

Columbia River Project Water Use Plan

Lower Columbia River

Reference: CLBMON #28 (Year 4)

***Lower Columbia River Adult White Sturgeon Monitoring
Program: 2011 Investigations Data Report***

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BC Hydro and Power Authority

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EXECUTIVE SUMMARY

White Sturgeon (*Acipenser transmontanus*) in the Canadian section of the lower Columbia River (LCR), are one of four populations that were listed as endangered under the Species at Risk Act in 2006. The population was identified as a priority during the Water Use Planning (WUP) process because it is undergoing recruitment failure and considerable uncertainties exist related to recovery. However given the high value of power generation mandated under the Columbia River Treaty (CRT), significant flow alterations on the system were not deemed feasible and as such the system was designated as a working river. As a result of this designation, management responses targeted on White Sturgeon were focused on the collection of biological information that could determine the possible mechanisms resulting in of recruitment failure and address issues related to recovery along with non-operational habitat improvements designed to increase spawning and rearing success. The general objectives of the early years of this program were to 1) collect mature adult White Sturgeon to serve as broodstock for the annual conservation aquaculture program, 2) determine White Sturgeon spawning locations, habitat use, and movements using both direct (capture) and indirect (telemetry) methods, and 3) collect biological and genetic data related to White Sturgeon spawning including the locations, timing, frequency, and number of contributing adults.

In 2011, conservation aquaculture broodstock targets were met with 8 males and 6 females being captured and successfully spawned at the hatchery. Similar to the past several years of the program, 27.8% of the 197 White Sturgeon collected during the broodstock program were first time captures supporting the need for a revised population estimate. Growth of adults (>150 cm fork length) was marginally lower (2.5 cm/year) compared to mean annual growth of adult wild White Sturgeon in the Roosevelt Reach (2.8 cm/year) but higher compared to adults in the Kootenay River (0.6 cm/year). Movement data indicated that activity generally occurred during the summer months as is assumed to be made for foraging or spawning. Site fidelity remains high (> 60%) to specific river locations and underlies the importance of maintaining spatial balance when sampling for adults. Adult White Sturgeon in the lower Columbia River are selecting deeper slower moving habitats in the river, which do not appear to be limited under the current operational regime.

Spawning was estimated to have occurred from late June into early August, with spawning in the upper portion of the river being later (e.g., early August) compared to downstream areas (i.e., Waneta). Further, spawning was identified near Kinnaird (rkm 13.0). The timing and duration of spawning activity was similar to past years, with the majority of Waneta spawning events occurring on the descending limb of the hydrograph and at water temperatures above 14 °C. Based on developmental stages of collected eggs, it was estimated that 8 spawning events happened at Waneta and 4 events happened at ALH. For the first time in 2011 we staged captured White Sturgeon larvae and estimated when spawning occurred using known development rates at different water temperatures. This increased the estimated number of spawning events for both at Waneta (19) and ALH (5). In addition to empirical estimates using developmental stages of eggs and larvae, genetic analyses are underway using to determine if estimates of spawning timing align for samples collected at different life stages.

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

Table ES1. CLBMON #28 Status of Lower Columbia River Adult White Sturgeon Monitoring Program Objectives, Management Questions and Hypotheses.

Management Question	Status
<p>What are the abundance trends, population structure and reproductive status of adult White Sturgeon in the lower Columbia River?</p>	<ul style="list-style-type: none"> - The abundance estimate for adult White Sturgeon remains at 1,100 in the Canadian section of the Lower Columbia as estimated by Irvine et al. 2007. In the coming years, a coordinated approach between BC Hydro and biologists in the United States will be conducted using a spatially balanced stratified random sampling approach to develop an improved population estimate. This will facilitate tracking recovery targets for this population. - Generally, the wild population remains dominated by adult age classes, with limited wild juveniles encountered. Importantly, juveniles released from the conservation aquaculture program are surviving and are represented in a large proportion of the adult captures. These juveniles have extended the estimated extirpation of this population by several decades. - Mature adults are abundant enough on an annual basis that individuals have not been reused for the broodstock program. Ongoing genetic analyses will help describe the number of breeding adults on an annual basis.
<p>How much spawning occurs annually at known spawning locations, and are there other spawning locations unidentified in the lower Columbia River?</p>	<ul style="list-style-type: none"> - Wild spawning has been detected annually, and while confidence around the estimates of the number of spawning events is unknown, it is estimated that multiple spawning events occur annually with eggs surviving to hatch. Genetic analyses are underway and will contribute to knowledge around this question. - Spawning occurs annually at the Waneta area, with the number of estimating spawning events varying by year. - Spawning has been identified through egg and larval captures downstream of HLK and ALH. This represents the second known location in the Canadian section of the lower Columbia River and has been incorporated into annual monitoring programs to further

