Columbia River Project Water Use Plan

Columbia White Sturgeon Management Plan

CLBMON-29 – Lower Columbia River Juvenile Sturgeon Detection Program

Implementation Years 2 and 3

Study Period: April 01, 2009 to December 31, 2010

BC Hydro and Power Authority

May 2013

EXECUTIVE SUMMARY

The population of White Sturgeon (*Acipenser transmontanus*) in the lower Columbia River 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 lower Columbia River, 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. It was identified during the development of the Columba 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 (abundance, growth, survival) were lacking and habitat suitability/availability across larval and juvenile life stages was unknown. Accordingly, larval and juvenile monitoring in the lower Columbia River over a longer period was deemed critical to addressing management questions related to recruitment.

We conducted passive sampling using drift nets in order to determine the relative abundance and distribution of White Sturgeon free embryos in the lower Columbia River. Consistent with previous years, sampling was conducted at multiple locations within the lower Columbia River in an attempt to identify if spawning had occurred above each distinct location. These locations were dispersed through the Canadian section and in the United States downstream of Waneta. We chose all sampling locations based on prior information related to White Sturgeon spawning. The first drift net sampling site was located at HLK/ALGS where spawning was documented using egg mats. The second site was located at river kilometer (rkm) 5.1, to determine if out-migrating larvae from the HLK/ALH spawning area dispersed that far down the Robson Reach. The third site drift net sampling site was located at river kilometer (rkm) 18.2 (Site 18.2). This site was chosen based on the capture of a single larval sturgeon in each of 2007 and 2008 and several in 2009. The fourth sampling location was located at rkm 56.0 (Site 56.0; Waneta) occurring just below the confluence of the Columbia and the Pend d'Oreille Rivers. This area is the only location where spawning has been documented (through egg and free embryo captures) and represents an area where a long term spawn monitoring program has been ongoing since 1993. Finally, we distributed 7 sites downstream of Waneta in the United States to look at downstream dispersal patterns from Waneta. We collected over 100 post hatch larvae at HLK/ALGS. All larvae captured were immediately post hatch (~ 1 day of age). No larvae older than 1 day were collected suggesting that hiding habitat is lacking for that area. At site 18.2, several one day post hatch larvae were collected demonstrating that spawning had occurred above that location. The ages of larvae collected did not align with spawning events at HLK/ALGS suggesting that an alternate spawning location exists in the upper section of the lower Columbia River. At site 56.0 (Waneta), a total of 90 larval White Sturgeon of varying ages were collected within Canada and at multiple sites downstream of the international border. Dispersing larvae are assumed to survive as far as the Northport spawning area (~10 km) as peak collections by US biologists align with peaks in downstream dispersal evident at Wnatea. Many of the larval captures at Waneta were of young age suggesting that habitat for successful hiding

might be limiting. In 2011, the drift net program will focus on further identifying the spawning location above Kinnaird, in the Kootenay, and downstream of HLK/ALGS.

An annual juvenile White Sturgeon program was initiated to describe important parameters related to growth, survival and distribution in the lower Columbia River. In order to ensure a spatially balanced sampling design, the lower Columbia River study area was stratified into 5 equal zones (11.2 km in length). Sampling effort was randomly distributed with equal probability within and across each of the zones. Juveniles were collected using three methods: gill nets, set lines, and angling to determine distribution of fish throughout the lower Columbia River. Captures were predominantly hatchery released juveniles with wild juveniles representing <1% of the total catch. High habitat use was documented in the Robson stretch, near Kinnaird, and downstream near Waneta with juvenile selecting primarily slower deeper sections of habitat (e.g. deep runs and eddy habitats). Generally, older ages represented larger proportions of the total catch (e.g. 25% 9 year olds) but all hatchery release ages were represented within the high use areas. Annual growth rates ranged from 14 cm in fork length for younger fish (1-3) and 10 cm per year for older aged juveniles (4-8). Average annual weight increases were smaller for younger fish (1-4) and larger for older ones (age 5-8), suggesting that growth in total length is more important in the early years than weight. In 2010, 25 juveniles were released from the hatchery with acoustic transmitters to determine post release movements and help identity habitat use. Results demonstrated that juveniles exhibited large downstream movements (regardless of their release location) within 24 hours of being released. 12% (n= 3) of the juveniles were never detected on the array following release while 32% (n=8) of the juveniles selected habitats in the United States portion of the Columbia River between the Canada/U.S. International Border and Grand Coulee Dam. The remaining juveniles were distributed among high use habitats previously mentioned. In 2011 the program will target areas of high use to increase the total number of recaptures available for survival analysis. This will be done by using distribution data from the first two years of the program. We will retain the spatial random sampling program but limit the sampling to demonstrated high use areas. Results from the juvenile monitoring program will provide information on the patterns of habitat use of juvenile sturgeon to better understand potential cause(s) of recruitment failure and (opportunities for) feasible mitigative actions.

A detailed habitat map for the entire lower Columbia River was initiated during the early stages of this program. Habitat data were collected and will be classified (e.g. fines, sand, gravel, cobble, boulders) in the coming years. Results from this long-term monitoring program will contribute to knowledge regarding larval and juvenile stages that will 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
1. What are the relative abundance, survival rates and distribution locations of free embryo and juvenile White Sturgeon in the lower Columbia River under current operating parameters?	• More data pertaining to timing, locations, and frequency of spawning in the lower Columbia River are needed to address this question at the larval stage. • Distribution of juveniles has been assessed and is throughout the lower Columbia River, restricted primarily to slower moving habitats like eddy's and deeper runs. As increased numbers of juveniles are captured, and recaptured, in the coming years, survival rates will be estimated.
2. 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.
3. How do normal river operations affect free embryo 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 free embryo's within a few days of hatch, the habitat at Waneta is presumed to be poor for hiding. Further work is needed to address current habitat conditions at the ALH site.
4. 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 lower Columbia River 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. More data is required to address this question

ACKNOWLEDGEMENTS

The 2009 and 2010 study years of the lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28) were funded by BC Hydro Water Licence Requirements White Sturgeon Management Program in Castlegar, B.C. BC Hydro would like to thank the following individuals for their contributions to the program:

BC Hydro

James Baxter
James Crossman
Dean Den Biesen
Gary Birch
Pat Vonk

Golder Associates Ltd. (Golder)

Larry Hildebrand

Freshwater Fisheries Society of BC

Ron Ek
Chad Fritz
Mike Keen
Aaron Wolff
Ken Scheer

Terraquatic Resource Management Ltd.

Marco Marrello Nelson, B.C.

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1.0 INTRODUCTION

The population of White Sturgeon (*Acipenser transmontanus*) in the lower Columbia River Canada was listed as one of four endangered populations under the Species at Risk Act (SARA) in 2006. In Canada, the lower Columbia River is defined as the reach of the Columbia River downstream of Hugh L. Keenleyside Dam (HLK) to the United States border, and there are an estimated 1,157 adult sturgeon (95% C.I. 414-1899; Irvine et al. 2007) located within this reach, with another 2,003 sturgeon estimated (95% C.I. 1093-3223) to reside between the border and Grand Coulee Dam (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. 2001) rivers. Despite some evidence of limited natural recruitment in the lower Columbia River, 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) recommended giving priority to conservation and recovery of White Sturgeon (Consultative Committee (CC) 2005). 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 (CC 2005). In order to meet this goal, data are required to assess habitat use and suitability/availability for all life stages of sturgeon residing in the lower Columbia River. These data include life history measures which are indicative of habitat quality including abundance and growth, development and condition, evidence of food availability and survival rates. Furthermore, providing estimates of successful reproduction (e.g. egg and free embryo captures) at both known and suspected spawning locations in the lower Columbia River is critical to addressing management questions related to recruitment.

The WUP CC report outlined a juvenile sturgeon program that would provide “annual monitoring (of) the relative abundance and distribution of juvenile sturgeon in the lower Columbia River” (CC 2005). The supporting rationale indicated monitoring was to “provide information on the patterns of habitat use of juvenile sturgeon to better understand potential cause(s) of recruitment failure and (opportunities for) feasible mitigative actions” (CC 2005). The rationale assumed that, with the release of hatchery supplemented juvenile sturgeon into the system, the probable bottleneck(s) affecting juvenile sturgeon survival could be determined and non-operational changes identified, which when implemented could result in 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 detection program shall “monitor the abundance, distribution and patterns of habitat use of juvenile White Sturgeon in the lower Columbia River in relationship to discharges from Hugh L. Keenleyside Dam (HLK)”.

Work in the Columbia River conducted since 2002, has identified sturgeon spawning locations in both Canada and the United States (Howell and McLellan 2007; Golder 2008) and the success of hatchery juvenile White Sturgeon stocked since 2002 (Golder 2009a). The estimated survival rates of stocked age 1+ juveniles and older sturgeon are high (Golder 2009a; Irvine et al. 2007) suggesting that the recruitment bottleneck is likely the result of poor survival during earlier life stages (Gregory and Long 2008; Golder 2009a), which is similar to other systems (Ireland et al. 2002; Gross et al. 2002). As a result, recent research has focused on the potential causes of mortality at the free embryo, larval, and young-of-the-year (YOY) life stages. This study represents the second (2009) and third (2010) years of ongoing monitoring in the lower Columbia River as a component of the lower Columbia River Water Use Plan under the project: CLBMON-29 Lower Columbia River Juvenile White Sturgeon Detection. Specific components of the study are to: 1) monitor free embryo and early life stage distribution and growth; 2) monitor movement and habitat use by sonic tagged hatchery age-1 White Sturgeon in order identify key habitats; 3) look at the distribution, growth and survival of both wild and hatchery origin juvenile sturgeon; and, 4) quantify and describe important sturgeon habitat through the combined use of both side scan sonar and spatial data analysis.

1.1 Management Questions

Key management uncertainties encountered during development of the Columbia River WUP related to how operations of Hugh L. Keenleyside (HLK) Dam may adversely affect habitat suitability and availability for juvenile sturgeon and thus potentially contribute to recruitment failure of White Sturgeon in the lower Columbia River (CC 2004). Fundamental management questions to be addressed through the juvenile sturgeon detection program may include:

5. What are the relative abundance, survival rates and distribution locations of free embryo and juvenile White Sturgeon in the lower Columbia River under current operating parameters?

6. What are the physical and hydraulic properties of this habitat that define its suitability as juvenile sturgeon habitat?

7. How do normal river operations affect free embryo habitat conditions in the lower Columbia River?

8. How do normal river operations affect juvenile habitat conditions in the lower Columbia River 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 sturgeon recruitment in the lower Columbia River, the precise mechanism(s) remain unclear. Early life stages through to free embryo dispersal to rearing areas appear to be most adversely affected. Mortality rates experienced by these early life stages may be impacted by spawning site selection and timing. The juvenile sturgeon detection program is not designed to provide experimental testing of research hypotheses, but rather provides baseline information that may be used to evaluate recruitment failure hypotheses and can be used in design of future operational or physical mitigative approaches.

The following management hypotheses may be used to guide juvenile 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 lower Columbia reach hydrograph) are affecting free embryo hiding/drift and dispersal behaviour, development and growth, and habitat selection, which result in reduced survival of early sturgeon 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 location and selection of suitable rearing habitat which result in reduced survival of later juvenile life stages.

H3: 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 stage (free embryo to rearing juvenile) sturgeon.

1.3 Objective and Scope

The lower Columbia River juvenile detection program in 2009 and 2010 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. The primary objectives of the juvenile sturgeon detection program are to:

1. Assess the development and condition (early hiding/drift development patterns and rearing juvenile conditions), behaviour (drift and movements), growth and survival of free embryo and juvenile sturgeon.

2. Determine early life stage distributions over time, locate free embryo hiding and juvenile rearing habitats, and define the parameters of these habitats.

3. Relate free embryo and juvenile habitat quality to variations in discharge from upstream dams and water levels of Lake Roosevelt reservoir.

4. Collect data in support of assessing the effects of current operations and the feasibility of management responses.

The scope of the juvenile program focuses on the collection of data that define free embryo and juvenile habitat conditions, the use of these data to determine the effect of existing hydraulic conditions, and to identify and assess the most suitable of several management responses to be considered in lieu of operational changes.

1.4 Study Area

The study area (Figure 1) is focussed from HLK Dam to the United States Border (American Eddy). This encompasses a 57 km stretch of river with river kilometer (rkm) markings starting at HLK (rkm 0) and increasing to the US border at American Eddy (rkm 57). The lower Columbia River is defined here as being that reach of the Columbia River downstream of HLK to the US border, although some sampling for this project occurred downstream of the border.

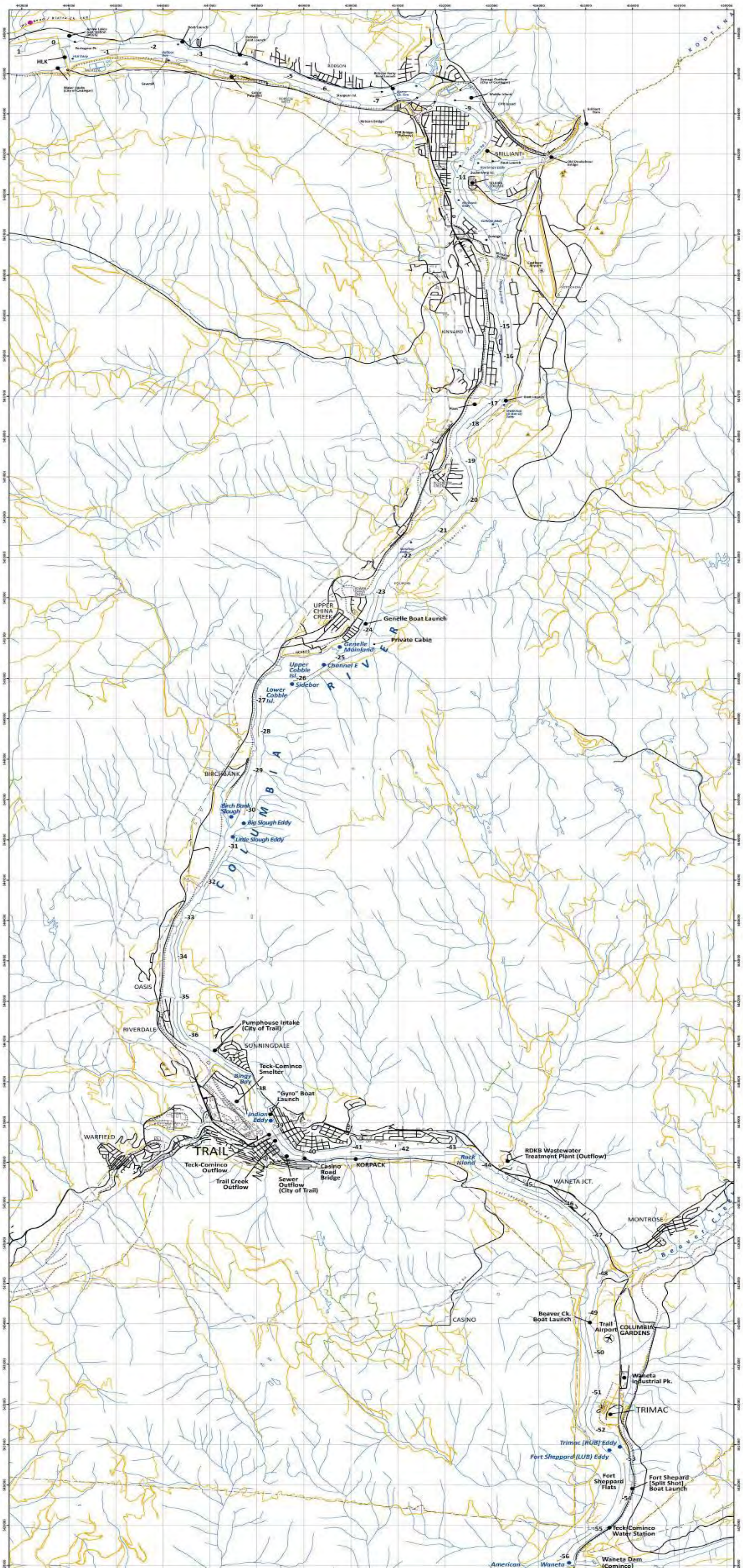


Figure 1. Overview of the study area between Hugh Keenlyside Dam (River Kilometer (rkm) 0) and the Canada/US border (rkm 57.0).

