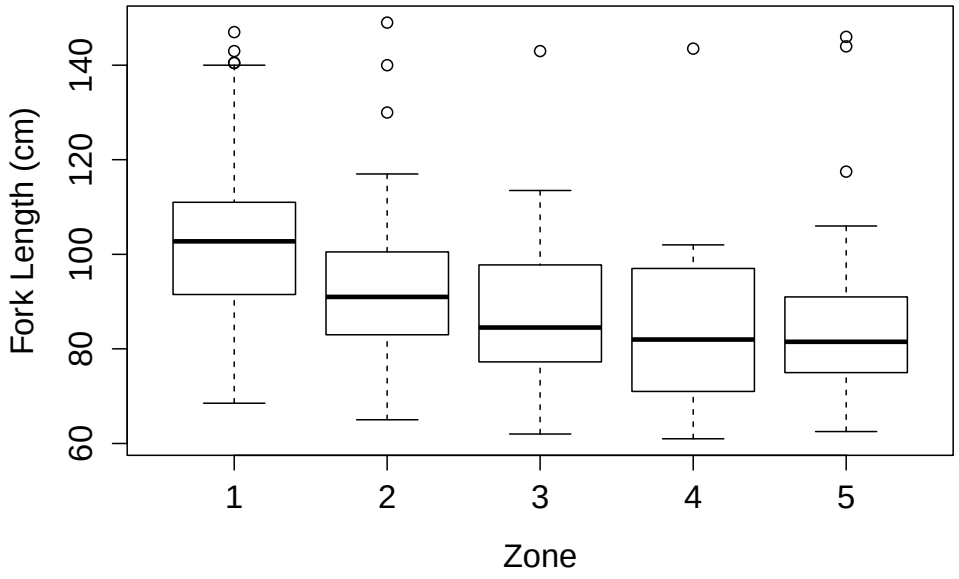


Figure 26. Fork length (cm) of juvenile White Sturgeon captured in the Canadian portion of the LCR by sampling zone during 2013 and 2014. Sampling zones represent 11.2 km increments starting from HLK Dam and moving downstream to the US Border.

3.3.2.2.2 Weight

Mean weight (kg) of juveniles collected in 2013 and 2014 was 6.5 ± 4.6 kg and 6.3 ± 2.9 kg, respectively (Table 14 and 15). Weight of juveniles as a function of year class (Table 14; Figure 27) and sampling zone (Table 15, Figure 28) is provided below. Generally, weight decreased as a function of YrC with the exceptions of YrC 2002 (7.9 ± 2.0) weighing more than YrC 2001 (7.5 ± 3.0; ns, *P*=0.073), YrC 2006 (4.0 ± 1.3) weighing more than YrC 2005 (3.9 ± 1.1; ns, *P*=0.9019), and no difference (ns, *P*=0.7023) between the weight of YrC 2007 (2.9 ± 1.2) and YrC 2008 (2.9 ± 0.9) (Table 14). This trend was also found for FL (Table 12). As also seen with FL, wild juveniles were significantly larger than all hatchery-reared fish (*P*<0.001; Table 14, Figure 27). Weight of fish captured in sampling zone 1 (7.1 ± 3.2 kg) was significantly larger than fish captured in zone 2 (5.8 ± 3.3 kg; P<0.0001), zone 3 (5.4 ± 3.9 kg; P=0.006), zone 4 (4,8 ± 4.1 kg; P=0.0003), and zone 5 (4.4 ± 4.3 kg; P<0.0001). Fish captured in zone 2 were significantly larger than fish captured in zone 5 (P<0.001) (Table 15, Figure 28).

Table 14. Mean (±SD) weight (kg) of juvenile White Sturgeon captured in the LCR during the 2013 and 2014 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 classes not connected by the same letter are significantly different in mean weight.

Year Class	2013		2014		Total	Wilcoxon Rank-Sum*						
	Spring	Fall	Spring	Fall								
2001	7.3 ± 2.2	7.8 ± 4.3	7.5 ± 2.4	7.3 ± 2.7	7.5 ± 3.0	A						
2002	7.6 ± 1.0	7.3 ± 2.0	9.0 ± 2.0	7.7 ± 2.1	7.9 ± 2.0	A						
2003	4.5 ± 1.7	5.4 ± 1.5	7.6 ± 3.2	6.3 ± 2.0	6.0 ± 2.1		B					
2004	4.9 ± 2.7	3.8 ± 1.1	5.3 ± 1.8	5.4 ± 1.9	5.2 ± 1.9			C				
2005	n/a	3.9 ± 1.2	4.1 ± 0.8	3.8 ± 1.2	3.9 ± 1.1				D			
2006	3.8 ± 0.0	4.1 ± 1.5	n/a	4.0 ± 1.3	4.0 ± 1.3				D			
2007	n/a	3.1 ± 1.5	n/a	2.5 ± 1.0	2.9 ± 1.2					E		
2008	n/a	2.8 ± .8	n/a	3.1 ± 1.0	2.9 ± 0.9					E		
2009	n/a	n/a	n/a	1.6 ± 0.3	1.6 ± 0.3						F	
Wild	22.7 ± 4.0	16.9 ± 5.9	n/a	15.0 ± 5.2	17.1 ± 5.8							G

*Comparison of all pairs is based on Total Weight; α=0.05

Table 15. Mean (±SD) weight (kg) of juvenile White Sturgeon captured in the sampling zones of the LCR during the 2013 and 2014 stock assessments. Sampling zones represent 11.2 km increments starting from HLK Dam and moving downstream to the US Border. Fish from zones not connected by the same letter are significantly different in mean weight.

Zone	2013		2014		Total	Wilcoxon Rank-Sum		
	Spring	Fall	Spring	Fall				
1	8.7 ± 4.9	6.9 ± 3.8	8.2 ± 2.4	6.5 ± 2.6	7.1 ± 3.2	A		
2	5.0 ± 1.8	6.3 ± 3.8	5.4 ± 1.8	5.8 ± 3.6	5.8 ± 3.3		B	
3	n/a	7.8 ± 9.0	n/a	5.0 ± 2.4	5.4 ± 3.9		B	
4	n/a	7.0 ± 7.5	5.9 ± 0.3	3.3 ± 2.1	4.8 ± 4.1		B	C
5	5.1 ± 3.1	5.1 ± 6.3	5.1 ± 1.9	3.5 ± 1.6	4.4 ± 4.3			C

*Comparison of all pairs is based on Total Weight; α=0.05

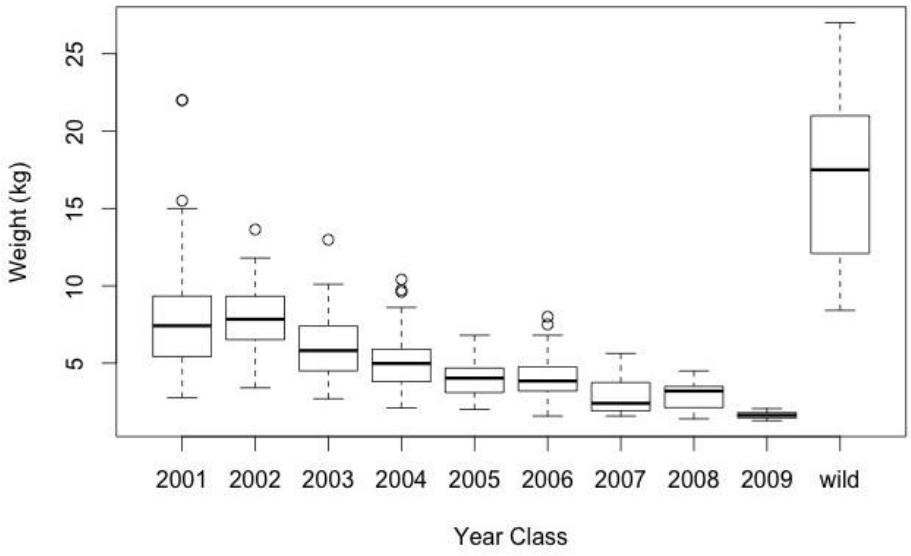


Figure 27. Weight (kg) of juvenile White Sturgeon as a function of year class in the Canadian portion of the LCR during 2013 and 2014. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag. Individuals with no PIT tag administered by the hatchery or lateral scutes removed were considered wild fish as a product of natural reproduction and of unknown age.