Management Question	Status
	<p>describe spawning frequency and duration.</p> <ul style="list-style-type: none"> - An additional spawning location is used annually in the vicinity of Kinnaird but the exact location remains unknown. - Additional spawning sites are used annually south of the international boundary.
<p>What is the degree of interaction among sub-populations of sturgeon in the lower Columbia River?</p>	<ul style="list-style-type: none"> - Though fidelity to specific habitats or locations has been identified as high, individuals have been identified to move throughout the river during the spring and summer months based on subsequent captures or telemetry tracking. Further, we know through direct capture and telemetry methods that fish move between Canada and the United States. However, though movements have been identified, further data are required to address the interaction (i.e., spawning) of individuals from different sections of the lower Columba River.
<p>How do existing river operations affect adult movements, habitat preference, spawning site selection or spawning?</p>	<ul style="list-style-type: none"> - Adults select deep, slow moving sections of the river, which are currently not limited by the existing operating regime of the river. Site fidelity is extremely high to very specific habitats and individuals spend >60% of their time at a single location. When movements do occur, they tend to occur during periods of warmer water and increasing flows for either feeding or spawning. - Spawning related movements have been identified for a select number of mature males and females and individuals tend to move to spawning locations within the reach of river where they spend the majority of their time. Additional data are required to increase our confidence regarding using acoustic telemetry to address spawning related movements.

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1.0 INTRODUCTION

White Sturgeon (*Acipenser transmontanus*) in the Canadian section of the lower Columbia River (LCR), are one of four populations that were listed as endangered under the Species at Risk Act in 2006. The population is undergoing recruitment failure (UCWSRI 2012) and the current level of natural recruitment is considered to be insufficient for maintaining a self-sustaining population. The exact mechanisms resulting in recruitment failure are unknown and as a result White Sturgeon were identified during the Water Use Planning (WUP) process as a priority species for conservation in the Columbia River, and as such a monitoring program was developed to address recovery of the population. It was recognized that in order to make progress towards recovery, baseline data were lacking on the population such as spawning locations used, spawning activity (timing and frequency), and population level metrics like habitat use, movements, growth, and age class distribution.

Identification of spawning locations, and spawning activity, is an important component of recovery as it allows critical spawning habitat to be located, and these areas can either be protected or enhanced as recovery moves forward. Past studies have identified sturgeon spawning sites at two primary locations in the mainstem Columbia, the confluence with the Pend d'Orielle River (Waneta; UCWSRI 2012) and in vicinity of the town of Northport, Washington (Howell and McLellan 2006). From additional work other sites have been located in the Canadian portion of the Columbia River based on egg and larval captures and adult movements. Spawning has been identified at the area immediately downstream of Hugh Keenleyside Dam (HLK) and the Arrow Lakes Generating Station (ALH; rkm 0.1; BC Hydro 2013) and is known to occur in the vicinity of Kinnaird (rkm 13.0 to 19.0; Golder 2009a, 2009b; BC Hydro 2013), though the exact location remains unknown. These results have demonstrated that there are still spawning locations that are undocumented in the Columbia River, and that the continued monitoring is important to describing adult reproductive ecology and to understanding underlying mechanisms resulting in recruitment failure.