2.0 Methods

2.1 Larval Stage

2.1.1 Sampling Design

We conducted drift net sampling to determine the relative abundance and distribution of White Sturgeon free embryos in the lower Columbia River. Drift net sampling has been used successfully to capture passively dispersing free embryos for many sturgeon species including White Sturgeon in the lower Columbia River (Golder 2009b), lake sturgeon (*Acipenser fulvescens*; Auer and Baker 2002), and shortnose sturgeon (*Acipenser brevirostrum*; Moser et al. 2000). As White Sturgeon larvae been demonstrated to disperse downstream after hatching in the nearby Kootenai River (Kynard et al. 2010), the use of drift nets was identified as a primary sampling technique for this project.

The drift nets used in this study consisted of stainless steel D shaped frames (0.42m^2) attached to a mesh bag (4 m in length) that tapered down to a 0.08 m diameter cod end. The nylon mesh measured 0.8 mm^2 to ensure that White Sturgeon free embryos and eggs could not pass through the material once captured. Drift nets were deployed and anchored in the river using the same system at each sampling site. A lead claw river anchor (30 kg) was used to hold the entire system to the river floor. We attached 15 feet of 5/8 galvanized chain followed by a smaller anchor (7 kg) to the lead anchor to ensure the anchor remained flat on the river bottom. Two 30 m sections of 1/2'" braided rope were attached to the second anchor. The first rope was attached to a buoy at the surface of the river which provided a means to remove the entire anchoring system. The second rope was attached directly to the front of the drift net. We attached an additional rope from the top of the d-ring on the drift net to a surface buoy to facilitate deployment and retrieval of the net. When retrieving the drift net, the buoy attached directly to the net would be picked up from the boat and the net brought to the surface. Once at the surface, the net would be detached from the anchor system and brought into the boat for collection cup removal. Drift nets were rinsed thoroughly with river water before being reattached to the anchor system and redeployed. The buoy attached directly to the drift net allowed the retrieval of the net without dislodging the anchoring setup and ensured that sites remained consistent across all sampling events. Information collected from each drift net sampling event included the time of net deployment and retrieval, physical parameters (discharge and temperature, described below), depth, and comments.

Following removal of the collection cup, the contents were rinsed into a white bucket (19 L) and diluted with river water. The contents were then transferred in small aliquots into several white plastic inspection trays. The white trays provided improved contrast when searching for White Sturgeon free embryos. For each net we recorded the number of White Sturgeon free embryos and identified other aquatic specimens (i.e. invertebrates, fish, etc) present in the sample to family or genus when possible. All White Sturgeon collected were immediately preserved in prefer so that morphological measurements, histology, and genetic samples could be taken. All other aquatic specimens were returned to the river.

Discharge (m^3/s) and water temperature (^oC) were collected at all drift net sites throughout the duration of sampling in both 2009 and 2010. We used an Acoustic Doppler Current Profiler (ADCP model 1200 kHz, Teledyne RDI Instruments) to measure daily discharge (m^3/s) and mean water velocity (m/s). ADCP's have been demonstrated as powerful tools to provide detailed information for physical habitat in rivers (Shields et al. 2003; Shields and Rigby, 2005). Transects were conducted at right angles to the flow, and endpoints were marked using a handheld GPS and fixed shoreline markers to ensure transects remained consistent across all sampling occasions. ADCP transects were conducted immediately upstream of the drift nets. Measurements were recorded in water >1.2 meters in depth. The distance to the shore from the transects endpoints was measured using a range finder and ADCP software (WinRiver II, ver 2.07) was used to extrapolate the missing data to complete the discharge measurement. Water velocity measurements were recorded at 4.5m intervals across the river channel. At each interval, velocity measurements were recorded every 0.25m down the water column to the bottom of the river. Within one sampling day each transect was traversed two to three times to ensure complete data collection as missing values occurred periodically due to interference from either bottom targets or the boats speed. ADCP transects were not possible for sampling sites located immediately downstream of hydro power facilities. This included both Waneta Dam and HLK/Arrow Lakes Hydro (ALH). For these two sites, daily discharge records were obtained from each facility.

Water temperature was recorded hourly using a water logger (Vemco, model minilog, +/- 0.1^{o}C) deployed in the vicinity of each sampling site.

2.1.2 Sampling Locations

Drift net sampling was conducted in two distinct sections of river. These two sections within the lower Columbia River were chosen in an attempt to further identify where spawning was occurring in the study area.

The first section was the Columbia River downstream of the Pend d'Oreille River confluence (Waneta eddy), and included sites in both Canada and the US. This area is the only location where spawning has been documented (through both egg and free embryo captures) annually and represents an area where long term monitoring has been conducted since 1993 (Golder 2008). In 2009 sampling was conducted at two sites immediately below the known spawning area that were consistent with previous sampling efforts. In 2010 sampling was conducted at the same two sites as well as at 8 sites downstream of the US border. In 2010 sites in the US were located at Sheep Creek (one net), Northport (one net), 1 km downstream of USDR7 (two nets), USDR7 (one net), USDR5 (one net), USDR3 (one net) and one ring at USDR2 (see Figure 8 for site locations).

The second section of river included the lower Columbia River upstream of Waneta eddy. Within this section we chose two sites in each of 2009 and 2010 as sampling locations based on prior information related to potential White Sturgeon spawning. The first drift net sampling site (sampled in 2010 only) was located at river kilometre 0.1 (Site HLK/ALH), with river kilometres (rkm) measured moving downstream from Hugh Keenleyside Dam (HLK, 0 rkm). The second drift net sampling site (sampled in 2009 only) was located at river kilometre 5.1 (Site 5.1) to capture any larvae dispersing downstream from the HLK/ALH area. These two upper sites were chosen based on two criteria. The first criteria was based on telemetry observations of mature male and female White Sturgeon predicted to spawn in 2009 migrating to an area immediately downstream of HLK (0.1 rkm). These fish were both tagged with acoustic transmitters in the spring of 2009 under a different Columbia Water Use Plan program (CLBMON#30). The second sampling criteria was based on qualitative observations of suitable spawning substrates and flows in the tailrace of ALH. Suitable spawning substrates can be qualitatively defined as cobbles and boulders while suitable spawning flows are typically swift water moving faster than 1-2m/s (Parsley et al. 1993). The third site drift net sampling site (sampled in both 2009 and 2010) was located at rkm 18.2 (Site 18.2). This site was chosen based on the capture of a single larval sturgeon in each of 2007 (Golder 2008) and 2008 (Golder 2009b).

The drift net sites differed in hydraulic parameters (discharge and water velocities), depths, and substrates. These differences among sites led to varying logistical challenges in sampling. At the HLK/ALH site in 2010, water velocities were variable due to flow increases and decreases from both HLK and ALH, which made fishing the nets for long periods of time challenging. At this site we fished between 3 and 5 nets (Figure 2), depending on water conditions and availability of nets. These nets were all fished on the downstream left bank, directly below the tailrace of ALH. Nets were retrieved daily from the front of the boat, between early morning and early afternoon. The nets were cleaned, samples collected, and the nets redeployed consistent with methods described above.

In 2009 at site 5.1, water velocities were relatively slow allowing easy deployment and retrieval of the drift nets. A total of 6 nets were spaced evenly (50m intervals) across the river channel (Figure 2) and sampled for 24hours a day. Nets were retrieved daily at 1900, cleaned, samples collected, and the nets redeployed. At site 5.1, drift nets were deployed and retrieved from the starboard side of the boat using an electronic winch.

In 2009 and 2010 at site 18.2, the water velocities were swift (>2m/s) permitting only limited sampling due to nets becoming plugged with detritus and debris in the river. In both 2009 and 2010, a total of 5 nets were deployed across the river channel at site 18.2 (Figure 2). Nets were deployed and retrieved at approximately 1845 and 0001 respectively each evening in 2009, and left over night and retrieved between 0800 and 1200 in 2010. Due to high water velocities, drift net deployment and retrieval at site 18.2 had to be conducted from the bow of the boat while the boat was under power.

Hydraulic conditions at site 56.0 were influenced by daily fluctuations in discharge from Waneta Dam on the Pend D'Oreille River. In both 2009 and 2010, two drift nets were deployed at sites consistent with past collection efforts (sites described in detail in Golder 2009b). Drift nets were deployed from approximately 1030 to 1400 on Monday, Wednesday, and Fridays following the detection of spawning events under a different monitoring program (details in CLBMON 28; Golder 2009; BC Hydro 2013).

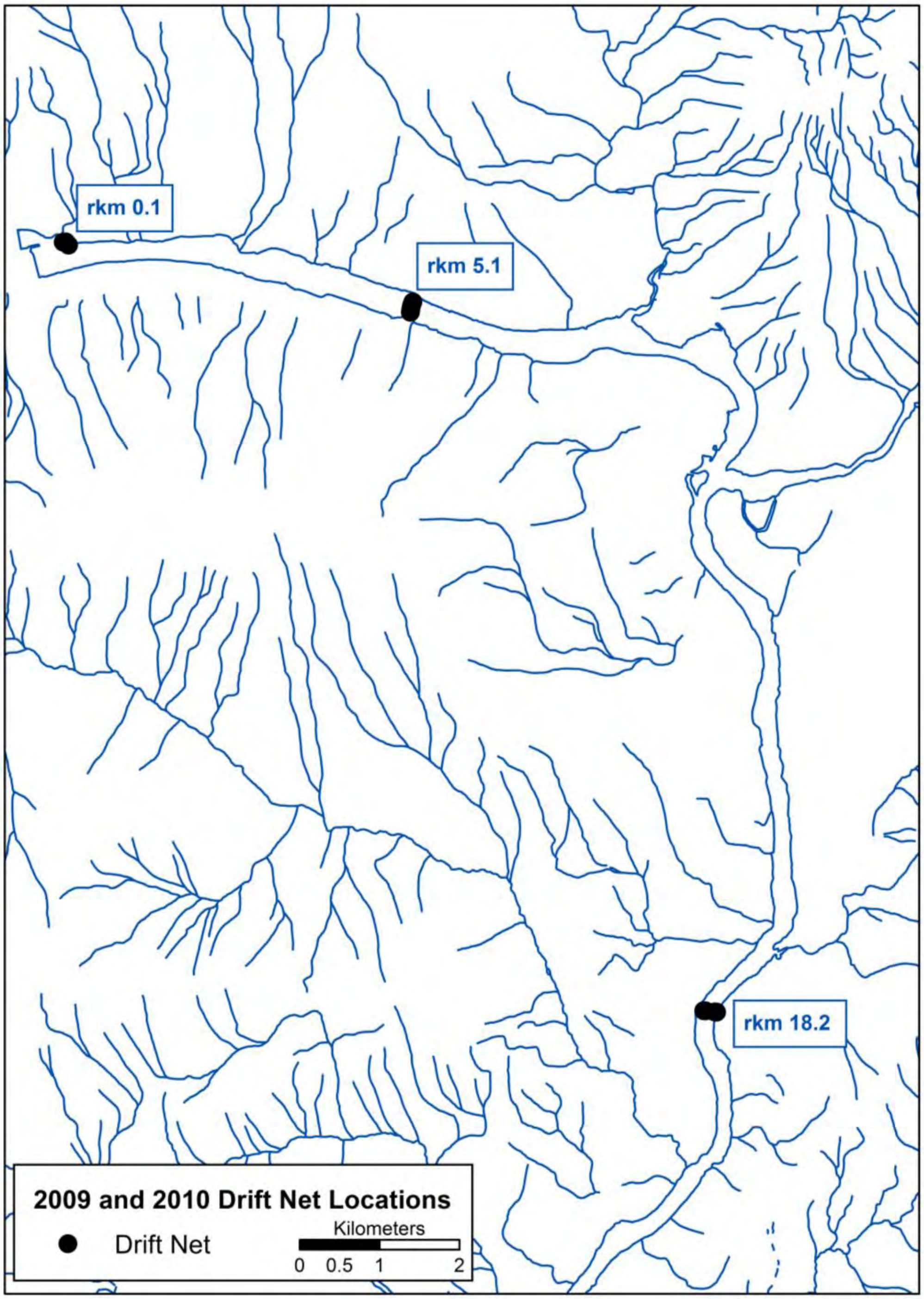


Figure 2. Sampling locations for drift nets deployed in 2009 and 2010 in the upper section of the lower Columbia River. Drift nets were deployed at the Hugh Keenlyside/Arrow Lakes Hydro spawning area (River Kilometer (rkm) 0.1), in the Robson Reach (rkm 5.1) and downstream of Kinnaird (rkm 18.2).

2.1.3 Laboratory Measurements, Staging and Estimation of Spawning Timing

Once the field data collection was completed, morphological measurements on the collected White Sturgeon free embryos were conducted using image analysis (Nikon, NIS Elements D, v3.1). Each White Sturgeon free embryo was measured for total length (mm) and yolk sac area (YSA; m^3). Total length was measured from the tip of the rostrum to the end of the notochord. YSA was calculated using the elliptical area tool provided in the image analysis software.

White Sturgeon free embryos were staged in the laboratory using a stereoscope to determine age at the time of capture. Free embryos were staged based on developmental (Beer 1981) and physical characteristics. The time at which hatch occurred was back calculated following Beer (1981). Once a free embryo age and time of hatch was assigned, the time at which egg fertilization occurred was estimated based on mean water temperatures recorded throughout the lower Columbia River and known rates of development at different temperatures (Wang et al. 1985).

2.1.4 Data Analysis

Total effort for a sampling site on a given day was calculated using the total amount of time a net was deployed (retrieval time minus deployment time) and summing across all nets. Total effort for a site over the entire sampling period was calculated by summing the effort across all days. We also calculated catch per unit effort (CPUE) for each site by dividing the total number of free embryos collected over the entire sampling period by the total cumulative effort. We qualitatively compared larval catch with physical river parameters, including temperature and discharge. Morphological data measured from larvae were used to examine free embryo total length by age as well as compare between sampling sites and times.