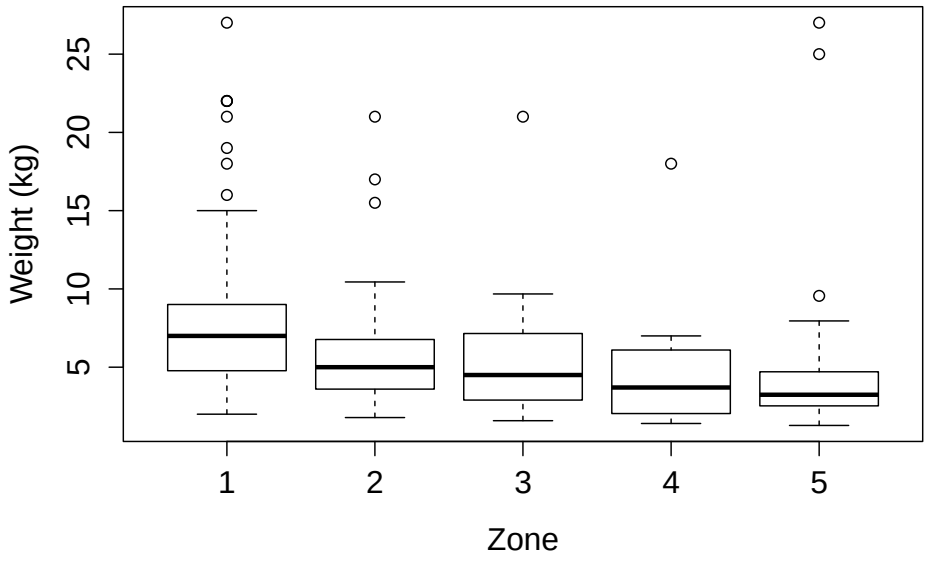


Figure 28. Weight (kg) of juvenile White Sturgeon captured in the Canadian portion of the LCR by sampling zone during 2013 and 2014. Sampling zones represent 11.2 km increments starting from HLK Dam and moving downstream to the US Border.

3.3.2.2.3 Relative Weight

Mean relative weight (W_r) for juveniles captured in 2013 and 2014 was 81.0 ± 7.9 and 81.2 ± 8.4 (Table 16 and 17). Relative weight was significantly different among year classes ($F_{9,551}$=5.0344, P<0.0001; Table 16; Figure 29) and sampling zones ($F_{4,556}$=8.0517, P<0.001; Table 17; Figure 30).

Table 16. Mean (±SD) relative weight (W_r) of juvenile White Sturgeon by brood year class captured in the LCR during the 2013 and 2014 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 classes not connected by the same letter are significantly different in relative weight.

Year Class	2013		2014		Total	Tukey-Kramer HSD		
	Spring	Fall	Spring	Fall				
2001	84.7 ± 6.4	83.4 ± 9.7	83.6 ± 7.8	84.3 ± 7.8	84.0 ± 8.1	A		
2002	81.6 ± 8.1	78.5 ± 5.8	79.8 ± 6.6	80.8 ± 6.2	80.2 ± 6.4		B	C
2003	77.5 ± 7.4	79.9 ± 5.7	78.0 ± 3.6	79.9 ± 9.4	79.5 ± 7.5		B	C
2004	82.2 ± 14.8	81.2 ± 7.6	79.3 ± 4.8	75.2 ± 6.1	77.2 ± 6.7			C
2005	n/a	77.2 ± 3.9	86.4 ± 2.3	80.7 ± 8.1	80.3 ± 7.2	A	B	C
2006	95.6 ± 1.8	82.3 ± 8.6	n/a	82.6 ± 8.2	82.9 ± 8.4	A	B	
2007	n/a	77.6 ± 8.8	n/a	78.2 ± 7.3	78.7 ± 8.5	A	B	C
2008	n/a	75.9 ± 3.4	n/a	81.7 ± 3.7	78.8 ± 4.5	A	B	C
2009	n/a	n/a	n/a	82.5 ± 7.3	82.5 ± 7.3	A	B	C
Wild	89.7 ± 21.5	80.0 ± 12.5	n/a	78.0 ± 10.1	80.8 ± 13.1	A	B	C

*Comparison of all pairs is based on total W_r; α=0.05

Table 17. Mean relative weight (W_r) of juvenile White Sturgeon by sampling zone in the LCR captured during the 2013 and 2014 stock assessment. Sampling zones represent 11.2 km increments starting from HLK Dam and moving downstream to the US Border. Fish from zones not connected by the same letter are significantly different in relative weight.

Zone	2013		2014		Total	Tukey-Kramer HSD		
	Spring	Fall	Spring	Fall				
1	83.7 ± 8.9	79.2 ± 7.0	80.7 ± 6.6	79.6 ± 6.6	80.1 ± 7.0	A		
2	86.4 ± 11.7	79.0 ± 11.8	87.1 ± 7.2	83.7 ± 7.5	83.4 ± 9.0		B	C
3	n/a	89.5 ± 8.2	n/a	85.6 ± 8.3	87.0 ± 8.4			C
4	n/a	80.2 ± 7.6	83.1 ± 2.0	82.1 ± 9.8	82.1 ± 8.2	A	B	C
5	79.2 ± 9.5	82.8 ± 8.3	79.7 ± 6.0	82.3 ± 11.5	82.1 ± 9.6	A	B	

*Comparison of all pairs is based on total W_r; α=0.05

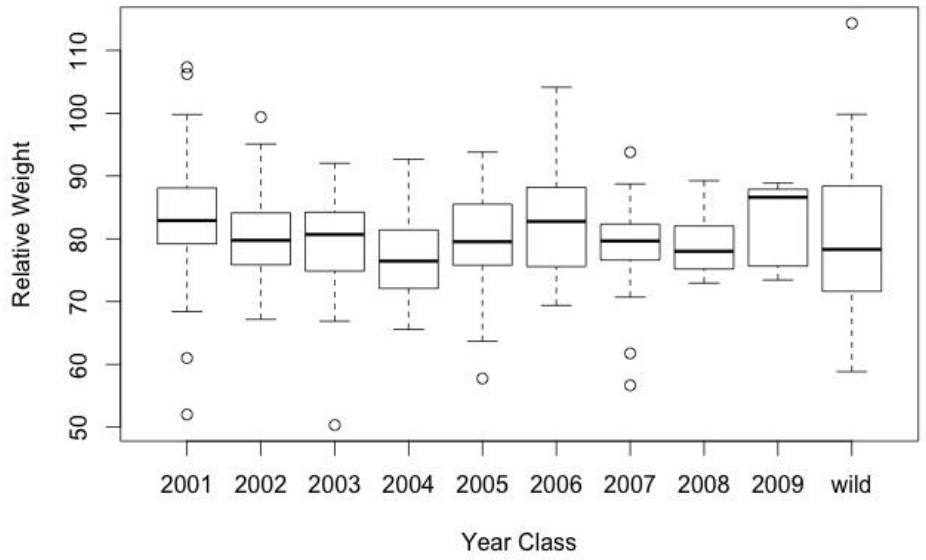


Figure 29. Relative weight (W_r) of juvenile White Sturgeon as a function of year class in the Canadian portion of the LCR by sampling zone during 2013 and 2014. Year class of hatchery origin fish was determined by external mark of removed lateral scutes and PIT tag. Individuals with no PIT tag administered by the hatchery or lateral scutes removed were considered wild fish as a product of natural reproduction and of unknown age.

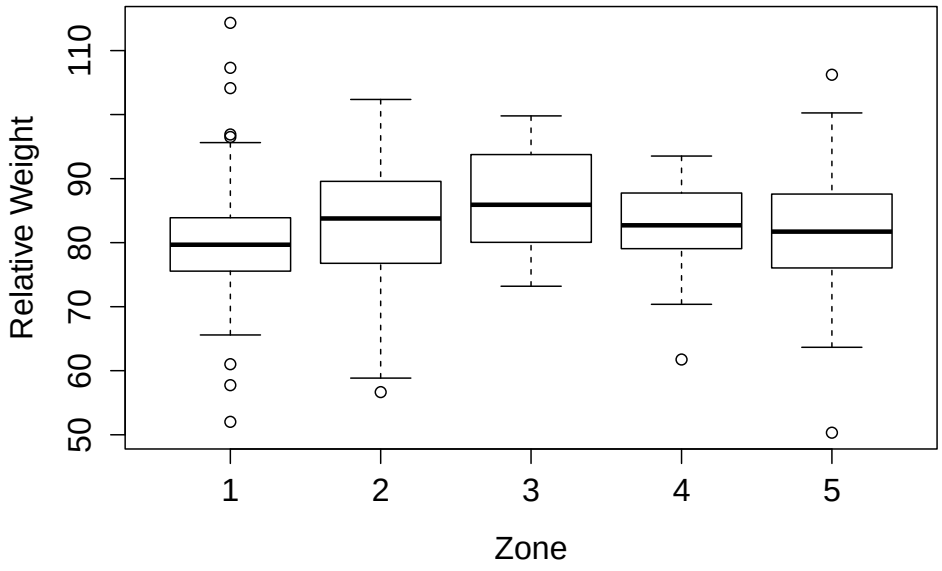


Figure 30. Relative weight (W_r) of juvenile White Sturgeon captured in the Canadian portion of the LCR by sampling zone during 2013 and 2014. Sampling zones represent 11.2 km increments starting from HLK Dam and moving downstream to the US Border.