In order to more effectively address sturgeon conservation and restoration needs, as well as evaluate population status and effects of management actions, genetic data have become a standard component of many sturgeon recovery programs (Anders et al. 2011). Molecular techniques can be used to answer questions related to White Sturgeon recruitment failure that are otherwise hard to address using conventional methods. Molecular techniques enable biologists to examine aspects of recruitment immediately after spawning (Wirgin et al. 1997; Duong et al. 2011), allowing estimates of spawner-recruitment relationships to be made during early life history stages when data can be interpreted based on stream conditions, which is an important aspect of this monitoring program. One example is spawning population size, which can be estimated based on mark-recapture, tagging, or observational studies. However reliable census data for spawning adults inhabiting large river systems can be labor-intensive and difficult to obtain, especially during spawning. Alternatively, naturally produced eggs and dispersing larvae can be captured by non-invasive methods, such as egg mats and drift nets, which have been used extensively in the LCR (Golder 2009b; BC Hydro 2011a, 2011b).

Data assessing annual spawning is required for recovery planning and includes estimates of successful reproduction, estimates of degree of spatial population structuring and number of adults contributing to natural recruitment. Genetic data obtained from naturally fertilized eggs or dispersing larvae may be used to estimate genetic relationships among adults spawning at different locations to determine whether evidence exists for spatial genetic structure among sub-populations that spawn in different locations. Using a combination of statistical and genetic techniques, it is possible to estimate the number of parents consistent with production of offspring of certain genotypes represented by captured eggs or larvae (Duong 2010). A number of empirical genetic studies of White Sturgeon have been conducted to develop microsatellite loci (Rodzen and May 2002; Drauch et al. 2006; Bork et al. 2008) and have investigated their usefulness for estimating parentage, relatedness and population structure (Rodzen et al. 2004; Drauch et al. 2006, 2008). These estimates will be determined through the use of microsatellite loci and pedigree analysis of eggs and larvae collected in the LCR at spawning locations previously identified (BC Hydro 2011b). These estimates will compliment indices of relative abundance (e.g., catch per unit effort; CPUE), censuses of spawners, or numbers of estimated spawning events based on staged eggs and larvae and will be critical to informing long-term restoration efforts.

Outside of annual monitoring programs, the sole conservation strategy implemented to date for this population has been restoration through releases of hatchery reared juveniles. The objective of this strategy was to initiate a conservation aquaculture program to supplement the population until adequate levels of natural recruitment could be restored (UCSWRI 2012). In 2001, a pilot broodstock acquisition program was developed that resulted in the capture of mature adults that were successfully spawned and contributed to the first supplemental year class released (BC Hydro 2009). Annual broodstock collection has been conducted since 2001 and, in addition to providing mature adults to the hatchery program, has served as sole method of providing information on the biology of the population (e.g., length frequency, growth rates, population estimates). The program has been successful in providing 130 individual adults (58 females and 72 males) that have contributed to juveniles released into the LCR. Individuals have never been used more than once in the duration of the program. The conservation aquaculture program has been successful in releasing 93,500 hatchery reared juvenile sturgeon into the Canadian section of the LCR (as of the spring of 2012).

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

1. Collect mature adult White Sturgeon, up to 10 females and 10 males, to contribute to the annual conservation aquaculture program;
2. Determine White Sturgeon habitat use, movements and identify spawning locations through acoustic telemetry;
3. Describe White Sturgeon spawning locations and the timing and frequency of spawning events through the deployment of egg mats and drift nets; and,

4. Estimate the number of adults contributing to offspring at the egg and larval stages using genetic analyses across the different spawning areas.

More specific objectives are provided in section 1.2.

1.1 Management Hypothesis

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

This monitoring program was designed to provide long term information on adult sturgeon abundance, biological characteristics exhibited under current operation conditions, and reproductive status. In addition, it was designed to include continued baseline data collection on the remaining wild adults, which will be utilized as foundation to evaluate and explore other recovery measures. Specifically, it will provide data on current adult movements and spawning site selection to assess future management responses, and may also be used to refine current and future recruitment failure hypotheses.

It is intended that future monitoring of the LCR adult White Sturgeon population may provide key information to help resolve a number of the following outstanding issues identified by the WUP Fisheries Technical Committee (FTC).