2.2 Juvenile Stage

2.2.1 Sampling Design

Juvenile White Sturgeon have been released annually into both the Canadian and United States sections of the lower Columbia River (Table 1) since 2001 at differing ages and sizes (Figure 3). Gill nets, setlines and angling have all been demonstrated as effective capture techniques in the lower Columbia River and were used (section 2.2.2) to collect juvenile White Sturgeon for this program. In order to ensure a spatially balanced sampling design, the lower Columbia River study area was stratified into 5 equal zones (11.2 km in length; see Figure 1). Sampling effort was randomly distributed with equal probability within and across each of the zones. We used a generalized random-tessellation stratified (GRTS) design developed by Stevens and Olsen (2004) to assign sampling locations within each river zone. This was conducted with the statistical package R (Program R, version 2.9.0) using the library packages spsurvey and sp, provided by the United States Environmental Protection Agency (US EPA). The library package spsurvey allows a user to input data/criteria needed for a GRTS sampling design. We developed shapefiles (i.e. geo-referenced maps) for each river zone using ArcMap (version 10.0, Environmental Systems Research Institute, Inc. (ESRI)). Each river zone shapefile was imported into spsurvey and 50 sampling sites were randomly generated with equal probability and distribution for each of the gear types described below (section 2.2.2). The locations of each sampling site (1 through 50) 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). Within each river zone, a proportion of the randomly generated sites could not be sampled. This occurred if the sampling site was generated in an area where sampling gear could not be deployed (e.g. water depth <1m) or where safety concerns were evident (e.g. high sustained river flows). If a site was omitted due to an inability to sample, the next site occurring on the list was sampled.

Table 1 Numbers of hatchery reared juvenile White Sturgeon released annually into both the lower Columbia River Canada (LCR) and Lake Roosevelt (LR) in the United States. Release numbers are presented by release year, brood year, and whether they occurred in the fall or spring.

		LCR Canada		LR USA	
Release Year	Brood Year	Fall	Spring	Spring	Total
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
	Totals	13,110	76,404	24,640	114,154

2.2.2 Juvenile Capture Techniques

2.2.2.1 Setlines

Set lines have been demonstrated to provide higher catch-rates, are less size selective compared to other sampling gear (e.g. gill nets), and rarely capture non-target species (Elliot and Beamesderfer 1990). Set lines have been successfully used in the lower Columbia River to capture juvenile and adult White Sturgeon for the past few decades (Golder 2006; Irvine et al. 2007). As described above, sampling effort was randomly distributed with equal probability within and across each of the 5 zones in the study area. On each sampling day, four setlines were distributed within the target zone. When deploying setlines, a rope (3/8) was attached to a large structure on the shore to act as an anchor (shoreline). The shoreline was then run out into the river to the approximate location where the setline was to begin. A 7 kg lead weight was attached to the end of the shoreline and the start of the setline. The setline was then deployed moving downstream of this anchor. Baited hooks were attached to the setline every 8 m using a short section of rope (0.3 m) and a swivel clip. The hooks (size 6/0 barbless) were baited with both kokanee (*Oncorhynchus nerka*) and earth worms (*Lumbricus terrestris*). At the end of the setline another weight was added along with a rope attached to a buoy. The setlines were fished between 4 to 6 hours before being retrieved, and were pulled in the order that they were set. Setlines were retrieved from the bow of the boat. When a fish was caught it was transferred into the boat and kept in a holding tank filled with ambient river water until processing. All collected fish were enumerated by species. All captured sturgeon were measured for fork length and weight assessed for external markings (removed scutes) and PIT tags. We followed the assumption that juvenile White Sturgeon captured without a PIT tag or scute mark were of wild origin. If a wild sturgeon was caught, a tissue sample was removed from the dorsal fin and preserved dry in a scale envelope for future genetic analysis. All wild juvenile sturgeon that were captured were tagged with a PIT tag and the second scute on the left side of the body was removed to serve as a permanent mark that the fish had been handled. Information collected from each gill net site included the date, time of deployment and retrieval of the net, weather conditions, water depth, and water temperature.

2.2.2.2 Gill Nets

Gill nets have been used successfully to capture juvenile White Sturgeon in the Columbia (Golder 2009a; Howell and McLellan, 2006, 2007), Kootenai/Kootenay (Ireland et al. 2002; Justice et al. 2009) and Fraser Rivers (Bennett et al. 2005). Gill nets used in this program consisted of a 5.1 cm stretched measure multi-filament mesh and measured 1.8 m deep by 30.5 m long (area of 54.9 m^2). Gill nets were set in areas with lower velocities to prevent the nets from drifting and snagging on the bottom and to minimize harm to any captured juveniles. All Gill nets were set during the day light hours. On each sampling day, four gillnets were set within the target zone following the sampling design described above. An anchor was attached to both ends of the weighted bottom line and a buoy was attached to both ends of the floating top line. Gill nets were deployed with the boat facing upstream and were slowly set by moving downstream ensuring the bottom and top lines were not tangled. Gill nets were deployed for 4 to 6 hrs before retrieval and were retrieved from the bow of the boat starting from the downstream end of the net. Gill nets were retrieved in the order they were deployed. Captured sturgeon were placed in a holding tank with ambient river water until they were processed. Fish processing was consistent with methods described for the setlines. Information collected from each gill net site included the date, time of deployment and retrieval of the net, weather conditions, water depth, and water temperature.

2.2.2.3 Angling

Angling was used as a capture technique for juvenile sturgeon as it has proven to be effective during adult sampling in the lower Columbia River. Angling was conducted between deployment and retrieval of both setlines and gillnets and was generally targeted for 2 hours of fishing time. Consistent with other sampling techniques, effort was randomly distributed with equal probability within and across each of the 5 zones in the study area. Three angling sites were sampled within the zone selected for a particular day. Angling was conducted for up to 30 minutes at one site and if no fish were captured, the next site was sampled. If sturgeon were being captured at an angling site, sampling remained at that site until a time where other fishing gear needed to be retrieved or fish captures were not occurring. Angling gear consisted of a fishing rod (model Big Cat) with 120 monofilament line, a 12-24 oz lead weight, and a size 6/0 or 8/0 barbless hook. Both kokanee (O*ncorhynchus nerka*) and earth worms (*Lumbricus terrestris*) were used for bait. Three anglers, each with a single rod, sampled each site. When a fish was caught it was brought into the boat, and placed in a holding tank until it could be processed and released. Information collected from each angling site included; date, weather, water depth, water temperature, bait used, angler, fishing effort (mins), fish fork length, fish weight, year released, pit tag number and any abnormalities.

2.2.3 Analysis

One objective of this project was to identify the distribution, growth and survival of both wild and hatchery origin juvenile sturgeon in the lower Columbia River. Identifying the distribution of juvenile sturgeon was an important component to the program during the first two years of implementation as previous sampling efforts were limited to specific spatial areas of the lower Columbia River (Golder 2006). It was acknowledged that the incorporation of a stratified random sampling approach, as described above, would identify distribution patterns and habitat use but may lead to a reduction in total captures. This may in turn limit the number of recaptures that could be used for developing age specific survival estimates. Limited numbers of recaptures precluded estimation of survival rates during the current program. However, future sampling efforts will be adjusted based on results of this work to ensure increased numbers of recaptures are available for estimating survival and evaluating success of the hatchery program, as conducted in other systems (Ireland et al. 2002; Justice et al. 2009)

We determined the proportional juvenile sturgeon catch by brood year for each of 2009 and 2010. This was calculated by dividing the number of fish captured for an individual brood year by the total number of fish caught in that particular sampling year. Total growth, in both length and weight, was calculated since release for individuals of hatchery origin where know size at release data were available. We also calculated the average annual growth in both total length and growth since release for hatchery released fish by dividing the total growth since release by the number of years the fish was at large.

Spatial distribution of juvenile White Sturgeon in the lower Columbia River was assessed qualitatively by placing fish capture location on maps and quantitatively by comparing catch per unit effort among sampling zones within each year. We also evaluated how location at the time of capture corresponded to location at the time of release as high site fidelity has been suggested for this population (Irvine et al. 2007; van Poorten and McAdam 2010). This was only calculated for sampling zones one and five since juvenile sturgeon have only been released in those locations to date. The number of fish captured in the same sampling zone they were released into from the hatchery was expressed as a percent across all captures within each zone.

All statistical analyses were performed using R (R Development Core Team 2011, http://www.rproject.org). Data were tested for normality and homogeneity of variances using a Shapiro-Wilk test and by examining residuals versus fitted values in R. In cases of non-normality or heterogeneity of variances, analyses were run using log transformed total length and weight data. We used a general linear model to test for differences in several dependant variables and model combinations. First, the size at time of capture was evaluated for both total length and weight. Fixed effects included in the model were brood year, zone of capture, gear type, and the interaction between zone of capture and gear type. We also tested for differences in annual growth rates for both total length and weight of captured fish. Included in the analysis were fixed effects of brood year and zone. We tested for zone of capture in this model based on the assumption of high site fidelity in this population and documentation of different growth rates attributable to spatially segregated groups in the lower Columbia River (van Poorten and McAdam 2010).

We also evaluated the performance of different maternal family groups since release for each year class from 2001 through 2007. Maternal family grouping was not known for the 2008 and 2009 released juveniles due to mixing in the hatchery prior to PIT tagging. We compared two dependant variables, average annual growth in both total length and weight, between maternal family groups within each year class using an analysis of variance. We also tested for differences between maternal family groups at the time of release from the hatchery, in the event that differences at the time of release were maintained while at large in the river.

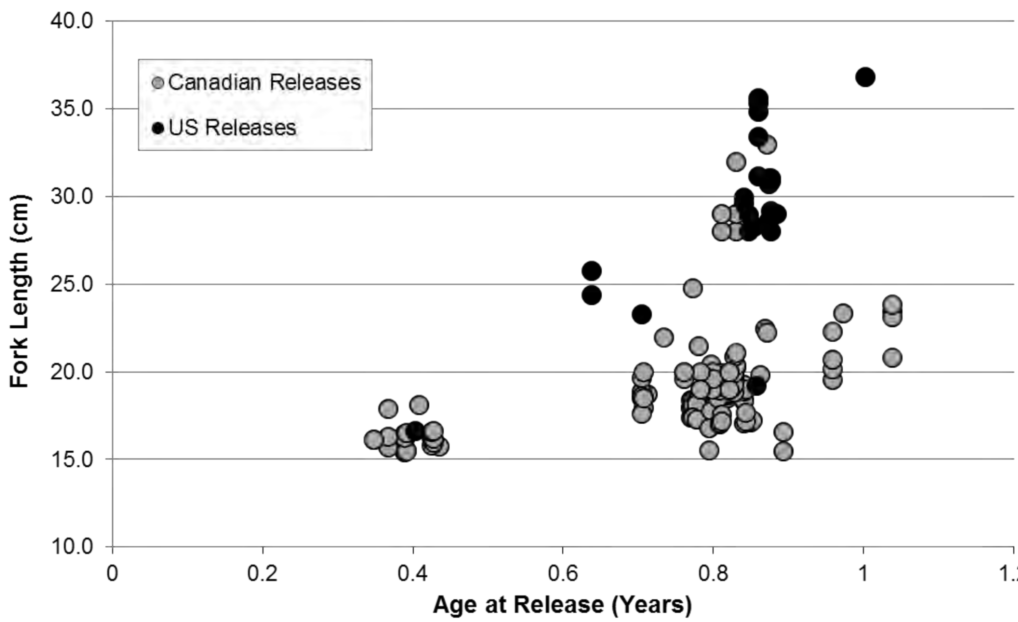


Figure 3. Size (fork length (cm)) at release age for juvenile White Sturgeon released from Canadian and US hatcheries into the transboundary Columbia River from 2001 through 2010.

Size-dependent mortality in hatchery-reared juvenile White Sturgeon has been identified in the Kootenai River, suggesting that size at release has important effects on survival (Justice et al. 2009). In the Columbia River, juvenile White Sturgeon were released in both the fall (~6 months old) and spring (~9 months old) in each of 2005, 2006, and 2007 in an effort to identify if: 1) there was a size/age threshold for survival, or 2) if survival through the first winter was a significant bottleneck in the lower Columbia River. Size at release data are presented for each year both fall and spring releases were conducted in table 2. We evaluated the proportion of fish within each of these release years in our catch that corresponded to either fall or spring releases. For years where samples sizes permitted, we examined differences in growth between the release ages.

Table 2. Mean (± 1 SD) fork length and weight for hatchery reared juvenile White Sturgeon released into the Columbia River in either the fall or spring of 2005-2007.

Year	Release	Fork Length (cm)	Weight (grams)
2005	Fall	16.2 ± 1.2	34.3 ± 8.7
	Spring	17.5 ± 1.9	39.5 ± 14.4
2006	Fall	16.0 ± 1.2	30.8 ± 7.0
	Spring	19.7 ± 2.5	56.4 ± 19.4
2007	Fall	16.8 ± 1.4	36.9 ± 9.9
	Spring	20.1 ± 1.2	63.8 ± 11.3

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 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 was used to predict juvenile White Sturgeon length-at-age from age using the solver tool in excel to predict model parameters.

Finally, we calculated the relative weight index (Wr) for all juvenile sturgeon collected to allow comparison to other populations. Relative weight (Wege and Anderson 1978) is a common method used in fisheries science (Murphy et al. 1991; Blackwell et al. 2000) as it does not change with different units of measure, incorporates species specific standard weights (Ws) that compensate for morphological changes during development, and it allows direct comparison of the condition of fish of different lengths from different populations. Importantly, this standardized measure of weight can help explain variation attributed to ecological variables (Blackwell et al. 2000). Relative weight was calculated for in our study using the equation:

$$Wr = \left(\frac{W}{Ws}\right) \times 100$$

where *W* is the weight of the juvenile sturgeon, and *Ws* is the length-specific standard-weight value developed for White Sturgeon by Beamesderfer (1993). The standard weight was calculated following Beamesderfer (1993) using the equation:

$$W = \alpha \times TL^{\beta}$$

where $\alpha = 1.95 \times 10^{-6}$ and $\beta = 3.232$ and TL (cm) corresponds to the total length of the individual juvenile sturgeon. We used an ANOVA to test for differences in relative weight of juveniles representing different age classes and for differences attributable to different river zones of capture.

2.2.4 Gastric Lavage

Qualitative information on the diet of juvenile White Sturgeon is important to informing estimates of growth and survival that will be developed as part of this work. Gastric lavage was used to document both prey type and abundance in the stomach content of juvenile White Sturgeon. Gastric lavage, or stomach flushing, can be used to safely remove contents from the stomach without sacrificing the individual. This method has been used with success on White Sturgeon (Sprague et al. 1993) and other species of sturgeon (Haley 1998; Brosse et al. 2002; Wanner 2006) to describe food preferences. Gastric lavage was conducted using a pressurized container with a tube attached to it that could regulate water outflow. The tube was inserted down the oesophagus into the stomach at which point water was flushed to induce regurgitation of stomach contents. Fish were not anesthetised and lavage was conducted until regurgitation of food particles ceased. The procedure was not conducted longer than 1 min per individual. The procedure for gastric lavage was conducted over a white tray that collected the stomach contents. Food items were collected from the tray using a mesh sieve or forceps and preserved in 95% ethanol. Food items were identified to family or genus when possible. Food items that were fish were identified to species when possible. Prey items were counted and overall diet composition was described by sampling zone, and when possible, age class.