3.3.2.2.4 Growth

The relationship that best described juvenile White Sturgeon length-at-age was the von Bertalanffy growth equation (Figure 31):

$$L_t = 142.97\left(1 - e^{-0.084(t-2.68)}\right)$$

The length-weight relationship was described by the model (Figure 32):

$$W = 2.96e^{-6} \times TL^{(3.176)}$$

As with the length-at-age relationship, this weight-length relationship predicted faster growth in fork length at younger ages (Figure 33) and faster growth in weight at later ages (Figure 34). The model results are similar to relationships presented for the LCR in previous years (BC Hydro 2013a, BC Hydro 2015c) and other White Sturgeon populations (Beamesderfer 1993).

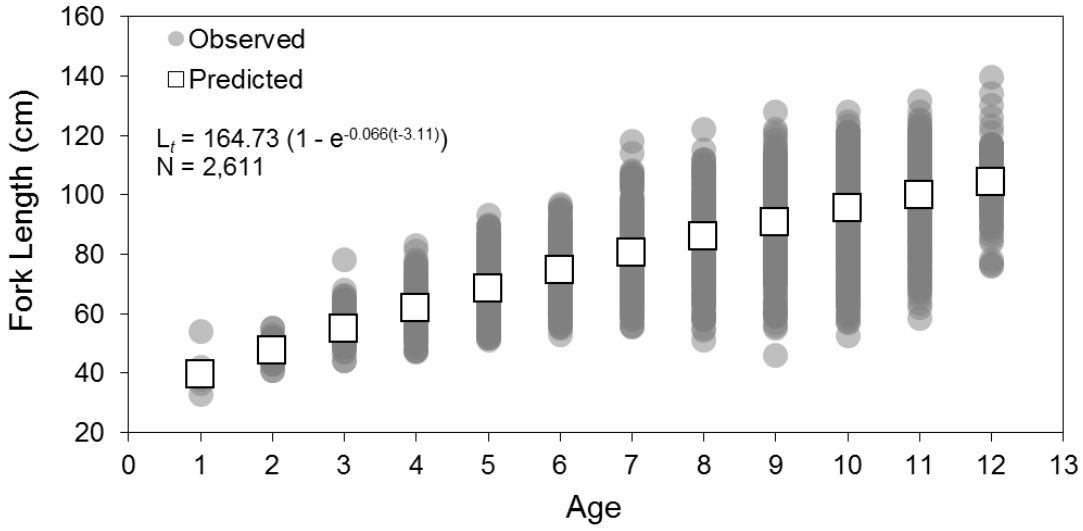


Figure 31. Length-at-age relationship and von Bertalanffy growth equation for juvenile White Sturgeon captured in the LCR during 2009 and 2014.

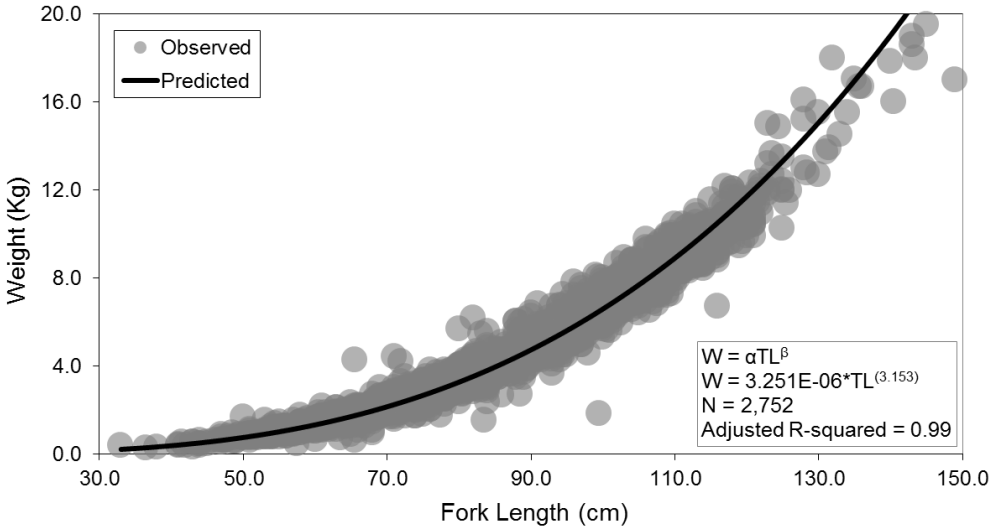


Figure 32. Observed and predicted length-weight relationship and equation for juvenile White Sturgeon captured in the LCR in 2009 through 2014.

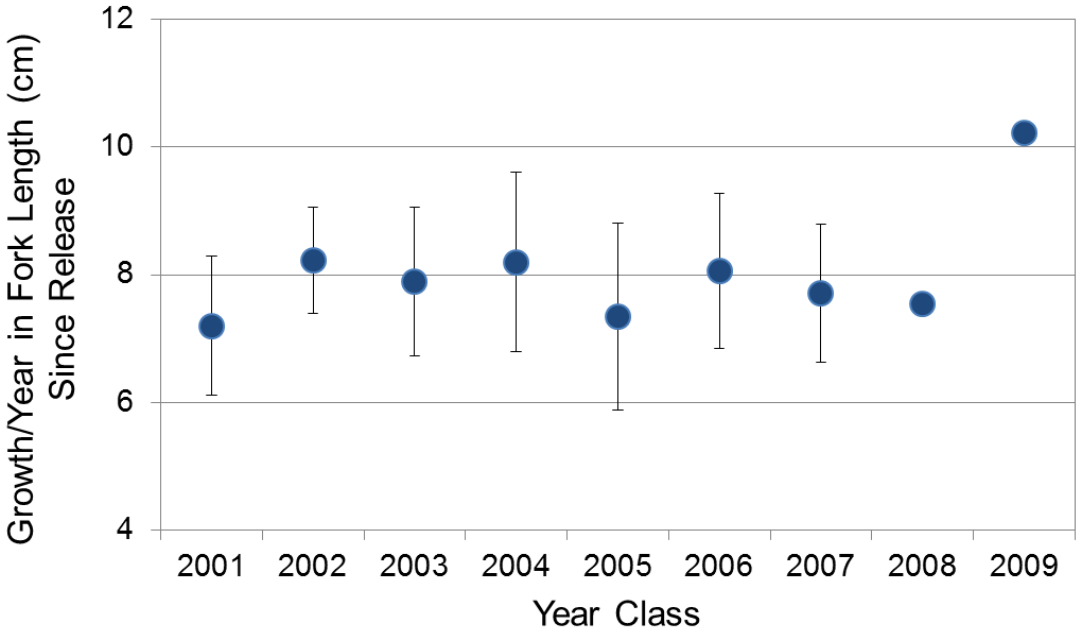


Figure 33. Fork length growth (cm/year) since release by year class for juvenile White Sturgeon captured in the LCR in 2013 and 2014. Year class of hatchery origin fish was determined by external mark of removed lateral scute and PIT tag.

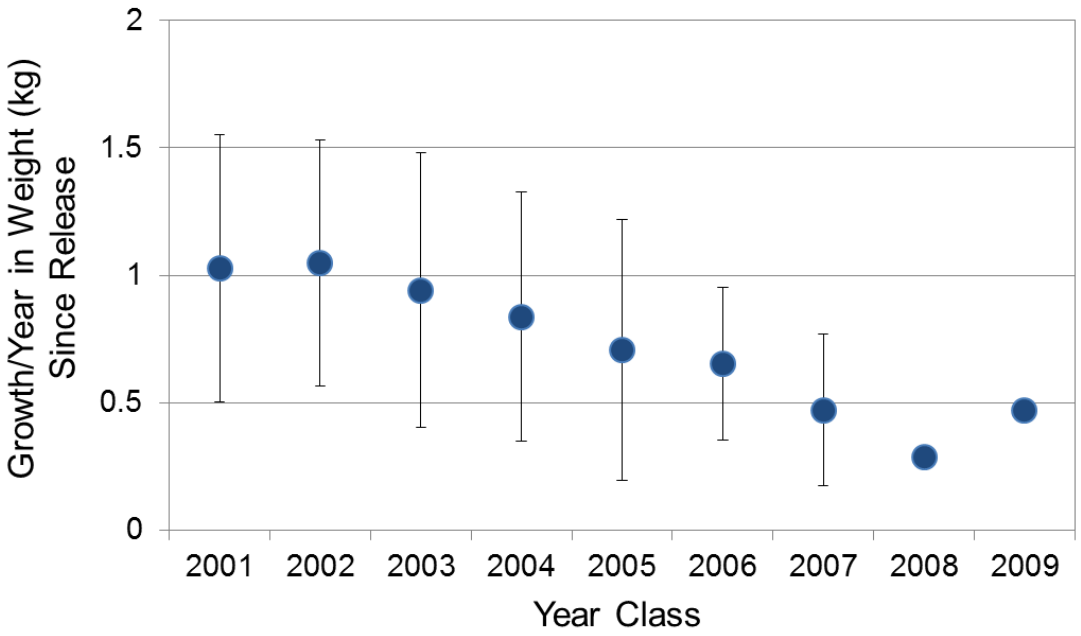


Figure 34. Growth (kg/year) in weight since release by year class for juvenile White Sturgeon captured in the LCR in 2013 and 2014. Year class of hatchery origin fish was determined by external mark of removed lateral scute and PIT tag.