- 1) As the annual average number of spawning events at Waneta Eddy appears small relative to the adult population size and the approximate female reproductive cycle, this adult monitoring program may identify additional spawning sites.
- 2) Changes in movement and spawning behaviour in response to management responses (relative to the baseline established through this monitoring program) may reveal that additional spawning sites (and sub populations) exist in the LCR.
- 3) Baseline information acquired through this monitoring program may verify that the abundance of adult sturgeon in the LCR will not be adversely affected by management response measures.
- 4) Of equal importance to the maintenance of the remaining sturgeon population; are there sufficient adults to continue the conservation culture program?

The overall approach of this monitoring program is intended to be descriptive rather than experimental in nature and, as such, is designed to provide baseline information that can be used in later years of the program to address the programs management question.

1.2 Objectives and Scope

The monitoring program is intended to address a number of uncertainties related to the current status of the population in the LCR, but it will also provide: (i) input to and assist with the ongoing consideration of recruitment failure hypotheses and the evaluation of the effects of future management efforts on spawning success; and (ii) new information to guide adult broodstock acquisition and assist with adjustments to stocking targets related to the conservation aquaculture program.

The objectives for this program will have been met when:

- 1) Adult sturgeon life history characteristics including size, growth, age structure, and condition, and population characteristics including abundance and trajectory, mortality rates, genetic status and reproductive potential are quantified with sufficient consistency to describe annual trends.
- 2) Biological characteristics including spawn monitoring to assess timing and trends, and movements to assess seasonal habitat use and spawning site selection under the current range of operating conditions are adequately defined.

The specific objectives related to the various components of this adult life stage monitoring program are summarized as follows.

1.2.1 *Broodstock Acquisition and Population Characteristics*

1. Provide eight to ten late-vitellogenic female and eight to ten mature males for transport to the Kootenay Sturgeon Hatchery.
2. Collect/update information on adult White Sturgeon age structure, growth rates, and population size.
3. Provide new information to guide future broodstock acquisition and adjustments to stocking targets related to the conservation aquaculture program.

Biological, mark-recapture and related age structure data accumulated through annual broodstock collection and other on-going research programs will be used to:

1. assess population age structure, abundance, mortality rates, and population trajectories;
2. guide future broodstock acquisition efforts and to guard against future sampling bias (i.e., selected locations and variable effort);
3. provide relative abundance and periodic updates to population estimates of the LCR White Sturgeon population; and,
4. periodically compared new length frequency data to archived fin ray age analyses to correct for possible aging underestimates.

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

1.2.2 *Spawn Monitoring*

1. Identify the timing and frequency of annual spawning events at Waneta using egg mats and drift nets to recover spawned White Sturgeon eggs.
2. Provide information on any suspected spawning areas, other than at Waneta.
3. Provide information on trends in the number of discrete spawning events as a measure of population demographics and reproductive potential.
4. Provide a baseline for comparison with monitoring of the effects of future management responses.
5. Use genetic methods on collected White Sturgeon larvae to estimate genetic relationships of natural spawning events.

1.2.3 *Movements*

Movements of new and existing acoustically tagged adult White Sturgeon will be monitored using a passive remote receiver array established throughout in the LCR and, when possible, through mobile tracking to:

1. assist with directing broodstock acquisition efforts;
2. provide new information on suspected staging areas, and other suspected spawning sites throughout the LCR that may be used during varying ranges of flows; and,
3. provide information on seasonal and annual movements, macro-habitat use and transboundary interactions.

1.3 *Study Area and Study Period*

The study area for the 2011 monitoring program consisted of the LCR between HLK Dam and the Canada/U.S. Border (just downstream of the Pend O'rielle River confluence; Figure 1), a 56 km stretch of river. The study area also included a small section (~2.5 km) of the Kootenay River below Brilliant Dam extending to its confluence with the Columbia River. Specific areas of the LCR sampled under the various components of the program (e.g., broodstock, spawning, etc.) are described below.