2.2.5 Movement Patterns of Wild and Hatchery Released Juveniles

Passive monitoring through the use of acoustic receivers was conducted to provide information on seasonal movements related to flows and to describe general habitat use in the lower Columbia River for both wild and hatchery origin juvenile sturgeon. We followed the assumption that juvenile White Sturgeon captured without a PIT tag or scute mark were of wild origin. If wild fish were captured, they were tagged with acoustic transmitters (Vemco model V9 or V13 depending on fish size) to determine movement patterns in relation to hatchery released juvenile sturgeon. Transmitters were implanted in the body cavity through an incision was made on the ventral surface just off the mid line. The incision was closed with three sutures applied in an interrupted pattern. Tracking movement of the tagged fish was conducted with a grid of anchored acoustic receivers (Vemco VR2 or VR2W Remote Telemetry Receiver Stations). The acoustic array has been in place the last decade and specific details are provided under CLBMON #28 Lower Columbia River Adult Sturgeon Monitoring and Broodstock Collection project. Generally, the array consisted of receivers stationed approximately every 2.5 to 3.0 km downstream of HLK to the international border. Data were downloaded bi-monthly and the anchoring systems of the receivers were checked regularly and adjusted as required in response to changing hydraulic conditions.

A total of 25 hatchery reared juvenile sturgeon tagged with acoustic transmitters (Vemco, model V9) were released on May 3, 2010 to determine movements and general patterns of habitat use in the lower Columbia River. Five tagged fish were released in the middle of each of the five zones of the river previously identified in section 2.2.1 (Table3). The battery life of the transmitters was estimated to be greater than one year following deployment. Movements of acoustically tagged sturgeon were examined using detection data from the array of receivers. Movement was classified as a sturgeon being detected on a receiver station that was different from the station associated with the previous detection. The distance a fish moved was calculated as the difference in river kilometres between the two receiver stations. These distances were calculated for all movements. Total, upstream, downstream, and net movements of tagged juvenile White Sturgeon were calculated using receiver detection data up to December 14, 2010. Total movement was calculated as the sum of all detected movements, regardless of direction. We also calculated both upstream and downstream movements by summing all detected movements in those specific directions. Finally, we also calculated net movement, which was the distance between the furthest upstream and furthest downstream locations a fish was detected (i.e., a representation of the range of a particular fish or group of fish). No mobile tracking of juvenile sturgeon was undertaken. Overwintering locations were not identified as the last download was on December 14, 2010, but it is likely that the location of a sturgeon at that time is indicative of where they would likely overwinter.

Table 3. Summary of release sites for age-0 hatchery reared juvenile White Sturgeon implanted with acoustic transmitters and released into the lower Columbia River in May of 2010. Release sites are presented by river kilometre (rkm) and zone.

Acoustic Tag	PIT Tag	Release Date	Release site (rkm, zone)
27134	985121006006119	3-May	5.5 (1)
27122	985121013530439	3-May	5.5 (1)
27141	985121005949527	3-May	5.5 (1)
27146	985121013480326	3-May	5.5 (1)
27133	985121013527422	3-May	5.5(1)
27131	985121013467870	3-May	16 (2)
27137	985121006497976	3-May	16 (2)
27123	985121005999947	3-May	16 (2)
27136	985121006029366	3-May	16 (2)
27127	985121005953774	3-May	16 (2)
27138	985121013422412	3-May	28.5 (3)
27128	985121005935809	3-May	28.5 (3)
27140	985121013425151	3-May	28.5 (3)
27143	985121013425607	3-May	28.5 (3)
27130	985121005917436	3-May	28.5 (3)
27132	985121006006054	3-May	39.8 (4)
27142	985121013481569	3-May	39.8 (4)
27124	985121005634638	3-May	39.8 (4)
27144	985121005949728	3-May	39.8 (4)
27125	985121006028976	3-May	39.8 (4)
27129	985121006028437	3-May	51 (5)
27145	985121013492037	3-May	51 (5)
27126	985121005950318	3-May	51 (5)
27139	985121013528921	3-May	51 (5)
27135	985121013426337	3-May	51 (5)

2.2.6 Physical Parameters

Temperature (°C) was collected hourly at several locations throughout the study area using loggers (Vemco minilog) accurate to +/- 0.1°C. Loggers were deployed at Kootenay eddy, Kinnaird and Waneta Eddy. A Garmin GPS/fish finder was used to collect water temperature and depth at the different sampling sites. Discharge was collected from the Birch Bank station as well as combined outflow from Hugh Keenlyside dam and Arrow lakes Generating Station.

2.3 Habitat Mapping

To address questions regarding the use and availability of suitable habitat for juvenile White Sturgeon in the Columbia River downstream of Hugh Keenleyside Dam (HLK) it is important to quantify physical habitat that can be tied to early life stage and juvenile data collected as part of this program. It is believed that large substrate with a high amount of interstitial spacing is important for survival of larval sturgeon by providing hiding habitat that they can use to avoid predators (McAdam 2011). Age-0 and older juvenile White Sturgeon tend to prefer substrates of hard clay, mud, silt, and sand (majority over sand; Parsley et al. 1993). However, uncertainties exist in the lower Columbia 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 lower Columbia River.

As part of this monitoring program, a habitat mapping program is in development for the lower Columbia River and is designed to describe and classify physical habitat in the Columbia River downstream of HLK to the US border. The mapping program has four main components which were implemented beginning in. These components are described below.

Component 1 – Establish Georeferenced Transects - Georeferenced transects of the Columbia River from HLK to the US border were developed using ArcMap. A transect running perpendicular to shore was established every 200 m along the river channel, with habitat sampling points along each transect at 20 m intervals (Figure 4). These transects serve as locations that can be randomly sampled for the collection of physical habitat data.

Component 2 – Sidescan Sonar Transects/Data Collection - A sidescan sonar (model StarFish, developed by Tritech International Limited) was used to survey the lower Columbia River and was mounted just below the hull of the survey boat. Overlapping transects (70 m wide swath) were run parallel to the current from a downstream to upstream location. Acoustic backscatter data collected along each transect were georeferenced and stored and converted to an file format (.xtf) suitable for post processing. Data collected by the sidescan sonar included location (UTM), water depth (m), and substrate classification (expected to be fines, sand, gravel, cobble, and boulder). In certain sections of river, successive parallel transects were undertaken to ensure complete coverage of the section of river being surveyed. When possible, other habitat descriptors were measured at the same time including velocity and turbulence, and water quality. In combination with depth and substrate data, such descriptors are common among other juvenile habitat studies (Parsley and Beckman 1994, Bennett *et al*. 2005, Young and Scarnecchia 2005).

Component 3 - Ground Truthing and Substrate Calibration - Substrate classification using the sidescan sonar was calibrated using an underwater video camera attached to a grid with a scale bar to measuring substrate diameter. The camera was lowered to the bottom at randomly selected points along transects developed for component 1 to allow measurement (diameter, cm) of the substrate in that area, and an estimate of the embeddedness of the substrate to be made. In addition to the underwater camera data, a physical sample of substrate was collected when possible using an Eckman grab.

Component 4 – Sidescan Sonar Data Processing and Mapping - Collected sidescan data files were imported into an acoustic seabed classification software, QTC Sideview (Preston et al. 2004; Quester Tangent Corporation, 2004). Results from other work using this technique suggest that acoustic data could advance habitat research for some bottom-associated fish species (Yeung and McConnaughey 2008). QTC Sideview is being used to covert all collected sidescan data into a product that can either be graphed visually within the software package or exported in a format that will permit analysis using a statistics package and mapping using GIS software. The data associated with each point will be substrate class and depth, and the software has the ability to interpolate areas of overlap or that were not sampled or returned data that didn't meet the quality control of the software. Analyses are currently preliminary and further detail will be provided in subsequent monitoring reports.

Figure 4. An example of transects generated to collect physical habitat data in the lower Columbia River, British Columbia. Transects were run perpendicular to the flow and points were spaced at 20 m intervals moving downstream.

3.0 Results

3.1 Larval Stage

2009 Data

During the larval stage sampling on the lower Columbia River in 2009 we collected 0 larval sturgeon at site 5.1 (CPUE = 0), 5 larval sturgeon at site 18.2 (CPUE = 0.01) and 39 larval sturgeon at site 56.0 (CPUE 0.43). Drift net sampling took place at site 5.1 from July 8 to July 31, 2009. During this period, mean sampling time per drift net was 23.4 hours (Table 1). Cumulative effort across the entire sampling period and among all nets was 131.5 days (3163.3 hours; Table 1). Average water temperature during the sampling period was 15.4 °C. No White Sturgeon free embryos were collected. Other aquatic invertebrates were identified which included mosquito larvae, mysid, black fly larvae, stonefly larvae. Several sculpin and other fish species were also sampled during this period.

Table 4. Estimation of spawn timing based on three possible locations of origin for one day post hatch White Sturgeon larvae captured on 30 July 2009 at Site 18.2, the Columbia River downstream from the Kinnaird Bridge.

Location	Mean Temperature Prior to Hatch	Time to Hatch	Estimated Spawning Date
Columbia River Above Confluence	15.9 °C (23 – 30 July)	176 h (~7.3 d)	23 July 2009
Lower Kootenay River	18.5 °C (23 – 30 July)	98 h (~4.1 d)	26 July 2009
Columbia River Downstream of Confluence	17.5 °C (23 – 30 July)	137 h (~5.7 d)	25 July 2009

*Based on known rates of development at different temperature regimes (Wang et al. 1985)

Site 18.2 was sampled from July 8 through to August 5, 2009. During this time the site had a total of 4 drift nets, however when five sturgeon larvae were collected on July 30, 2 additional drift nets were added. All five larvae were measured for total length (mm) and when possible, yolk-sac area (mm^3). Mean total length (±1 SD) of the 5 captured larvae was 11.5 ± 1.4 mm. Mean yolk-sac volume was 8.2 ± 0.8 mm^3. The CPUE for this site was low (0.01 White Sturgeon/hour), despite each drift net being fished for an average of 8.24 hours/day for a cumulative total of 976.1 hours. Water temperature averaged 16.6°C during the sampling). Other invertebrates were collected in the drift net samples including mosquito larvae, mysis shrimp, black fly larvae, and stonefly larvae along with several other aquatic fish (e.g. sculpins) and invertebrate specimens. Developmental stages (days post-hatch; dph) were determined for all five larvae collected at site 18.2. Similar to previous captures near this location in 2007 and 2008, all larvae were staged to be 1-3 dph. The most likely origin of these larvae is assumed to be one of three locations, as described by Golder (2009). These sites include: 1. The Columbia River upstream of the Kootenay River confluence (e.g. Tin Cup Rapids area or HLK/ ALH tailrace areas), 2) The Kootenay River between Brilliant Dam and the Columbia River confluence, and 3) The Columbia River downstream of the Kootenay River confluence in the Kinnaird Rapids. The temperature conditions differ across each location and therefore the timing of when egg fertilization may have occurred was estimated separately for each location (Table xx). Based on these estimates, the most likely date for when spawning occurred was 10 or 11 July 2009. This estimation is much later compared to previous estimates for larvae collected near this location (e.g. July 10-11th 2008; Golder 2009b).

Table 5. Number of larval sturgeon collected and sampling effort (Hours) at three larval White Sturgeon sampling sites in the lower Columbia River in 2009.

Site (rkm*)	Total Catch	Mean Effort /Net	Total Effort	Catch Per Unit Effort (CPUE)
5.1	0	23.4	3,163.3	0.00
18.2	5	8.2	976.1	0.01
56.0	39	3.5	90.1	0.43

*rkm: River Kilometer

At site 56.0, drift net sampling commenced July 8 through to August 12, 2009. The nets were fished every 2-3 days for an average of 3.47 hours/day for a cumulative 90.08 hours. During the sampling, water temperatures averaged 20°C. A total of 39 larval sturgeon were collected between July 10 and July27 with a CPUE of 0.43 sturgeon larvae/hour. The drift nets also collected a total of 33 White Sturgeon eggs. Predominantly young larvae were collected, with the dominant stages being 38-39. Mean total length (± 1 SD) and yolk-sac area was 11.9 ± 1.8 mm and 6.8 ± 2.1 mm^2, respectively, further supporting the lack of older larvae.

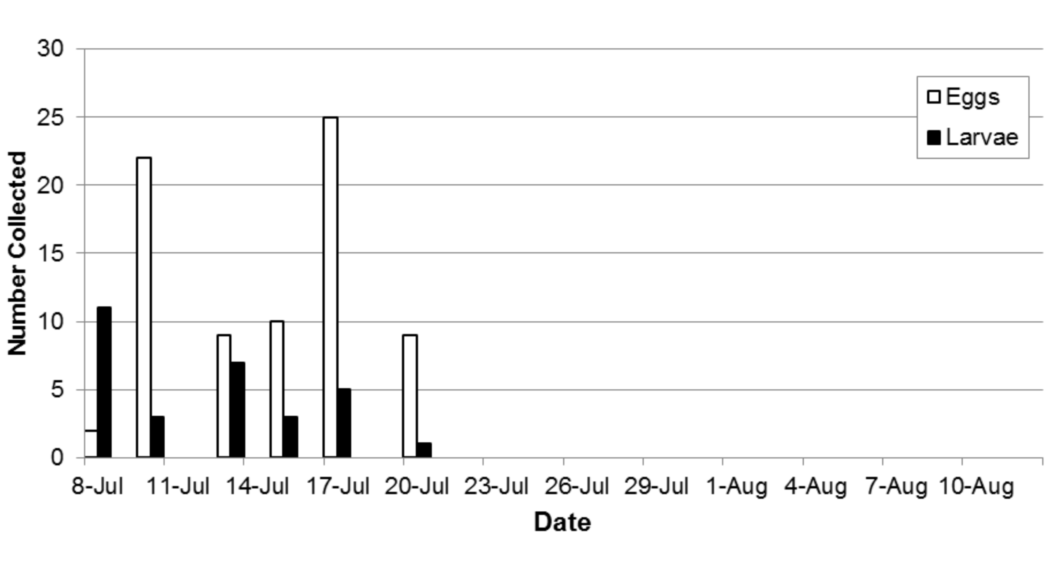


Figure 5. Numbers and timing of White Sturgeon eggs and larval collection at the Waneta spawning area on the lower Columbia River in 2009.