3.3.3 Diet Assessment

We captured 48 juvenile White Sturgeon in the LCR in 2012 and 131 in 2013 (Figure 35) at locations that ranged from 9.0 to 37.3 m in depth (mean = 17.5 m, SD = 6.8) and at temperatures from 11.8 to 14.8°C (mean = 12.9 °C, SD = 0.9). The mean time to land a juvenile White Sturgeon after it was hooked was 1.28 min (SD, 0.72). Per individual, GL was performed within 10.57 min (SD, 9.32) of capture and lasted 2.32 min (SD, 1.75) on average. For removal samples in 2012, individuals were immersed in the lethal dose of MS-222 for 14.67 min (SD, 5.92), and the digestive system was preserved within 40.73 min (SD, 13.57) of the fish being landed.

In total over both sampling years, lavage was performed on 179 juvenile White Sturgeon that ranged from 43.0 to 126.5 cm FL and from ages 2 to 12 (Figure 35). A total of 946 prey items, representing 14 prey taxa, were collected via lavage (Table 18). The percent of juveniles from which lavage successfully recovered prey items varied among river sections.

In 2012, digestive systems were surgically removed from 48 juvenile White Sturgeon ranging from 50.0 to 109.5 cm FL and ages 4 to 11 (Figure 35). In total, 24,478 prey items representing 15 prey taxa were collected via stomach removal (Table 18). One stomach (foregut and midgut) was empty. The subset of hindguts that were examined did not contain any unique prey taxa that were not recovered in the rest of the digestive system. In total, 45 bottom grabs were completed throughout the study area (Table 18). Over the combined 2-year study, the 10,048 prey items identified in the BG samples consisted of 19 unique

prey taxa, whereas 18 were identified in the diet (lavage + removal).

Not all prey taxa were common among the three sample methods, which resulted in the identification of 25 unique taxa (Table 19). Lavage contributed 56% of the total prey taxa collected, removal contributed 60%, and bottom grabs 76%. Percent frequency of occurrence was calculated for each prey taxa by sampling method (Table 19). The four predominant prey taxa — Diptera, Gastropoda, Mysida, and Trichoptera — combined contributed >95% to the total numerical abundance of prey items within the diet. Prey diversity in grab samples differed, the predominant prey taxa being Anthomedusae, Diptera, Ostracoda, and Trichoptera, which that combined constituted 87.7% of the total numerical abundance of grab taxa.

For the four dominant prey taxa within the diet, %F varied among river sections and between years (Table 20). As a mean across years, Diptera, Gastropoda, and Mysida occurred at a higher FO in stomach removal samples collected in the section 1 than in downstream section 3. Trichoptera was recovered in all removal samples from section 3 compared with only a few samples from section 1. Similar results were seen in lavage samples for Gastropoda, Mysida, and Trichoptera. Diptera occurred at a higher FO in section 3 than in section 1 in lavage samples.

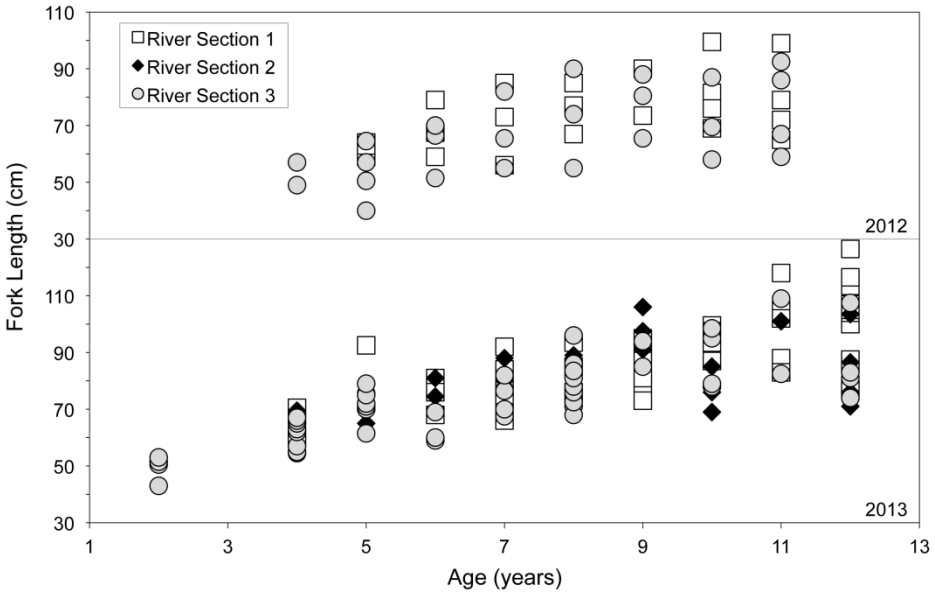


Figure 35. Size and age distribution of juvenile White Sturgeon captured within different river sections. In 2012, gastric lavage (GL) was performed on all juveniles followed by surgical removal of the digestive system to collect the remaining stomach contents (SC). In 2013, only GL was performed on all juveniles.

Table 18. The percent of samples where identifiable prey were recovered from juvenile White Sturgeon in the LCR using gastric lavage, surgical removal of stomach contents, and from the river bottom using benthic grabs. Dashes indicate that no sample was taken.

River Section	N	Prey abundance (number)	Recovery of prey (%)
		Gastric lavage	
1	75	445	70.4
2	29	137	82.8
3	75	364	40.0
Total	179	946	64.4
		Stomach removal	
1	23	4,059	100.0
2	-	-	-
3	25	20,419	96.0
Total	48	24,478	98.0
		Benthic grab	
1	20	2,574	100.0
2	6	5,870	100.0
3	19	1,604	100.0
Total	45	10,048	100.0

Table 19. Percent frequency of occurrence of prey taxa collected in 2012 and 2013 from juvenile White Sturgeon in the LCR using gastric lavage versus surgical removal of stomach contents and from the river bottom using benthic grabs. The four dominant prey taxa in each method are highlighted bold for comparison, and the number of samples is in parenthesis.

	Frequency of occurrence (%)		
	Gastric Lavage	Stomach removal	Benthic grab
Prey taxon	(108)	(47)	(45)
Amphipoda	2.8	12.8	8.8
Anthomedusae	0.0	0.0	**70.2**
Arachnida	0.0	4.3	8.8
Bivalvia	3.7	25.5	38.6
Cladoceron	0.0	0.0	36.8
Coleoptera	0.0	0.0	1.8
Copepoda	0.0	0.0	43.9
Cottoidea	0.9	2.1	0.0
Decapoda	0.0	2.1	0.0
Diptera	**17.6**	**63.8**	**100.0**
Ephemeroptera	4.6	34.0	36.8
Gastropoda	**19.4**	**63.8**	52.6
Hirudinea	1.9	6.4	0.0
Isopoda	0.0	4.3	8.8
Mysida	**71.3**	**53.2**	5.3
Nematode	3.7	10.6	29.8
Odonata	0.0	0.0	7.0
Oligocheata	3.7	17.0	63.2
Osteichthyes	0.0	14.9	0.0
Ostracoda	0.0	0.0	**87.7**
Platyhelminthes	2.8	0.0	47.4
Plecoptera	0.0	0.0	5.3
Polychaete	0.9	0.0	0.0
Trichoptera	**17.6**	**55.3**	**71.9**
Unidentified organic matter	3.7	2.1	0.0
Proportion of total	0.56	0.60	0.76

Table 20. Percent frequency of occurrence of the four predominant prey taxa in the diet of juvenile White Sturgeon in the LCR, as expressed across samples collected using gastric lavage (GL), versus surgical removal of stomach contents (SC), and from the river bottom using benthic grabs (BG). Dashes indicate that no sample was taken, whereas the zeros indicate the taxon was not present.

	%F											
	Diptera			Gastropoda			Mysida			Trichoptera		
Habitat	GL	SC	BG	GL	SC	BG	GL	SC	BG	GL	SC	BG
						2012						
1	58.3	78.3	100.0	8.3	78.3	54.5	25.0	95.7	0.0	0.0	8.7	54.5
2	-	-	100.0	-	-	66.7	-	-	0.0	-	-	100.0
3	42.9	50.0	100.0	14.3	50.0	37.5	0.0	12.5	0.0	64.3	100.0	75.0
Total	50.0	63.8	100.0	11.5	63.8	54.8	11.5	53.2	0.0	34.6	55.3	77.4
						2013						
1	4.3	-	100.0	28.3	-	22.2	97.8	-	33.3	4.3	-	33.3
2	12.5	-	100.0	12.5	-	50.0	83.3	-	0.0	25.0	-	100.0
3	8.3	-	100.0	16.7	-	72.7	75.0	-	0.0	16.7	-	72.7
Total	7.3	-	100.0	22.0	-	50.0	90.2	-	11.5	12.2	-	65.4
						Total						
1	15.5	78.3	100.0	24.1	78.3	40.0	82.8	95.7	15.0	3.4	8.7	45.0
2	12.5	-	100.0	12.5	-	61.1	83.3	-	0.0	25.0	-	100.0
3	26.9	50.0	100.0	15.4	50.0	57.9	34.6	12.5	0.0	42.3	100.0	73.7
Total	17.6	63.8	100.0	19.4	63.8	52.6	71.3	53.2	5.3	17.6	55.3	71.9

3.3.3.1 Prey Diversity

For stomach removals (2012), we found no significant relationship between prey diversity for juvenile White Sturgeon and age (Poisson regression: $P = 0.522$), length ($P = 0.642$), or weight ($P = 0.959$). However, juveniles in river section 1 consumed significantly higher numbers of unique prey taxa (mean = 4.6, SD = 1.9) than did fish collected from river section 3 (mean = 2.9, SD = 1.4; $t = 2.01$, $df = 46$, $P < 0.01$; Figure 36). The number of unique prey taxa identified within each sampling method differed significantly between river sections (Table 21).