2010 Data

During the larval stage study on the lower Columbia River in 2010 we collected 30 sturgeon eggs and 115 larval sturgeon at site 0.1 (HLK/ALH) (CPUE 0.06), site18.2 produced 3 larval sturgeon (CPUE 0.004) and site 56.0 produced 89 larval sturgeon (CPUE 0.79; Table 6). All larval samples were collected at young ages, with only early developmental stages (38, 39, and 40) identified. Drift net sampling took place at the HLK/ALH site 0.1 from July 14 to August 11, 2010 (Figure 6). During this period, mean sampling time per drift net was 21.56 hours (Table 6). Average water temperature during the sampling period was 17.3°C. Sampling at site 18.2 was from July 16 through to August 11, 2010 (Figure 7). Water temperature averaged 17.4°C during the sampling. At site 56.0 (Waneta), drift net sampling commenced June 30, 2010 and continued through to July 30, 2010. The nets were fished every 2-3 days for an average of 3.09 hours for a cumulative 113.35 hours, with an average water temperature of 17.2°C.

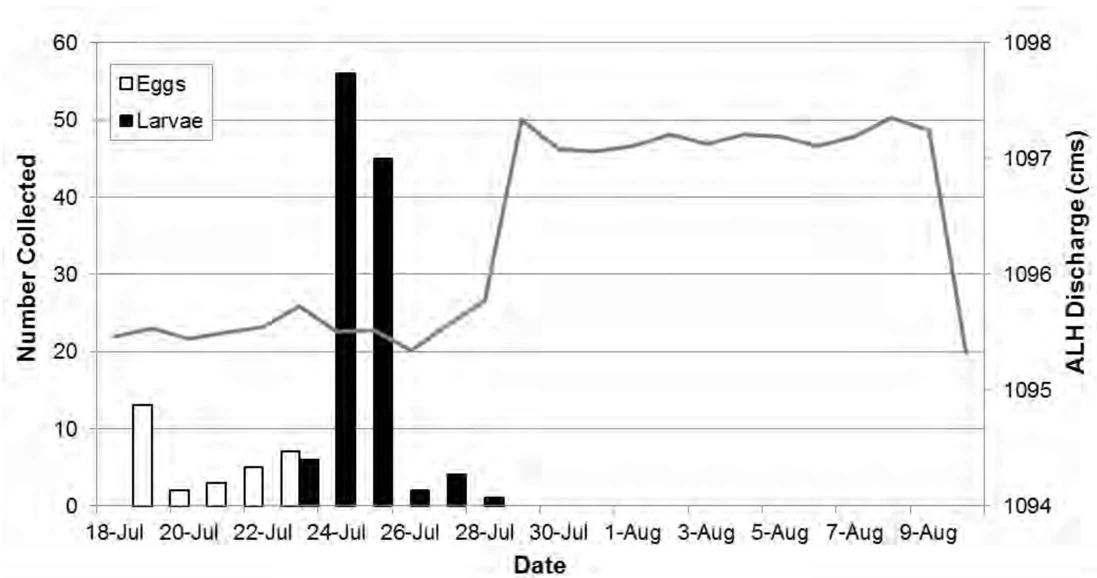


Figure 6. Numbers and timing of White Sturgeon eggs and larval collection at the HLK/ALH spawning area in 2010.

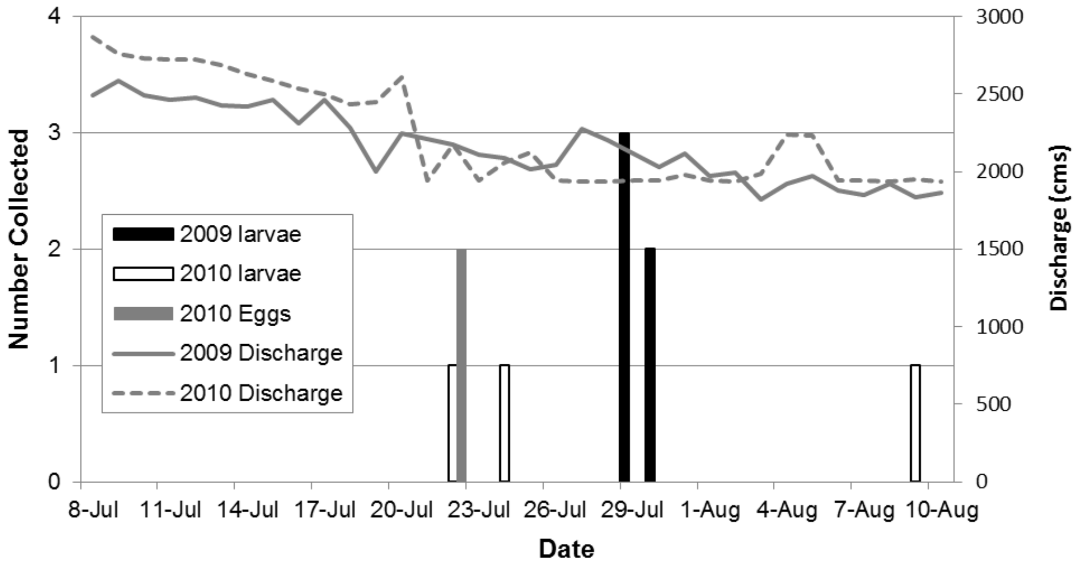


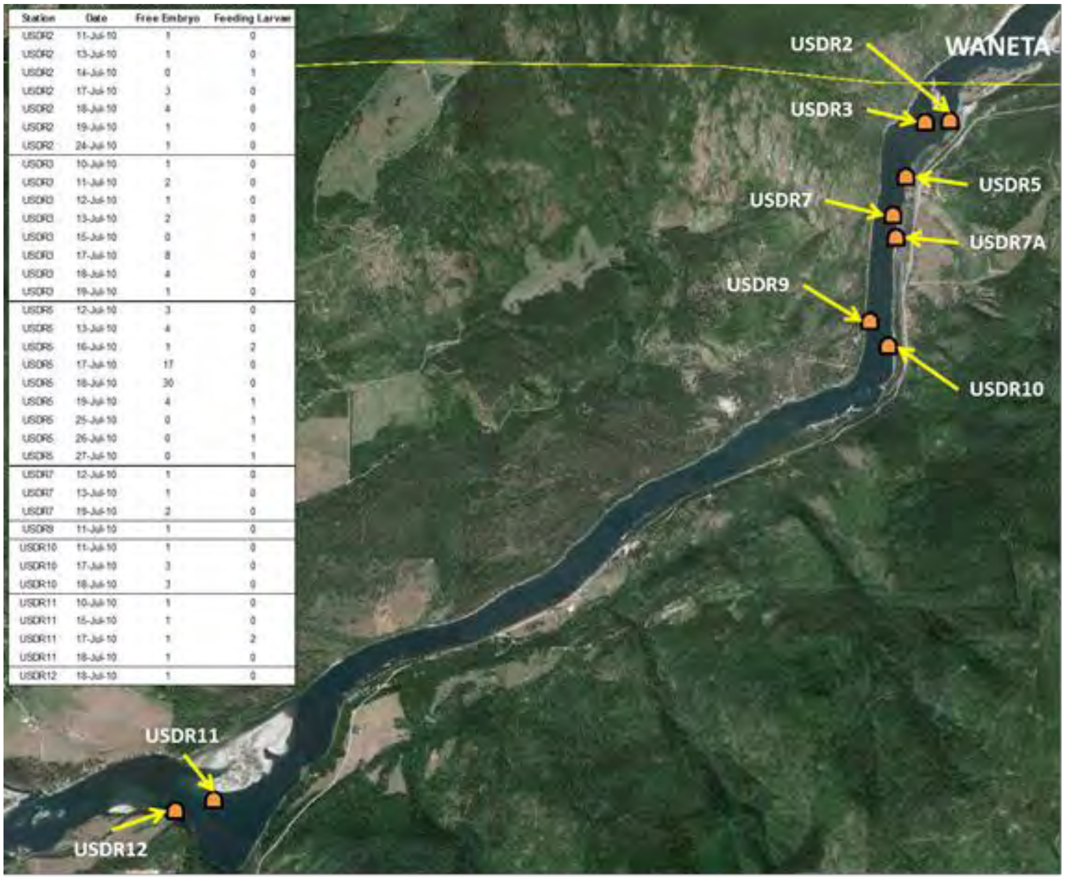
Figure 7. Numbers of White Sturgeon eggs and larvae collected at site 18.2 in 2009 and 2010 on the lower Columbia River. Site 18.2 is approximately 5 km downstream from Kinnaird.

Table 6. Number of larval sturgeon collected and sampling effort (Hours) at three larval White Sturgeon sampling sites in the lower Columbia River in 2010.

Site (rkm)	Total Catch	Mean Effort /Net	Total Effort	Catch Per Unit Effort (CPUE)
ALH (0.1)	115	21.6	2,084.1	0.060
18.2	3	18.3	2,103.6	0.004
Waneta (56.0)	89	3.1	113.4	0.790

*rkm: River Kilometer

At the eight sites in the US that were sampled in 2010, drift net sampling commenced on July 10, 2010 and continued through to July 27, 2010. The nets were fished every day for an average of 4.30 hours/day for a cumulative 494.24 hours, with an average water temperature of 16.8°C. A total of 111 (101 free embryos, 10 feeding larvae; Figure 8) larval sturgeon were collected with a CPUE of 0.24 sturgeon larvae/hr. In addition 60 White Sturgeon eggs were collected with the majority (n=42) collected at an upstream site (Site USDR5; see Figure 8).



Station	Date	Free Embryo	Feeding Larvae
USDR2	11-Jul-10	1	0
USDR2	13-Jul-10	1	0
USDR2	14-Jul-10	0	1
USDR2	17-Jul-10	3	0
USDR2	18-Jul-10	4	0
USDR2	19-Jul-10	1	0
USDR2	24-Jul-10	1	0
USDR3	10-Jul-10	1	0
USDR3	11-Jul-10	2	0
USDR3	12-Jul-10	1	0
USDR3	13-Jul-10	2	0
USDR3	15-Jul-10	0	1
USDR3	17-Jul-10	8	0
USDR3	18-Jul-10	4	0
USDR3	19-Jul-10	1	0
USDR5	12-Jul-10	3	0
USDR5	13-Jul-10	4	0
USDR5	16-Jul-10	1	2
USDR5	17-Jul-10	17	0
USDR5	18-Jul-10	30	0
USDR5	19-Jul-10	4	1
USDR5	25-Jul-10	0	1
USDR5	26-Jul-10	0	1
USDR5	27-Jul-10	0	1
USDR7	12-Jul-10	1	0
USDR7	13-Jul-10	1	0
USDR7	19-Jul-10	2	0
USDR9	11-Jul-10	1	0
USDR10	11-Jul-10	1	0
USDR10	17-Jul-10	3	0
USDR10	18-Jul-10	3	0
USDR11	10-Jul-10	1	0
USDR11	15-Jul-10	1	0
USDR11	17-Jul-10	1	2
USDR11	18-Jul-10	1	0
USDR12	18-Jul-10	1	0

Figure 8. Numbers of White Sturgeon free embryo and feeding larvae collected at 9 different drift net stations deployed downstream of the Waneta spawning area on the Columbia River in 2010

3.2 Juvenile Stage

A total of 187 and 337 juvenile sturgeon were captured in each of 2009 and 2010 respectively. A single wild juvenile was captured in each year representing 1 and <1 percent of the catch in 2009 and 2010, respectively. The 2001 year class (age of 9 years) represented the largest proportion of the total catch in each of 2009 and 2010 (Figure 9). Juvenile sturgeon were distributed widely throughout zone 1 (Figure 10), were caught in very specific areas in zones 2 (Figure 11) and 5 (Figure 14) and appear to only exhibit minor habitat use in zones 3 (Figure 12) and 4 (Figure 13; Table 7). A total of 29% of fish recaptured in zone 1 were originally released into zone 1 from the hatchery. Alternatively, 61% of juvenile White Sturgeon caught in zone 5 were originally released there from the hatchery.

Table 7. Numbers of juvenile White Sturgeon captured by age and sampling zone on the lower Columbia River in 2009 and 2010.

	Sampling Zone				
Age	**1**	**2**	**3**	**4**	**5**
1	1	-	-	-	3
2	-	1	-	-	8
3	-	3	-	-	41
4	9	3	-	-	56
5	10	2	2	1	69
6	20	12	-	-	40
7	9	3	-	-	45
8	44	6	-	-	46
9	46	7	-	-	37

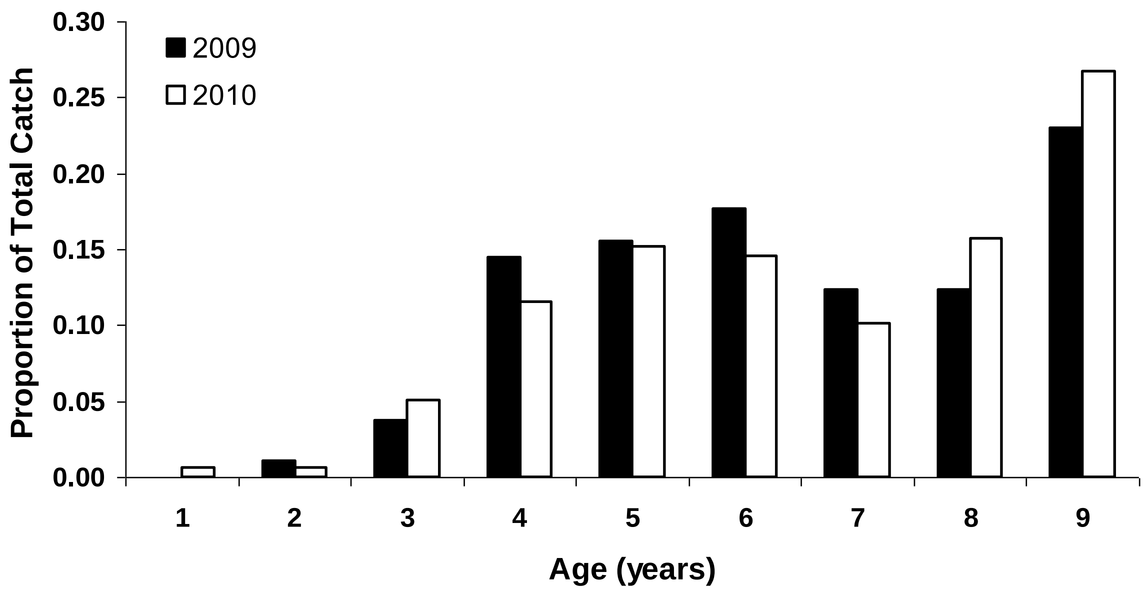


Figure 9. The proportion of juvenile White Sturgeon collected by age class in the lower Columbia River Canada in each of 2009 and 2010.

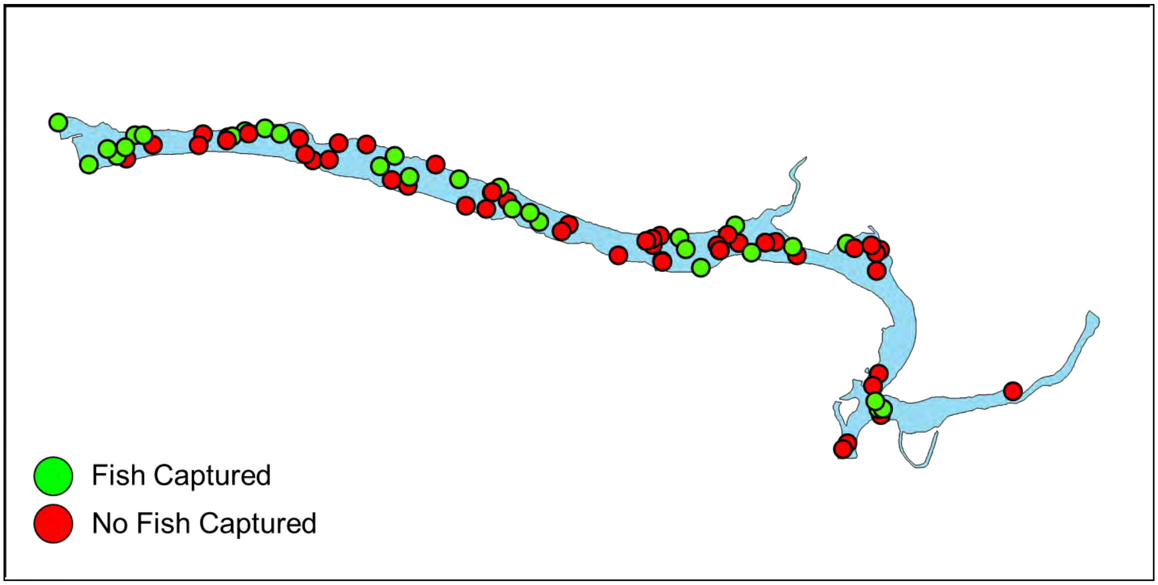


Figure 10. Juvenile White Sturgeon distribution in Zone 1 based on the locations of sampling effort and fish capture during 2009 and 2010.

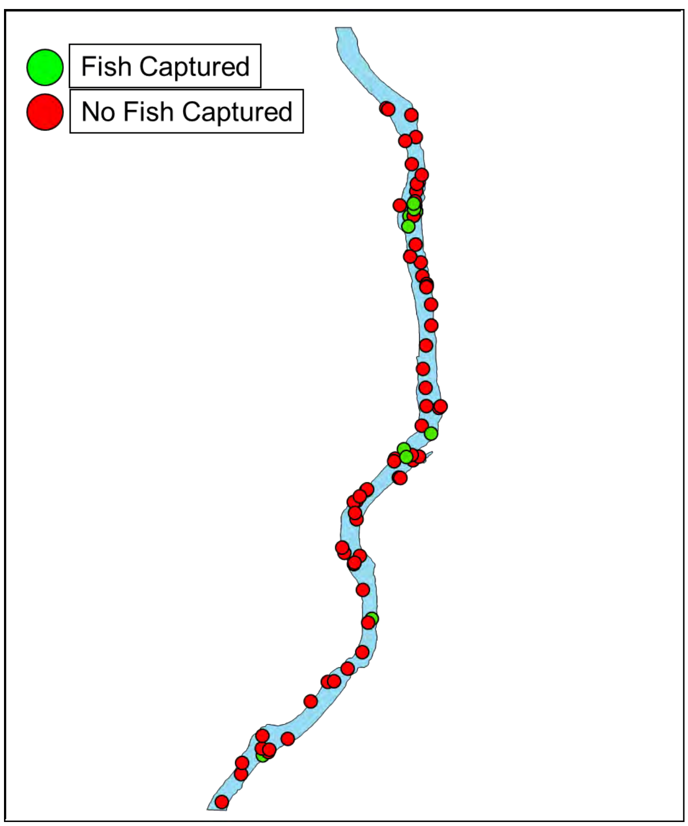


Figure 11. Juvenile White Sturgeon distribution in Zone 2 based on the locations of sampling effort and fish capture during 2009 and 2010.

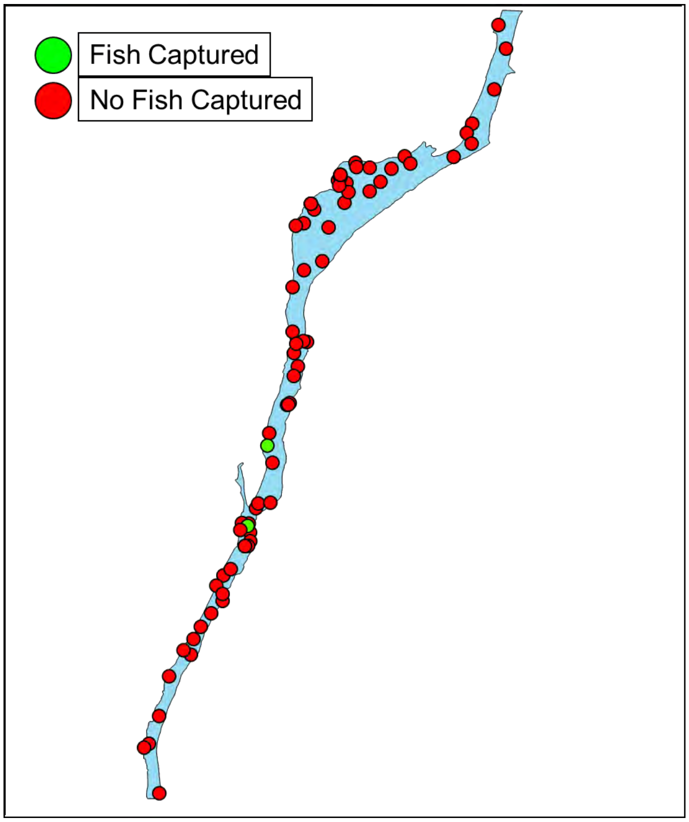


Figure 12. Juvenile White Sturgeon distribution in Zone 2 based on the locations of sampling effort and fish capture during 2009 and 2010.

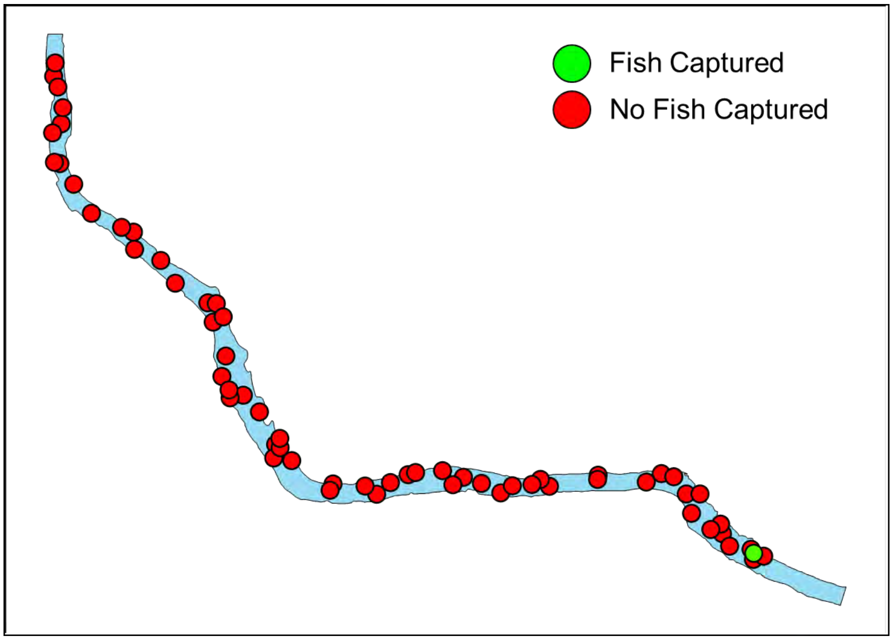


Figure 13. Juvenile White Sturgeon distribution in Zone 4 based on the locations of sampling effort and fish capture during 2009 and 2010.

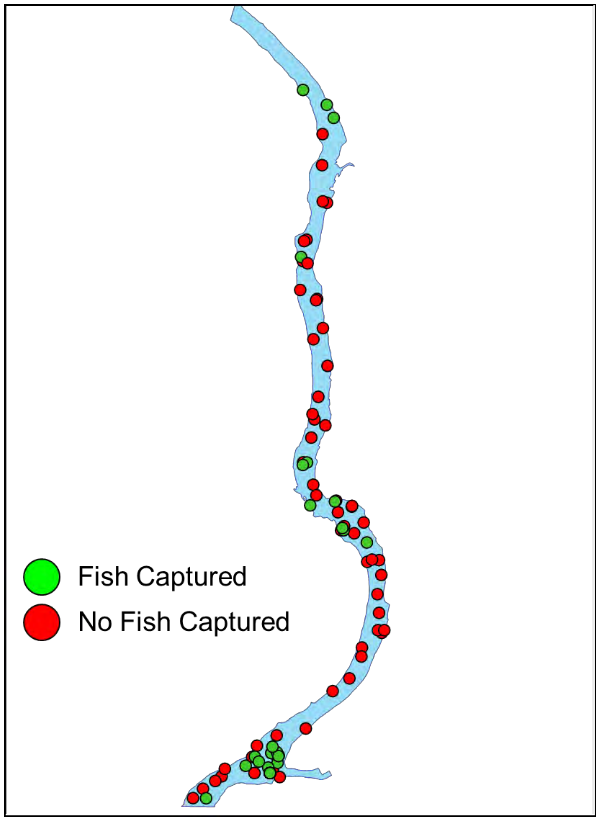


Figure 14. Juvenile White Sturgeon distribution in Zone 5 based on the locations of sampling effort and fish capture during 2009 and 2010.

3.2.1 Juvenile Capture Techniques

Comparison of effort, and catch per unit effort is provided below for each gear type using the 2009 catch data.

3.2.1.1 Setlines

During the juvenile White Sturgeon study in the Columbia River a total of 82 setlines were deployed, accounting for 41.1% of total hours sampled (417.43 hours of 1014.87 hours). Setlines were responsible for catching 5.3% (10 of the 189 White Sturgeon) of juvenile White Sturgeon during the study at a rate of 0.02 fish per hour (Table 8). Set line sampling in zone 1 took place October 5-26, 2009. Each set line was fished for an average of 5.15 hours for a cumulative total of 110.26 hours. A total of 9 juvenile White Sturgeon were caught with an average length of 92.2 cm and an average weight of 6.1kg. Set Lines were deployed in zone 2, October 8-28, 2009. Each setline was fished for an average of 5.12 hours for a cumulative total of 3.41days or 88.2 hours. Zone 3 sampling commenced October 7, 2009 and ended October 27, 2009. Each set line was fished for an average of 4.41 hours for a cumulative total of 3.31 days or 84.3 hours, with an average water temperature of 11.8°C. Set Lines were deployed in zone 4, October 2-19, 2009. Each setline was fished for an average of 4.41 hours for a cumulative total of 2.20 days or 56.18 hours. No White Sturgeon were captured in zones two, three and four. Sampling in zone 5 commenced October 9, 2009 and ran through to October 29, 2009. Each set line was fished for an average of 5.15 hours for a cumulative total of 3.17 days or 78.49 hours. 1 White Sturgeon was caught with a length of 54 cm and a weight of 1.1kg.

3.2.1.2 Gill Nets

Gill net sampling during this study was responsible for a total of 15.34% (20 of the 189 White Sturgeon) of total sturgeon caught (Table 8). The CPUE of 0.06 fish/hour was achieved. A total of 49.7 % (504.23 hours out of 1014.87 hours) of sampling time was spent gill netting during the juvenile capture program. A total of 101 gill nets were set, each measuring a total of 54.9m2. A total of 5544.9 m2 of area was sampled throughout the project. Gill net sampling in zone 1 commenced October 5 and ran through October 26, 2009. Each gill net was fished for an average of 5.06 hours for a cumulative total of 3.5 days or 92.01 hours. There was a total of 5 White Sturgeon caught with an average length of 61.6 cm and an average weight of 1.68kg. Gill net sampling in zone 2 ran from October 8-28, 2009. Each gill net was fished for an average of 5.35 hours for a cumulative total of 4.53 days or 117.23 hours. A total of 7 White Sturgeon were caught with an average length of 52.8 cm and an average weight of 1.1kg. Gill nets were deployed in zone 3, October 7 to October 27, 2009. Each gill net was fished for an average of 4.58 hours for a cumulative total of 3.31 days or 84.35 hours. One White Sturgeon was caught with a length of 64 cm and weight of 1.8kg. Zone 4 sampling period commenced October 2, 2009 and ended October 19, 2009. Each gill net was fished for an average of 5.01 hours for a cumulative total of 2.3 days or 60.14. No White Sturgeon were caught during this time, contributing factors may include: turbulent flows or large sub straight. Gill net sampling in zone 5 occurred October 9-29, 2009. Each gill net was fished for an average of 4.34 hours for a cumulative total of 6.17 days. A total of 20 White Sturgeon were caught with an average length of 57.2 cm and an average weight of .97kg.

3.2.1.3 Angling

Angling juvenile White Sturgeon in the study area proved to very successful in specific locations, and low in other areas. Large back eddies proved to very abundant opposed to faster moving current. Of all the fish captured during the study period 79.4% were captured from angling (150 of 189 fish) with a majority of White Sturgeon captured within the lower reaches of zone 5 (Table 8). CPUE for angling was 1.61 fish per hour. Sampling in Zone 1 took place October 5-26, 2009. Each angling location was fished for an average of .51 hours for a cumulative total of .36 days or 14.32 hours. 1 White Sturgeon was caught with a length of 78 cm and a weight of 7.7kg. Angling in Zone 2 took place October 8-22, 2009. Each angling location was fished for an average of .51 hours for a cumulative total of 16.21 hours, 1 White Sturgeon was caught with a length of 75 cm and a weight of 2.85kg. Angling took place in zone 3 from October 7-28, 2009. Each angling location was fished for an average of 1.09 hours for a cumulative total of 1 day or 24.18 hours, however no White Sturgeon were captured. Angling in Zone 4 was conducted on October 6, 2009. Each sample location was angled for an average of 1.03 hours for a cumulative total of 9.3 hours. No White Sturgeon were captured, contributing factors could include: low abundance, fast current and or large sub straight. Zone 5 was a very productive zone capturing 98.66% of total juvenile White Sturgeon during angling portion of the study. Sampling commenced October 9, 2009 and ended October 29, 2009. Each angling location was fished for an average of 0.09 hours for a cumulative total of 1.13 days or 29.2 hours, 148 out of the 150 White Sturgeon were caught with an average length of 67 cm and a an average weight of 2.0 kg.

Table 8. Numbers of juvenile White Sturgeon collected in 5 different stratified sampling zones in the lower Columbia River in 2009 using three gear types: Setlines (SSL), gill nets (GN), and angling (AG).