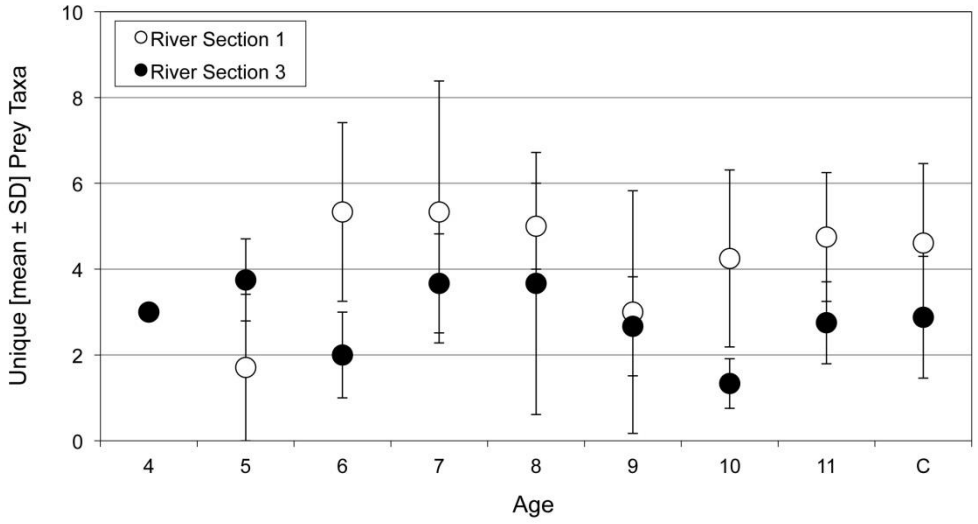


Figure 36. The mean (± SD) number of unique prey taxa identified after surgical removal of the stomach contents (SC) of known age juvenile White Sturgeon collected from upstream (section 1) or downstream (section 3) in 2012. A comparison (C) of overall means between sections is also provided.

Table 21. Comparison of the number of unique prey taxa across samples collected from juvenile White Sturgeon in the LCR using gastric lavage versus removal of stomach contents and from the river bottom using benthic grabs. Different letters denote significant differences (P ≤ 0.05) between river sections via a t-test or Wilcoxon's rank-sum test.

River Section	Unique prey taxa (mean ± SD)
Benthic grab (t-test)	
1 z	8.05 ± 2.42
2 z	7.78 ± 1.93
3 y	5.89 ± 2.08
Gastric lavage (Wilcoxon)	
1 z	1.59 ± 1.01
2 z	1.52 ± 0.82
3 z	1.54 ± 0.72
Stomach removal (Wilcoxon)	
1 z	4.04 ± 1.61
3 y	2.96 ± 1.46

3.3.3.2 Efficiency of GL

Through the collection of SC, we were able to determine the efficiency of GL. Of the White Sturgeon sampled for both GL and SC in 2012, a total of 16 prey taxa were collected with 14 prey taxa identified in river section 1 and 10 prey taxa identified in river section 3 (Table 22). Gastric lavage recovered 57% and 60% of

total prey taxa found in the diet of fish from river sections 1 and 3, respectively. Across both river sections, 69% of total prey taxa were collected by GL, with a single prey taxa in river section 3 detected by GL and not SC. The resampling exercise to evaluate the ability of GL to describe juvenile diet at the population level, identified that sample sizes of 25, 50, and 100 juveniles resulted in the identification of 54, 72, and 90% of total prey taxa, respectively (Figure 37).

Table 22. Efficiency of gastric lavage (GL) in recovering prey by comparison of surgically removing stomach contents (SC) of juvenile White Sturgeon. Recovery of prey total abundance of prey recovered, and unique prey taxa identified for each GL and SC are provided for comparison.

		Recovery of prey items (%)		Prey abundance		Unique prey taxa (Proportion of total)	
Habitat	N	GL	SC	GL	SC	GL	SC
1	23	52.2	100.0	67	4,126	8 (0.57)	14 (1.0)
3	24	58.3	100.0	342	20,761	6 (0.60)	10 (1.0)
Total	47	54.2	100.0	409	24,887	11 (0.69)	16 (1.0)

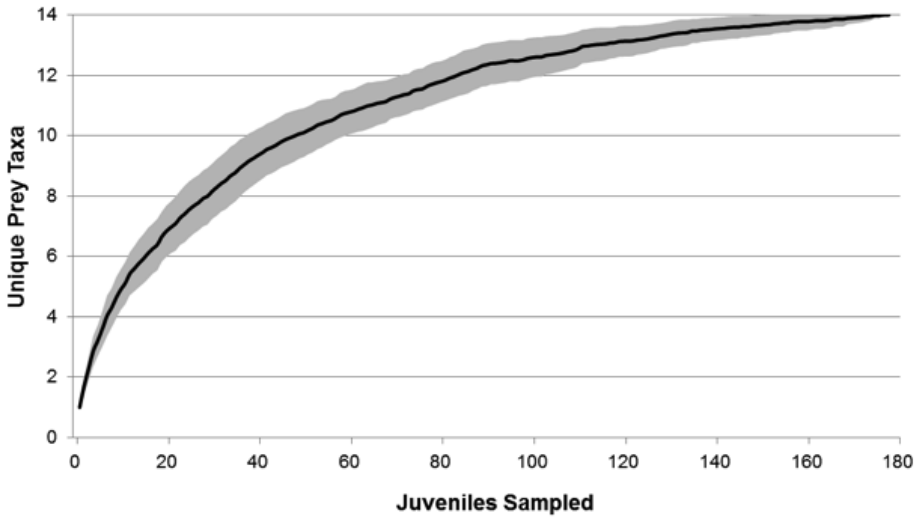


Figure 37. The cumulative proportion (mean ± 95% CI) of unique prey taxa identified in gastric lavage (GL) samples collected from juvenile White Sturgeon in 2012 and 2013.

3.3.3.3 Prey Selection

Juvenile White Sturgeon prey selection was variable and most prey taxon were selected less than their availability in the river with mean prey selection indices being -0.18 and -0.26 in 2012 and 2013, respectively (Figure 38). Mysida were the main exception to this trend, selection index values being >0.5. We calculated Schoener's similarity index to determine the degree of diet overlap between juveniles residing in river sections 1 and 3 in 2012 and found no

significant overlap using either SC (α = 0.46) or GL (α = 0.56) data in the prey taxa chosen by each group. Additionally, using GL data, Schoener's similarity index indicated there was no significant overlap between the diet of juvenile White Sturgeon in the UCR in 2012 compared to 2013 (α = 0.20), with different dominant prey categories in each year. Finally, we also compared across different river sections in 2013 using GL data and found significant overlap in resource use between fish in the two most downstream river sections (river sections 2 and 3, α = 0.77, Figure 5) with fish in the upstream river section (1) having dietary overlap values of 0.51 and 0.58 when compared with river sections 2 and 3, respectively.

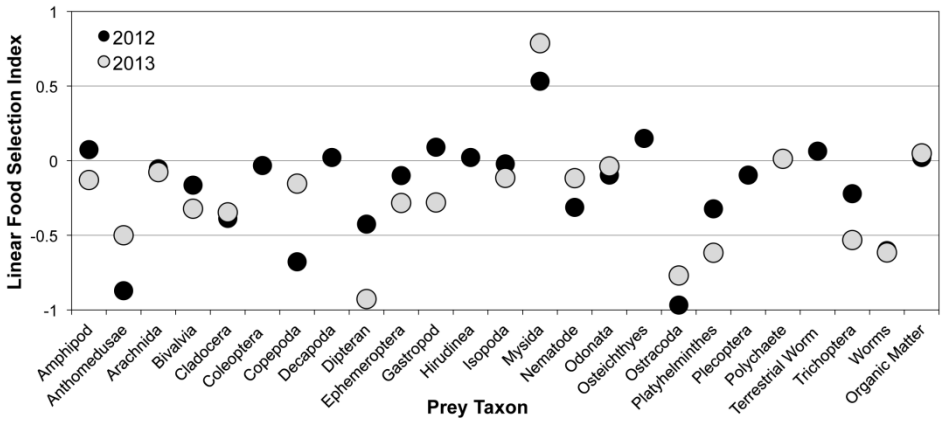


Figure 38. Prey selection by juvenile White Sturgeon in 2012 and 2013 calculated by the linear food selection index (*L*; see methods).