Zone	Gear Type	Total Capture	Mean Sample Time (hours)	Total Effort (hours)	Catch Per Unit Effort Fish /hour
1	SSL	9	5.15	110.26	0.08
1	GN	5	5.06	92.01	0.05
1	AG	1	0.51	14.32	0.07
2	SSL	0	5.12	88.20	0.00
2	GN	2	5.35	117.23	0.02
2	AG	1	0.51	16.21	0.06
3	SSL	0	4.41	84.3	0.00
3	GN	1	4.58	84.35	0.01
3	AG	0	1.09	24.18	0.00
4	SSL	0	4.41	56.18	0.00
4	GN	1	5.01	60.14	0.02
4	AG	0	1.03	9.30	0.00
5	SSL	1	5.15	78.49	0.01
5	GN	20	4.34	150.5	0.13
5	AG	148	0.09	29.2	5.07

Fish captured on setlines were significantly larger ($F_{2,174} = 16.3$, $P < 0.001$) in fork length compared to those captured using gill nets and angling (Figure 16). The relationship that best described juvenile White Sturgeon length-at-age was the von Bertalanffy growth equation: $L_t = 157.6(1-e^{-0.07(t-2.72)})$ (Figure 15), with L being fork length in centimeters and t being age in years. Based on this relationship, juvenile White Sturgeon grew faster in length at younger ages and the means are provided in Figure 17 for comparison. Juveniles released in the spring were significantly larger than those released in the fall of the same brood year. Mean (± 1 SD) length at release for juveniles released in the spring and fall is presented in Table 2. For years where both fall and spring releases occurred, juvenile White Sturgeon released in the spring were represented in higher proportions in our captures for each of 2005 (0.88, n=75), 2006 (0.95, n=65), and 2007 (1.0, n=24) release years. Though marginal, the proportion of juveniles released in the fall represented in the catch increased with increasing age.

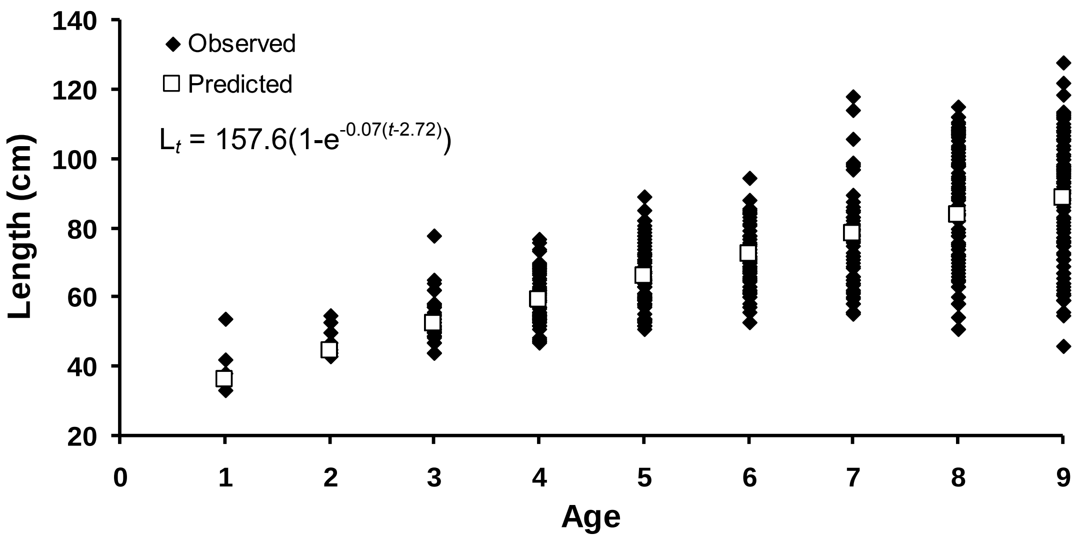


Figure 15. Mean length at age and von Bertalanffy predicted length-at-age for juvenile White Sturgeon in the lower Columbia River Canada.

Juvenile White Sturgeon were reared separately by maternal family group prior to release into the lower Columbia River. We evaluated performance in growth following release and found that for fish released at a similar mean size, different maternal families grew at significantly different rates following release. This was significant for 5 of the 6 years we evaluated (Table 9). An example from juveniles released in 2005 from the 2004 brood year is presented in Figure 19.

Table 9. Results from analysis of variance conducted for 6 age classes to determine differences in growth by family since release.

Brood Year	# Families Captured	F-value$_{df}$	P-value
2001	5	$3.4_{4,83}$	0.01
2002	4	$2.1_{3,47}$	0.11
2003	5	$406.6_{1,62}$	<0.001
2004	6	$1099.1_{1,92}$	<0.001
2005	5	$785_{1,94}$	<0.001
2006	5	$315.6_{1,76}$	<0.001

We were able to accurately predict juvenile White Sturgeon weight using total length. The final fitted model (Figure 18) yielded an intercept (α = 2.778E-06), slope (β = 3.193), and correlation coefficient (r^2 = 0.910) that are similar to relationships presented for other populations of White Sturgeon (Beamesderfer 1993). As with length at age predictions, the weight length relationship showed faster growth in length at younger ages (1-4) and faster growth in weight at later ages (5-9).

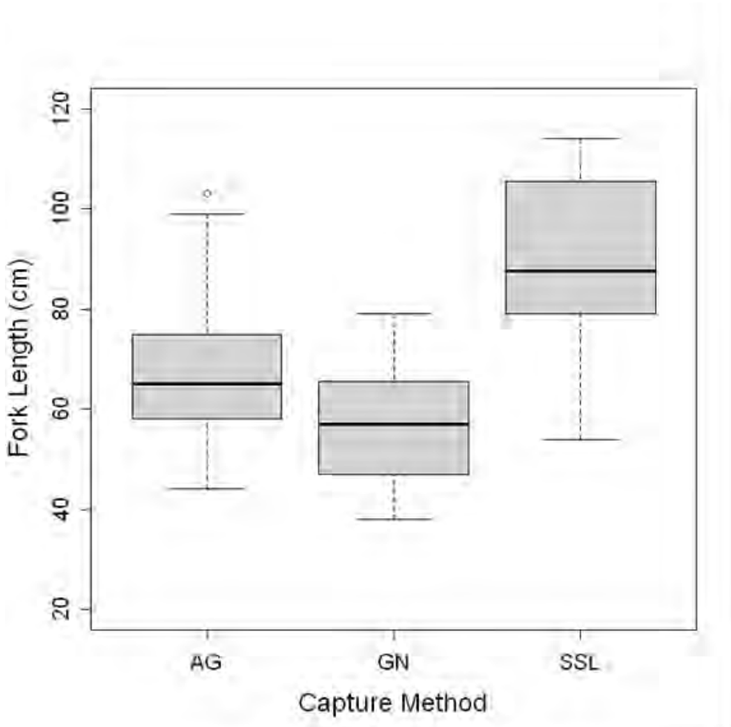


Figure 16. Mean fork length of juvenile White Sturgeon captured using setlines (SSL), gill nets (GN) and angling (AG) in the lower Columbia River in 2009 and 2010.

Relative weight varied by age and capture location with only capture location influencing mean relative weight. Mean relative weight (± 1 SD) was highest in the upper river (Zone 1; 103.3 ± 39.6) and decreased moving downstream through Zone 2 (97.8 ± 7.5), Zone 3 (95.7), and Zone 5 (83.7 ± 19.2). Mean relative weights were variable by juvenile age (Table 10).

Table 10. Mean relative weight (± 1 SD) by age class for juvenile White Sturgeon captured in the lower Columbia River in 2009 and 2010.

Age	Mean Relative Weight
8	93.2 ± 30.2
7	82. ± 9.8
6	86.0 ± 16.1
5	75.8 ± 12.6
4	87.6 ± 16.0
3	89.7 ± 29.0
2	75.1 ± 12.9
1	86.7 ± 1.0

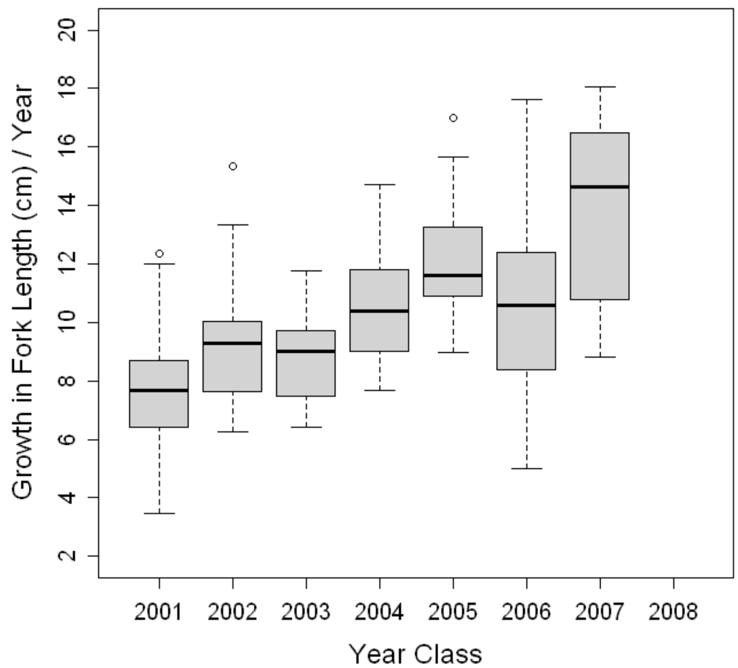


Figure 17. Growth in fork length (cm) per year for juveniles of known age classes captured in the lower Columbia River in 2009 and 2010.

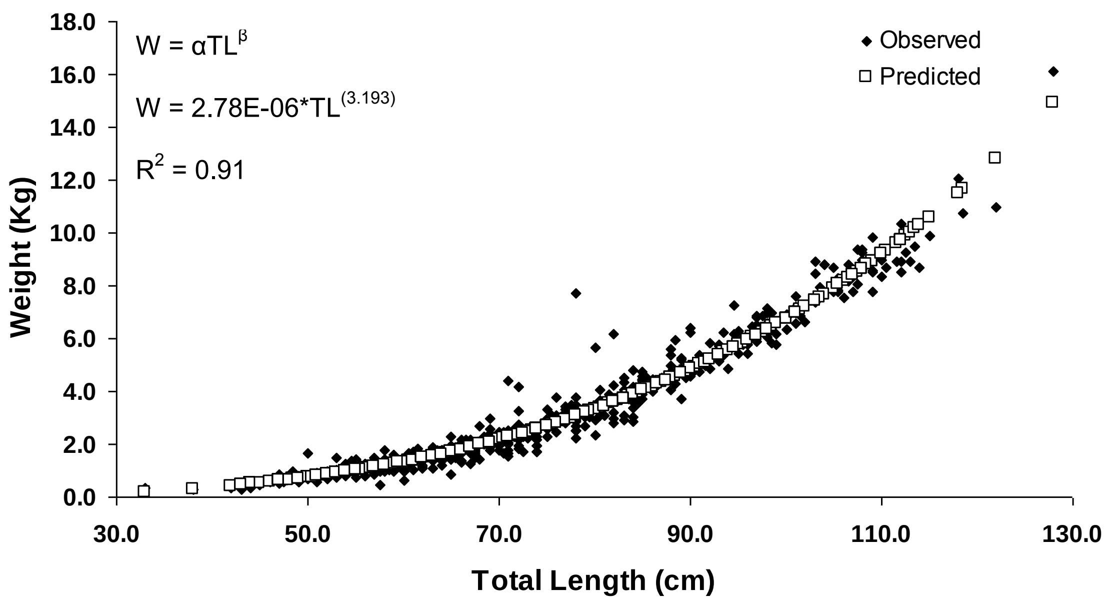


Figure 18. Observed and predicted weight versus length relationship for juvenile White Sturgeon collected in the lower Columbia River in 2009 and 2010.

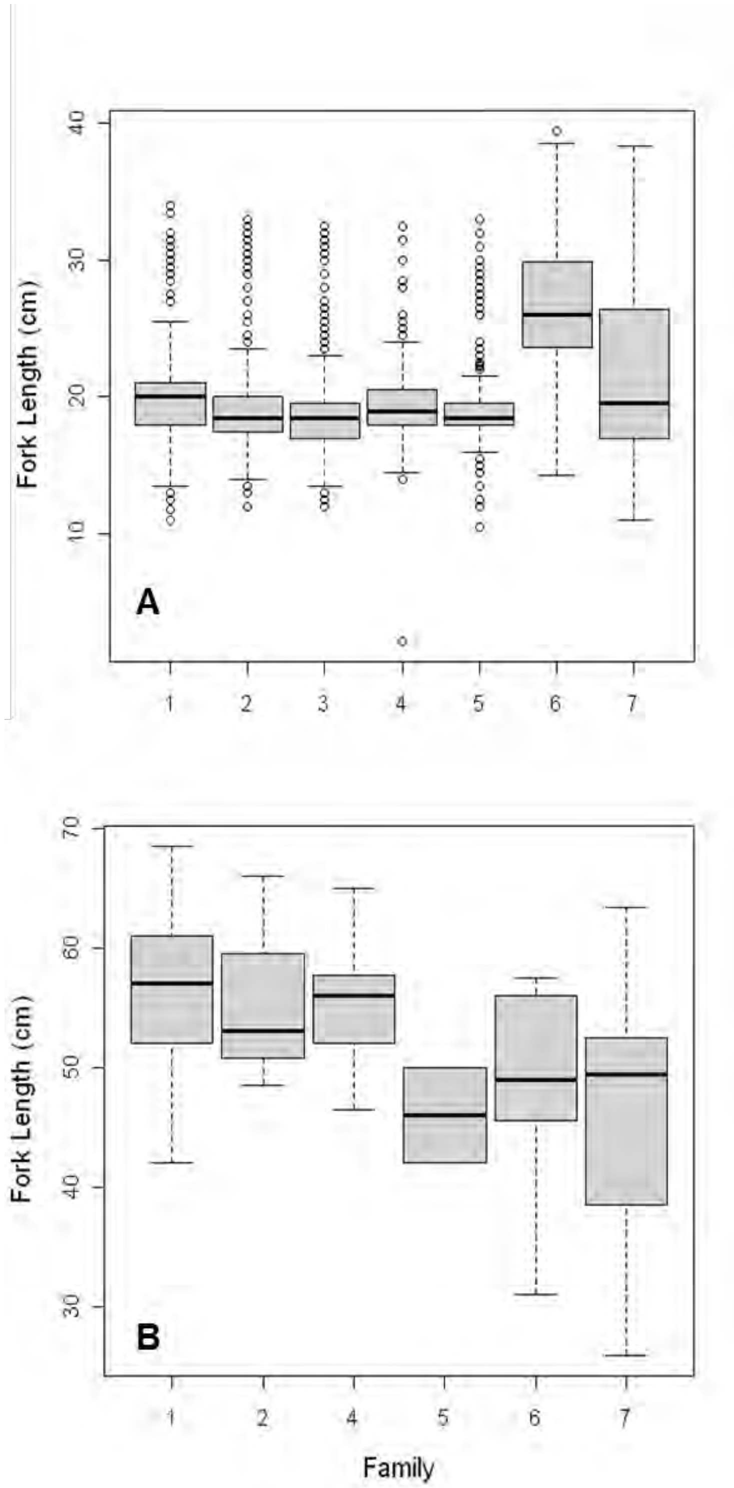


Figure 19. Mean fork length (cm) for juvenile White Sturgeon from different maternal family groups released in 2005 (Panel A) and then recaptured in 2010 (Panel B).

3.2.2 Gastric Lavage

Gastric lavage was attempted on the majority of juveniles captured to describe diet preferences. The success of this technique was limited and collection of prey items from individual juveniles was inefficient. This is attributed to the bend in the oesophagus just anterior to the stomach limiting the back flushing capability of the technique. White a few smaller prey items were identified (e.g. mysid shrimp, caddis spp), it is recommended that future studies identify the efficiency of the technique prior to providing quantifiable data on diet preferences.

3.2.3 Movement Patterns of Wild and Hatchery Released Juveniles

All juvenile White Sturgeon with acoustic tags were released on May 3, 2010. Sturgeon released in Zone 1 at rkm 5.5 showed variable movement patterns with 2 of the fish eventually moving to upstream location in the vicinity of HLK dam at the time of last detection, and 3 fish exhibiting downstream movements (Table 11). Sturgeon released in Zone 2 at rkm 16.0 all eventually moved to downstream locations, with one fish making a significant downstream migration into the United States at rkm 93.2 (Flat Creek Eddy) where it remained for over 7 months until the last tracking session (Table 11). Of the sturgeon released in Zone 3 at rkm 28.5 and that had detections (one fish not detected; n=4) all eventually moved to downstream locations, with two fish making significant downstream migrations into the United States at rkm 96.8 and 82.8, both locations of deep water, eddy habitat in the lower Columbia River (Table 11). Two of the sturgeon released in Zone 4 at rkm 39.8 were never detected, and the remaining three made downstream migrations with two moving to rkm 89.5 in the US (Table 10). All the sturgeon released in Zone 5 at rkm 51.0 made downstream migrations with two fish making short migrations to areas around Waneta Eddy and three fish moving downstream a significant distance to habitat in the US (Table 11).

It should be noted that 14 of 25 (56%) sonic tagged sturgeon were either never detected or were only detected until mid-May, 2 weeks following release. It is likely that these fish either were utilizing habitat between acoustic receiver stations and making minimal movements, or the tags had malfunctioned, although this is unlikely. Generally, when juvenile sturgeon made movements, the initiation of these movements typically occurred with the onset of darkness and between the hours of 21:00 and 05:00 similar to results from juvenile tracking in the Mid-Columbia River (Golder 2011).

Table 11. Summary of movements for hatchery released juvenile White Sturgeon released into the lower Columbia River on May 3rd 2010. Movements are presented as net, upstream (US) and downstream (DS) distances travelled.

Tag ID	Release Site*	Net Movement (km)	US Movement (km)	DS Movement (km)
27134	5.5 (1)	41.8	0.0	41.8
27122	5.5 (1)	23.9	3.0	7.9
27141	5.5 (1)	5.0	3.0	1.0
27146	5.5 (1)	25.2	0	25.2
27133	5.5(1)	7.0	5.0	1.0
27131	16 (2)	33.3	0.0	33.3
27137	16 (2)	17.4	0.0	17.4
27123	16 (2)	77.2	0.0	77.2
27136	16 (2)	35.1	3.8	35.1
27127	16 (2)	5.8	0.0	5.8
27138	28.5 (3)	105.70	17.0	68.3
27128	28.5 (3)	4.9	0.0	4.9
27140	28.5 (3)	58.5	2.1	56.4
27143	28.5 (3)	2.2	0.0	2.2
27130	28.5 (3)			
27132	39.8 (4)			
27142	39.8 (4)	49.7	0.0	49.7
27124	39.8 (4)			
27144	39.8 (4)	43.0	0.0	43.0
27125	39.8 (4)	9.5	0	9.5
27129	51 (5)	43.4	9.5	33.9
27145	51 (5)	31.8	0.0	31.8
27126	51 (5)	0.5	0.0	0.5
27139	51 (5)	0.5	0.0	0.5
27135	51 (5)	24.4	0.0	24.4

*Release site: River Kilometer (rkm) and zone of release

3.3 Habitat Mapping

A detailed habitat map for the entire lower Columbia River was initiated during the early stages of this program. Acoustic backscatter data were collected with a sidescan sonar and will be validated and classified (e.g. fines, sand, gravel, cobble, boulders) in the coming years. Finished habitat maps will be used to display data visually from a number of WUP programs in the lower Columbia. It will also allow sturgeon capture and movement data to be overlaid for all age classes. An example of the data being collected is presented in Figure 20, which is located in the vicinity of Kinnaird.

Figure 20. An example of acoustic backscatter data classified into substrate types (Colour patterns) that was collected in the lower Columbia River using a side scan sonar. The validation of substrate types is ongoing.

4.0 DISCUSSION

Larval Stage

A spawning area was identified at the HLK/ALH area which represents the second known spawning area in the Canadian section of the transboundary reach. This is encouraging as the main spawning depositional area appears to be in the ALH tailrace which allows for more fine scale monitoring of larval habitat use in that area. The lack of older larvae in the captures indicates that though spawning habitat (and physical properties) may be suitable for spawning and egg incubation, they may be unsuitable for larval hiding which has been hypothesized as an important barrier to recruitment (McAdam 2011). Spawning substrate is comprised mainly of larger boulders (~300 mm in diameter) with minimal smaller sized materials which likely reduces the amount of available interstitial space for hiding during the larval stage. Further work describing the spawning and early rearing habitat will be important going forward. Larval dispersal downstream from the HLK/ALH spawning area is limited by hydraulic conditions through the Robson Reach. This 8 kilometer stretch of river has hydraulics that differs from areas sturgeon larvae typically disperse through and is characterized by slower water velocities and limited hiding habitat (larger cobble boulder). Further, the Robson Stretch supports a significant predator population including native Rainbow Trout (*Oncorhynchus mykiss*), Mountain (*Prosopium williamsoni*) and Lake (*Coregonus clupeaformis*) Whitefish as well as introduced species like Walleye (*Sander vitreus*) and Northern Pike (*Esox lucius*). Predation is one of several competing hypotheses that are assumed to contribute to recruitment failure (Gregory and Long 2008). It could be hypothesized that the Robson Reach has habitats that could support rearing of larval White Sturgeon and further monitoring should describe the suitability and availability of habitat types as well as describe food availability.

As in past years (Golder 2009b), 1 day post hatch larvae were captured dispersing downstream of Kinnaird. Though this site is thought to support some level of reproduction, it is unsure where the exact location is and future monitoring should incorporate sampling that helps identify the main spawning area. Further, the timing and frequency of spawning is uncertain in this section of the river. Results to date suggest that spawning is later in this area compared to Waneta as temperatures reach 14 ^{o}C later due to the colder influence of the Kootenay River which joins the Columbia River just upstream. Given the uncertainties in larval origin, determining the habitat properties, and their suitability at the early life stages, isn’t feasible until more data are collected in this section of river. As more larvae are collected, genetic analyses could help identify if these individuals originated from the HLK/ALH spawning area upstream as well as describe the numbers of contributing adults.

A number of larvae were captured in drift nets below the Waneta spawning area demonstrating natural recruitment to this life history stage. Substrate surveys have indicated that coarser substrates with interstitial spaces are available at the Waneta area (Golder 2009b). However, early stage larvae are collected in significantly higher abundance compared to older feeding larvae despite available hiding habitat. It is unknown whether this dispersal pattern is reflective of habitat conditions or displacement due to hydro operations. One additional hypothesis could be that the sampling equipment is in close proximity to the spawning area and the immediate section of river downstream could support early hiding and rearing. In this study, sampling downstream of Waneta across the international border resulted in higher numbers of older feeding larvae in the collections which could indicate that some hiding habitat is available. However, the numbers of feeding age larvae were generally low and habitat suitability is presumed to be poor. Further research and monitoring into the effects of substrate suitability on the larval stage is warranted.

Juvenile Stage

Hatchery released 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 were rarely encountered and represented < 1% of the total catch. One of the main objectives of this program was to identify the distribution of both wild and hatchery origin juvenile sturgeon in the lower Columbia River. Using a spatially balanced and randomly assigned sampling design, we were able to describe juvenile habitat use throughout the lower Columbia River. We found that habitat use was high through the upper section of the river from HLK down as far as tin cup rapids. This habitat is characterized primarily by deep slow moving water and smaller substrates (e.g. sand, gravel, cobbles). Moving downstream from the Kootenay River confluence, habitat use became restricted to eddy features and deeper runs. Juvenile White Sturgeon did not appear to use the section of the river downstream of Genelle to just south of the City of Trail. This section is characterized primarily by fast flowing water, larger substrates and bedrock. High habitat use was then identified near Fort Sheppard and Waneta Eddy's. Habitats with slower moving water and smaller substrates likely increase feeding efficiency while reducing the metabolic demands on the individual. Generally, juveniles select deeper slower areas of the river and these habitats are not limited by the current operational regime of the lower Columbia River. Further, juvenile habitat distribution is similar to, and overlaps with, adult habitat use (described in BC Hydro, 2013).

A percentage (29%) of the fish recaptured in zone 1 (Robson Reach) were originally released in that zone. Though high fidelity (>60%) to certain areas of the river has been demonstrated for the adults in this population (van Poorten and McAdam 2010; BC Hydro 2013), dispersal following release from the hatchery is likely quite active and aligns with results of juveniles implanted with acoustic transmitters and released in each zone. Almost all fish with acoustic transmitters exhibited downstream dispersal following release, a behaviour noted for other juvenile White Sturgeon (Golder 2011) and juvenile sturgeon of other species (Crossman et al. 2011). Comparatively, 61% of juveniles captured in zone 5 (e.g. Fort Shepard and Waneta Eddy's) were originally released there. Releases of hatchery juveniles occur annually at Beaver Creek and Fort Sheppard and Waneta Eddy's would represent some of the first suitable habitats for fish making downstream migrations. High site fidelity to this area of the river following release is an important consideration for stocking programs, as release locations are typically dictated by logistical constraints related to accessing the river. In the lower Columbia River, release strategies of juvenile White Sturgeon shouldn't be restricted to only two locations (upstream and downstream) but should consider releasing juveniles in the middle section of the river (e.g. Kootenay eddy and Genelle) so habitat use following release can be further evaluated.

Our ability to estimate age specific juvenile survival was precluded by low numbers of recaptured individuals. Further, recaptures were limited to only a few age classes which did not permit development of age specific survival rates. Generally, older ages represented larger proportions of the total catch (e.g. 25% 9 year olds) but all hatchery release ages were represented within the high habitat use areas. Based on earlier work with this population (Golder 2006) and that conducted in other systems (Ireland et al. 2002; Justice et al. 2009) we expect that survival rates of released juveniles may be initially low in the first year following release as juveniles acclimate to the natural environment. In subsequent years, survival rates should be quite high and further stabilize with increasing age (McCabe and Tracy 1994; Gross et al. 2002; Justice et al. 2009). It is critical that age specific survival rates are developed in the coming years so that annual stocking targets can be adjusted for this population.

Based on growth rates observed in this study, we hypothesize that survival rates are as high as reported by Golder (2006) and have been maintained since that study was finalized. Annual growth rates in total length of juvenile sturgeon calculated for this population are high. Growth rates ranged from 14 cm in fork length per year for younger fish (1-3) and 10 cm per year for older aged juveniles (4-8). Average annual weight increases were smaller for younger fish (1-4) and larger for older ones (age 5-8), suggesting that growth in total length is more important in the early years than weight. These growth rates are more than double observations from the Kootenai River where hatchery released juveniles were found to grow 6.4 cm per year in for length and 0.21 kg per year in weight (Ireland et al. 2002). These higher growth rates will result in individuals reliably recruiting to the juvenile sampling gear at a young age (3-4 years, or >50 cm FL) and the adult sampling gear soon after (5-7 years of age) as demonstrated by by-catch during the broodstock program (BC Hydro 2013).

Three years of fall and spring releases were conducted from 2005-2007 in order to identify if the first winter was a significant survival threshold. Higher proportions of juveniles from the spring release event were represented in our captures from each of the three years. Interestingly, proportions of fall releases increased with increasing age suggesting they may possibly be recruiting to the sampling gear later in life. Differences in size (length and weight) at release were more pronounced in 2007 compared to 2005. Fish released in the fall likely do not exhibit much growth over the winter and may even lose weight if food resources are low or if competition exists. They would be behind in growth compared to fish of the same age that were released in the spring and may take an additional year to recruit to the sampling gear. Further monitoring in the coming years will help identify if fall released juveniles are recruiting to sampling gear at a later age compared to spring released fish or if survival through the first winter is low.

Though only qualitative, juvenile White Sturgeon in the upper section of the lower Columbia River prey heavily on mysid shrimp. This introduced food source made up higher percentages of the diet in juveniles captured in the upper stretches of the river compared to those captured in lower sections. It is important to note that these observations come from prey items identified from gastric lavage samples, a technique that needs further evaluation in its effectiveness in describing prey items in the stomach. Observations from the larval drift netting work found that mysid were available in higher abundance in the upper section of the river below HLK and abundance subsequently declined with increasing river distance downstream.

Angling was the most efficient capture method used in our study though it was selective for older juveniles. Limitations with hook sizes prevented capture of younger (<3 years of age) juveniles on setlines however setline effort can be easily distributed throughout all habitats and effort should be increased in the coming years. Gill nets have been demonstrated to be an effective means of collecting juvenile sturgeon older than 2 years

(Golder 2006; Howell and McLellan 2007) however the short duration sets deployed in this study limited the number of fish collected. Short set gill nets were implemented to minimize risk of mortality of collected fish and ensure that any adults entrapped in the nets were released in a timely fashion. Further, gill nets were set during the daylight hours and activity levels are known to be highest at dusk and dawn (Golder 2011; this study). For monitoring going forward, effort should be restricted to setlines, distributed randomly through the habitat, with angling used as a supplemental capture technique.

5.0 RECOMMENDATIONS

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

Larval Sampling

- Sampling should continue to occur annually at the HLK/ALH spawning area to determine spawning timing and frequency at this area.
-
- Sampling should start in early July and continue through the middle of August as the timing of spawning in the upper parts of the lower Columbia River is still uncertain.
-
- Drift nets maximize catch per unit effort of eggs and larvae from 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.
    - Drift net effort 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.

Juvenile Sampling

- Maximize capture of juveniles across habitat types (e.g. upstream versus downstream) and age classes to partition differences in growth observed in this study.
    - Maximizing captures could increase the number of recaptured individuals which would allow for more detailed growth curves and survival estimates to be produced.
    - The first two years of juvenile sampling was spatially balanced throughout the study area. Future sampling to maximize juvenile captures could be

distributed to areas of fish presence using results from this study (e.g. see section 3.2 Figures 8 through 12).
    - Sampling effort should 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 lower Columbia.
- Evaluate the efficiency of gastric lavage in describing the diet of juvenile White Sturgeon in the lower Columbia River.
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Habitat Sampling

- Continue to develop a habitat map for the entire lower Columbia River. 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 the HLK/ALH location. Focus should be given to determining the suitability of the immediate larval hiding habitat and downstream rearing habitat.

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