3.4 Habitat Mapping

Recorded images have been edited and processed identifying ten acoustic substrate classes. Detailed results of analyses are provided in 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.

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 do not represent all years of this program. While this monitoring program has contributed significant knowledge pertaining to larval and juvenile White Sturgeon ecology and the overall success of the Conservation Aquaculture Program, additional years of data are required to assess trends and further address the management questions of this program.

4.1 Yolk Sac 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 YSL, spawning was estimated to have occurred mid-July downstream of Kinnaird in 2013. In 2014, no viable samples were preserved to developmentally stage for estimating spawning duration. However, based on previous sampling years (BC Hydro 2015c) and developmentally staging eggs collected in 2013 (BC hydro 2015a) and 2014 (BC Hydro 2015b) duration and timing of spawning activity has been similar, with the majority of estimated spawning days occurring on the descending limb of the hydrograph and at water temperatures above 14ºC (Golder 2012).

In 2013, dispersing larvae were again collected within the vicinity of Kinnaird, which has now had spawning documented annually since 2007. However, the exact location of the spawning area (egg deposition) remains unknown and should be of focus in the next several years of this program. For spawning areas where the exact geographical location is uncertain, drift nets are the most effective tool to collect larval White Sturgeon as they can represent all areas upstream of the sampling location. While egg mats are used once the main areas of egg deposition have been identified, drift nets should be used primarily when attempting to assign a general location where spawning may be occurring. To address the objectives of this program as it relates to describing new spawning areas or determine the distribution of larvae, it is recommended that use of egg mats be restricted to Waneta, and that drift nets are the primary technique used in areas where spawning locations are uncertain (e.g., Kinnaird). Once geographical boundaries of the spawning location can be described, a monitoring program that includes the use of egg mats should be developed consistent with other locations (e.g., Waneta (Golder 2013) or Revelstoke (AMEC 2014)).

Reduced quality of early life stage habitat used for egg incubation and early rearing of larvae is one of the recruitment failure hypotheses for this population. Larvae that are young in development 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. 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 YSL burrowing behaviour and young-of-year rearing conditions and the potential effects of habitat on recruitment. Further, it will be important to incorporate results from larval monitoring programs in the US section of the TRA, as captures of larvae at feeding stages occur annually (Hildebrand and Parsley 2013). These results suggest that hiding habitat is present between the Waneta spawning location and the capture location downstream of Northport WA. Possible genetic analyses 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 Temperature Effects on Development

Our investigations of White Sturgeon yolk-sac larval period, extends previous research for a life period where information pertaining to developmental rate and growth of morphological traits is lacking. Temperature effects on YSL development were documented for ten stages, from hatch to exogenous feeding, as a function of time, ATU and RTi, and we described these effects on specific morphological traits. In terms of time, increased rearing temperatures significantly hastened YSL development, consumption of yolk sac, and the onset of first feeding. These observed thermal induced responses were similar to other studies examining YSL development in sturgeon species (Lake Sturgeon *A. fulvescens* Wang et al. 1985; Shortnose Sturgeon *A. brevirostrum,* Atlantic Sturgeon *A oxyrhynchus*, Hardy and Litvak 2004; Green Sturgeon *A. medirostris,* Van Eenennaam et al. 2005; Pallid Sturgeon *Scaphirhynchus albus,* Miller et al. 2016*;* Shovelnose Sturgeon *S. platorynchus*, Kappenmen et al. 2013). While these type of results based on direct measurements of development over time can be used as a tool to understanding early life history, we further partitioned the variability between temperature treatments which can help understand recruitment processes, adult reproductive ecology, and natural adaptability in altered systems. We discuss our results below in terms of variability attributed different measurements of development, which we feel is a critical consideration for studies focused on describing spawning related measures (e.g. timing, frequency, and duration) in the wild.

Time to reach developmental stages

Relative Time (RT_i) – The relative amount of time between developmental stages was independent of temperature with no significant difference across all treatments. The use of RT_i in early developmental stages has been proven to be an appropriate character for scaling of ontogeny, independently of temperature (Eckes et al. 2015; Kilmogianni et al. 2004). While considerable variation between treatments was explained using RT_i in our study, we found that development remained faster in the warmest treatment compared to all other treatments (Table 5). For example, YSL spent 26, 22, and 28% of their developmental time transitioning from stage 40 to stage 41 in treatments 12.5°C, 14.0°C, and 15.5°C, respectively. YSL in treatment 17.0°C spent considerably less developmental time (15%) transitioning between the same stages.

Accumulative Thermal Units (ATU) – ATU, or counting degree-days, is a common approach for measuring fish development and is widely used in aquaculture to predict when hatching will occur. ATU is expected to standardize development across varying rearing temperatures, as seen in other studies (Boucher et al. 2014). However, we observed differences in developmental rate as a function of ATU between the upper (15.5°C and 17.0°C) and lower (12.5°C and 14.0°C) temperature regimes with variation between treatments increasing in later stages, starting at stage 40, where a delay in developmental rate was observed. Similar trends have also been recorded during the egg stage (Parsley et al. 2011). Importantly, evidence of developmental rate deceleration is particularly apparent in colder temperatures when development is expressed by ATU (Figure 11). This delay appears to be associated with the development of major structures in both egg (neural tube; following stage 19; Parsley et al. 2011)

and YSL (liver development; following stage 40; this study) stages. It is uncertain how this cumulative delay in egg and YSL development will affect later life stages.

Hours Post Hatch (hph) – Developmental rate was temperature dependent, decreasing significantly with decreasing rearing temperatures. This translates into additional time at the YSL stage for individuals reared in colder environments, extending time spent near spawning grounds or undergoing drift behaviour while underdeveloped, potentially exposing fish to additional risks. For example, spawning activity of White Sturgeon in the most upstream portions of the lower Columbia River typically begins in late July at the coldest known temperatures (9 - 11°C; AMEC 2014) for the species. Egg incubation has been documented to last for 20 days at this temperature regime (Parsley et al. 2011) followed by an extended YSL development period of up to 30 days (Crossman and Hildebrand 2012) resulting in larval dispersal occurring into the early fall. This prolonged period of early development directly affects the developmental stage and size of individuals entering critical transitional periods (e.g. fall and winter), potentially reducing survival probabilities.

Based on these results, we recommend future studies to focus on developmental stage when comparing experimental treatments or YSL groups, as developmental rate can differ greatly between temperature regimes depending on how it is measured. Researchers should consider incorporating 2 or 3 measures of development timing into the study design to ensure variation between stages is captured.

Morphological Traits

This study is the first attempt to show temperature-mediated effects on specific trait development in White Sturgeon YSL. We standardized trait growth by developmental stage across cold (12.5°C) and warm (17.5°C) temperature treatments to acknowledge differences described above in the time to reach any given stage.

Hours post hatch (hph) - Morphological traits BA, HA, TL, MA, PA (Figure 12a and 12b), and GFA (Figure 12c and 12c) exhibited similar trends of larger trait size as a function of time (hph) in the warm temperature treatment compared to individuals reared in the cold temperature treatment. An inverse relationship was observed for YSA in relation to time, with smaller YSA recorded in the warm temperature treatment. These trends directly relate to the increase developmental rate at warmer temperatures (Figure 11) increasing morphological trait growth and absorption of yolk-sac reserves. This has also been observed in other sturgeon (Atlantic and Shortnose Sturgeon, Hardy and Litvak 2004; Lake Sturgeon, Wang et al 1985) and teleost (Kamler 2008) species.

Developmental stage – Temperature effects on morphological trait growth was generally inversed as a function of developmental stage compared to hph. Depletion of yolk reserves was higher across all stages and morphological traits of BA, HA, TL, MA, and PA tended to be larger starting at stage 40 in YSL of the cold temperature treatment. This coincides with the observed delay in developmental rate occurring at stage 40, particularly pronounced in individuals

reared in colder temperatures (Figure 11). The apparent connection between delayed development and appearance of major structures (i.e., liver development) appears be further coupled with increased growth of most morphological traits (excluding GFA) measured in this study. When standardized by developmental stage, GFA was larger in warm temperature treatments; a trend also observed as a function of time. This allocation of resources could be an evolved mechanism required for individuals reared in warmer temperatures where levels of dissolved oxygen are lower compared to colder water and therefore a larger GFA is of higher priority and essential for survival.

The thermal induced responses observed either as a function of time or developmental stage could have both beneficial and detrimental effects on survival of individuals at the YSL stage and later in life. Increased yolk utilization and growth rates seen at warmer temperatures sooner initiate the transition to exogenous feeding (Wang et al. 1987), ability to escape (Hardy and Litvak 2004), and drift behaviour (Duong et al. 2011) avoiding additional risks of predation at the vulnerable YSL stage. While individuals of slower development due to colder temperatures later in the season (e.g., fall) may also experience mismatch between onset of exogenous feeding and environmental conditions (Laurel et al. 2011), missing the period of optimal food resources available to warmer reared YSL earlier in the season (e.g., summer). However, larger morphological traits observed in cold reared YSL could enhance ability to swim and avoid predation (Miller et al. 1988) when transitioning to the drifting larval stage as well as increase the size of prey individuals are capable of digesting when transitioning to exogenous feeding (Schael et al. 1991). For seasonally early YSL (e.g., spring), slower development may be beneficial by prolonging endogenous resources when river productivity is relatively poor. Further studies to examine these effects of the rate of temperature induced trait development on fitness and survival of YSL and later life stages are required.

Management Implications

A detailed time series of White Sturgeon YSL development as it relates to rearing temperature is a valuable tool for fish culturists and conservational researchers with the ability to enhance rearing production and knowledge of factors effecting natural recruitment that are vital to restoration efforts. However, results from this study indicate that caution needs to be exercised when comparing YSL in the absence of developmental stage information. We compared three different methods to describe development and while overall trends are similar, differences exist at specific stages.

We determined developmentally staging YSL is instrumental when comparing individuals across experimental treatments or conditions in the wild. Failure to due so could lead to disproportional representation of YSL at different developmental stages. Experimental studies that pool YSL from multiple days post hatch (dph) at the start of the experiment (e.g. Pallid Sturgeon, 0-4 dph, Miller et al. 2016) could suffer from confounding effects within treatments based on differences in developmental rate and morphological trait development between stages observed in this study. Additionally, studies making inferences on results strictly based on dph should use caution, especially when summarizing information across temperature regimes, as results can't be compared using dph

alone. Therefore, it is crucial to apply experimental treatments as a function of developmental stage rather than time (dph).

Confounding effects of egg incubation temperatures on subsequent YSL development also needs to be considered in experimental design. Boucher et al. (2014) examined White Sturgeon larval growth, development, and survival from eggs incubated at 15°C and YSL reared at two temperature treatments of 13.5 and 17.5°C. However, egg incubation temperature has a significant influence on development (Parsley et al. 2011; Wang et al. 1987) and size at hatch (Wang et al. 1987) with unknown effects on later life stages. To remove confounding effects, and better represent natural conditions found in the wild, temperature treatments should be initiated at time of fertilization and applied through both egg and YSL stages.

Our data has the ability to provide insight into YSL behaviour and White Sturgeon reproductive ecology, enhancing recovery planning and conservation aquaculture programs. Our study results in increased precision for estimates of egg fertilization and hatch dates of wild YSL produced through back-calculation from the time of capture as a function of mean water temperature. These estimates are indicative of duration of spawning activity, number of spawning days, and spawning related responses to environmental cues such as water temperatures and flow regimes (Jay et al. 2014). Alternately, the larval dispersal period could be estimated to determine possible factors restricting recruitment such as predator abundance, prey availability, conspecific density, or environmental factors (e.g., temperature, flow).

Aquaculture programs rearing fish in controlled water temperature environments could use our data to select rearing temperatures required to achieve desired developmental rates. Artificial fertilization involving multiple adults may occur over multiple days, offsetting development between family groups. Incubation temperatures could be altered to synchronize the onset of first feeding between family groups to simplify hatchery procedures. If fish are being raised for release of larvae, adjusted incubation temperatures could maximize larval size or synchronize release date with optimal environmental conditions (i.e., temperature, flow, natural larval drift, prey availability, etc.). If naturally produced YSL are needed for stocking purposes, collecting individuals representing a range of ages (based on estimated date of fertilization) will increase number of contributing adults, increase effective breeding numbers, and lower coancestry among offspring, helping to maintain levels of genetic diversity in the collected YSL relative to levels represented in the natural spawning population (Crossman et al. 2011; Jay et al. 2014).

Conclusions

Changes during early ontogenetic development are directly related to year-class strength (Myers 1997), survival, and recruitment (Cushing 1972). Standardization of developmental rate allows for improved predictions on timing of important life changes to help describe YSL ecology and determine restrictions on recruitment. Further research is required to determine the effect of thermal regimes on fitness of an individual with immediate effects on phenotypic traits and future effects including developmental rate, behaviour, physiology, and

morphology, not only within the YSL stage but to extend to later juvenile stages (e.g. Atlantic and Shortnose Sturgeon, Spear and Kieffer 2016; Sterlet Sturgeon *A. ruthenus*, Mandal et al. 2016). Importantly, methods should involve developmentally staging specimens to eliminate possible confounding effects and to ensure equal development within a group as duration to stage may differ based on family, temperature variation, or available substrate.

It is important to understand the different effects of temperature and the developmental consequences that may occur, as early ontogeny represents the most crucial developmental period in terms of thermal tolerance and survival, particularly at the extreme temperatures (both high and low) experienced by the species where mortality is increased (Dahike et al. 2016). Influence of temperature is important to know for species ecology as well as to predict future effects from changing temperatures due to climate change or anthropogenically altered environmental conditions.

4.3 Juvenile Population Assessment

For approximately the last 40 years, recruitment of White Sturgeon in the Transboundary Recovery Area (TRA) 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, the Upper Columbia White Sturgeon Recovery Initiative (UCWSRI) was formed in 2000, and developed a Recovery Plan, a key component of which is the supplementation of the existing White Sturgeon population through broodstock collections, hatchery rearing, and stocking of juvenile White Sturgeon (UCWSRI 2002).

In total, 136,942 hatchery-reared juvenile White Sturgeon have been released into the TRA from 2002 to 2014 (yearly releases ranging from 4,302 in 2012 to 21,603 in 2005). These juveniles are being monitored annually by various agencies (i.e., Golder, BC Hydro, Washington Department of Fish and Wildlife (WDFW)). Results from monitoring indicate that hatchery-reared juveniles are growing and surviving well in the LCR. These juveniles represent a significant learning opportunity as juvenile age classes are lacking in many sturgeon populations throughout the world. Though this program serves as a means of identifying wild juveniles, they remain rarely encountered and represent < 4% of the total catch to date since the monitoring program began. 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 7 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).

While monitoring studies to date have provided data regarding the distribution, growth, and condition of the hatchery-reared juvenile sturgeon, data and analysis regarding their survival have been limited. The next steps of this program will be to develop a dataset that includes juvenile captures throughout the TRA to provide a preliminary analysis of hatchery reared juvenile White Sturgeon population abundance and survival estimates, similar to other populations (Justice et al. 2009). Results from this work can then be used to guide future aquaculture efforts (e.g., size at release and release numbers) and management decisions (long-term population targets).

4.4 Diet Assessment

We quantified the diet of known-age juvenile White Sturgeon over different size-classes and ages in the LCR using two methods. Our results indicated that GL, if conducted on appropriate numbers of fish, is effective at describing sturgeon diets. We found that lavage needed to be performed on >100 juvenile White Sturgeon (Figure 37) to explain 90% of the diet. While we feel this threshold is important to understand, we are fortunate to have access to large numbers of juvenile White Sturgeon in the LCR. This threshold may differ among systems or research interests, where small population size and species status may reduce sample sizes.

The diet of juvenile White Sturgeon described in this study was found to be similar to previous work conducted in the Columbia River and elsewhere. Juveniles (<60 cm TL) are known to feed on tube-dwelling amphipods, mysids, isopods, Corophorium, and other benthic invertebrates such as chirono- mids, as well as on the eggs and fry of other fish species (Schreiber 1962; Radtke 1966; Cochnauer 1983). Our results agree with previous studies conducted within the transbounary Columbia River (Golder Associates 2006a; Parsley et al. 2010) and lower Columbia River, USA (Muir et al. 1986) that found similar compositions of diet, including prey taxa such as Mysida, Trichoptera, Diptera, as well as Isopoda, Pelecypoda, Gammaridae Amphipoda, Ephemeroptera, and fish. When White Sturgeon reach sizes of about 60–80 cm TL or larger, their diets diversify and they begin to eat fish (Muir et al. 1988; Sprague et al. 1993), small mollusks (Bajkov 1949), and crayfish (McKechnie and Fenner 1971). White Sturgeon of the Fraser River were found to be more piscivorous (FO = 48.8; Semakula and Larkin 1968); however, juveniles sampled ranged from ages 9 to 16, and fish were more commonly found in the diet of larger individuals. We also sampled a large range of juvenile sturgeon sizes and ages; however, fish did not contribute significantly to the diet, which was surprising given the results of the studies outlined above where fish were relatively high proportions in the diet (FO > 20).

In our study, Mysida were an important food source for juvenile White Sturgeon in upstream section 1 in 2012 and for all sections in 2013, despite poor representation in the bottom grab samples or in samples passively collected in the water column (J. A. Crossman, unpublished data). Mysids were first introduced into Arrow Lakes Reservoir (upstream of Keenleyside Dam) in 1967 as a food source for native fish species and existing mysid populations are supplemented indir- ectly through an annual nutrient addition program in the reservoir (Schindler et al. 2013). Mysids are entrained from Arrow Lakes

Reservoir through the discharge outlets of Keenleyside Dam. Based on limited sampling, entrainment occurs primarily at night and varies seasonally (highest in winter as discharge increases and reservoir levels decline), and mysid densities decrease rapidly with increased downstream distance from Keenleyside Dam (R. L. & L. Environmental Services 1985). Anecdotally, mysids are thought to be mostly consumed prior to making it to the downstream section 3. However, under certain flow conditions they are collected near the international border. The relationships between mysid production in Arrow Lakes Reservoir, entrainment through Keenleyside Dam, and down- stream dispersal in the LCR is poorly under- stood but warrants additional study, especially considering results of an earlier study by Golder Associates (2006a), who found that mysids composed >90% of the total prey items identified in juvenile (ages 1 to 3) White Sturgeon stomach removal samples and were present in 80.4% of the 46 stomachs examined.

Even though efficiency is not 100%, lavage is acknowledged as the accepted method to quickly assess the diet of endangered species like sturgeon (Jackson et al. 2002; Gerrity et al. 2006). It is important to understand recovery rate in the wild when extrapolating samples obtained from individuals using lavage to the diet preferences of the larger population. Our recovery rate using lavage was 54.2% of the total unique prey taxa found in the 48 stomach removal samples, where all prey from the digestive system could be examined. Importantly, the predominant prey species were similar between lavage and stomach removal samples. In our study, lavage was not effective at quantifying the amount of prey items in individual digestive tracks, and only a small proportion of the total prey abundance was collected via GL (Table 22). However, other studies have reported GL to have high recovery rates of prey items for sturgeon captured in the wild (>85% for both Atlantic Sturgeon A. oxyrinchus and Lake Sturgeon A. fulvescens; Guilbard et al. 2007) and in experimental settings (67.5% for Siberian Sturgeon A. baeri, Brosse et al. 2002; 74.9% for Pallid Sturgeon Scaphirhynchus albus, Wanner 2006). Experimental work also suggests that recovery rates are reduced with increased time after prey are ingested (e.g., >2 h; Brosse et al. 2002) and that the size or morphology of a prey type can influence recovery once ingested (Brosse et al. 2002; Wanner 2006).

While data on diet at the individual level is informative, especially when describing mechanisms influencing measured growth rates (Jackson et al. 2002), we did not find a tremendous advantage to removal of the digestive system as variability did not partition by fish size or age and was more a function of the river section occupied. Based on our comparison between lavage and stomach removal sampling methods, we believe lavage can be used with confidence to explain the diet at the population level, as long as adequate sample sizes (e.g., Figure 37) and spatial representation of all habitats used by the species of interest are incorporated into the study design. Additional work to assess comparisons across ages (juveniles, subadults, and adults; e.g., Guilbard et al. 2007) and seasons (e.g., Barth et al. 2013) would be an important next step. While our results acknowledge the importance of spatial coverage when defining sampling approaches, additional sampling to describe seasonal changes to the diet would further increase our knowledge of feeding ecology and indicate whether seasonal changes occur in relation to prey availability or are a function of foraging for high-value prey (e.g., spring- run eulachon species eggs; McCabe et

al. 1993).

Identifiable prey taxa were recovered from 60.3% of juvenile White Sturgeon sampled using lavage. While encouraging, this result is lower than reported for other sturgeon species that had lavage samples taken in the wild (98% for European Sturgeon A. sturio [Brosse et al. 2000], 73–93% for Atlantic Sturgeon [Haley 1998; Savoy 2007], and 81% for Shortnose Sturgeon A. brevirostrum [Haley 1998]). Many of these studies were conducted during a specific period of the year. Previous work (Barth et al. 2013) examined shifts in the diet of juvenile Lake Sturgeon across both season and habitats and recovered identifiable prey items from an average of 33.2% of all 345 sturgeon sampled, though success was highest in the spring and summer (range: 30.5–65.4%) compared with the fall (October; range, 0–3.8%). Our study was conducted in October, when juvenile White Sturgeon in the LCR are actively feeding (as evidenced by high catch rates), but the seasonality of the sampling is important to consider because productivity between systems can differ at different times of the year. Additionally, we chose to not anesthetize juveniles prior to undergoing lavage, though this has been done in other studies conducted in the wild (Savoy 2007). Understanding if lavage efficiency is influenced by the use of anesthetic would be a useful laboratory experiment. Further, though not evaluated in our study, understanding how time following capture influences the success of the lavage and, ultimately, the ability to assess the diet, is important. Brosse et al. (2002) suggested that lavage would probably recover only the most recently ingested food items. Digestion of soft bodied prey items is assumed to be rapid, further complicating recovery rates and taxonomic identification because handling individuals soon after feeding in the wild is not always logistically possible due to the types of gear generally used to capture sturgeon (e.g., setlines or gill nets).

There was a difference in the diet of juvenile White Sturgeon that occupied different river sections, both in terms of the mean number of prey taxa and dietary overlap. As discussed above, lavage is thought to recover recently ingested prey and may differ between prey types of different sizes and morphology. Because we recovered fewer unique prey items via lavage than stomach removal and certain prey types were more abundant in the diet than others, it is not surprising to see slightly higher dietary overlap using lavage. While we found a difference between prey items consumed in different river sections in 2012, in 2013 diets were predominated by Mysida throughout all river sections (Table 20), and there was only a marginal overlap (20%) in the diets of juvenile White Sturgeon between the two study years. Although previous studies indicated a positive relationship between discharge from Keenleyside Dam and Mysida abundance in the LCR (R. L. & L. Environmental Services 1985), the flows we observed were similar in both years yet showed considerable variation in mysid abundance, presumably due to factors other than flow variability. Mysida FO in the 2013 lavage samples from river sections 1 and 3 were substantially higher in 2013 than in 2012. The mean discharge from Keenleyside Dam during the sampled period in 2012 (1,230 m^3/s) was only slightly higher than the mean 2013 discharge (1,194 m^3/s). The trend observed in previous studies regarding the decreased Mysida abundance with increased downstream distance was supported by our lavage data in both study years. Juvenile Lake Sturgeon occupying different habitats were also found to have differences in diet composition (Barth et al. 2013), which further supports the importance of spatially balanced sampling for a

species with high site fidelity to specific habitats. Examining dietary overlap provided a sense of the resource use between fish in different river sections, in addition to the quantitative diet information collected using the stomach removal data.

Sturgeon are generalists and this was the case in our study revealing a diverse variety of 16 prey taxa in the diet. However, though just a few prey taxa predominated the diet, most prey were selected less than their availability in the river (Figure 38). More information on prey selectivity at the larger juvenile sizes (>1 m) as they start to compete for subadult and adult food sources will be useful for this population. Larger fish (>1.5 m) will probably begin taking advantage of seasonally abundant high-quality food resources like kokanee Oncorhynchus nerka or Mountain Whitefish Prosopium williamsoni spawners or excavating eggs from Rainbow Trout Oncorhynchus mykiss redds (Irvine et al. 2013). Additionally, despite success in implementing flow protection measures to promote native species (e.g., Rainbow Trout and Mountain Whitefish), the aquatic community in the LCR has been altered in the past decade with the invasion of new fish species (e.g., Northern Pike Esox lucius; Ford and Thorley 2012), and discussions around reintroducing salmonid species back into the LCR are underway (details available at www.ucut.org). The addition or deletion of species from a community can have significant effects on the growth rates of fish (Werner et al. 1983) and understanding how resource availability, especially the benthic prey base, is partitioned among competing fish species in the LCR will be important for White Sturgeon recovery.

Results from our study suggest that lavage is reliable for describing the diet when incorporated into sampling designs that acknowledge known biological differences in a population (e.g., growth rates by habitat), as well as habitat differences in the system. Detecting annual trends in the diet will be important to the long-term management of this population (e.g., identifying density dependent effects on growth) because conservation aquaculture remains the primary form of recovery to replace wild juvenile age-classes that have been absent for several decades.

4.5 Habitat Mapping

The lower Columbia River (LCR) was surveyed with a sidescan sonar, primarily to map riverbed character to assist in delineating habitat. Raw acoustic data were used to generate maps of riverbed character by segmenting the survey area into regions of homogeneous acoustic character that are acoustically distinct from other regions (e.g. sand, rock, and silt). Important next steps will be to ground truth the maps produced to produce a final habitat map for the LCR that can be used to identify important areas for White Sturgeon early life stages.

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 spawning area 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 eggs 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 (e.g., upstream versus downstream) and age classes.
- As numbers of recaptured individuals increases, survival should be modelled by year class, size-at-release, and age-at-release to allow for models to be revised as additional data is collected going forward. Results from survival estimates should be used to develop 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.

- Describe the diet of juvenile White Sturgeon in the LCR and evaluate the efficiency of gastric lavage in describing juvenile White Sturgeon diet.

- Use known age hatchery-reared juveniles to develop ageing methodology to improve confidence in the ages of wild origin juveniles.

- 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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