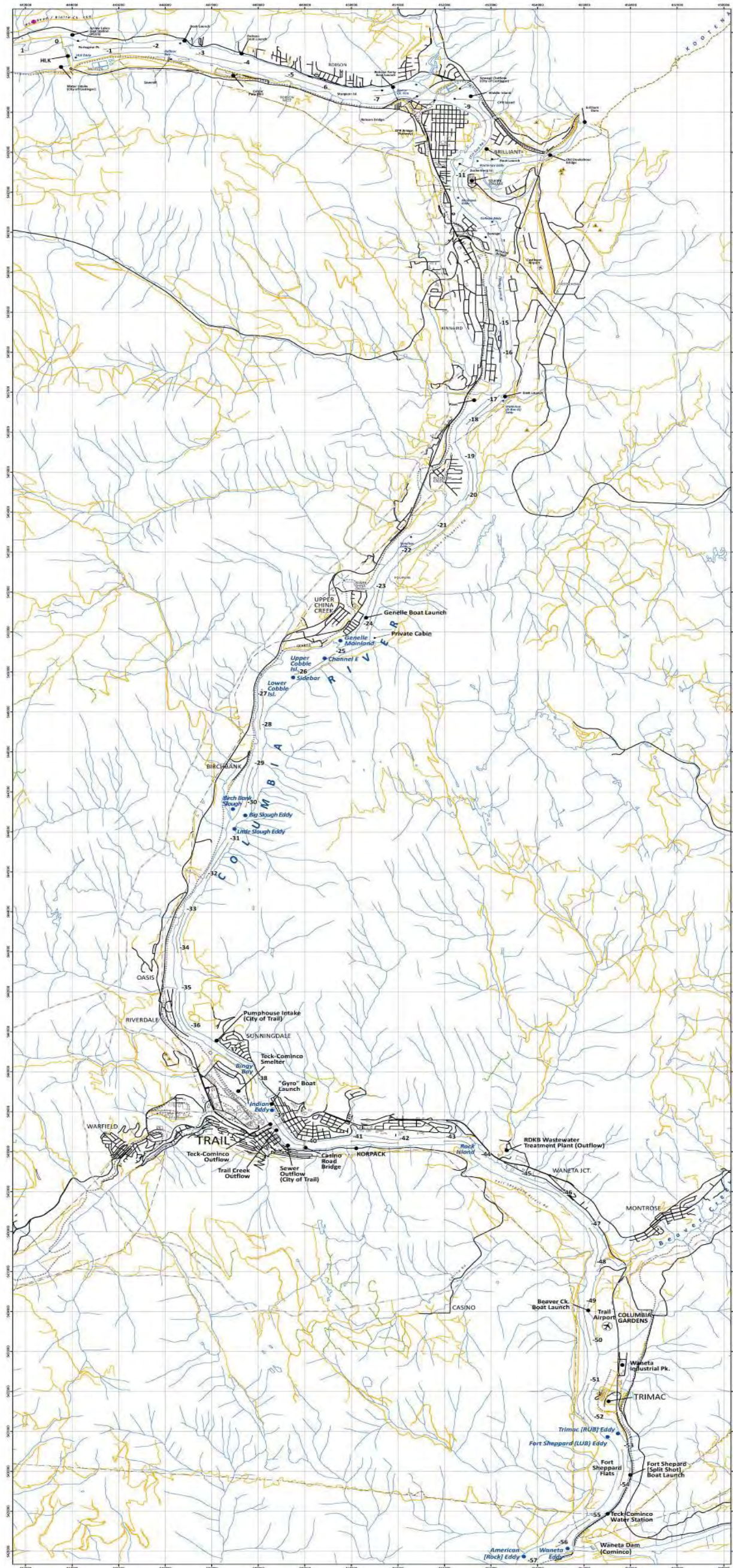


Figure 1. Overview of the study area between Hugh Keenlyside Dam (River Kilometer (rkm) 0) and the Canada/US border (rkm 56.5).

2.0 METHODOLGY

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

2.1 Physical Parameters

2.1.1 Discharge

In 2011, discharge records for the Columbia River at HLK (combined HLK and ALH discharges from Arrow Lakes Reservoir), the Kootenay River downstream of Brilliant Dam, the Columbia River at Birchbank, and the Columbia River at the Canada/United States border were obtained from BC Hydro power records. Discharge data were recorded at one minute intervals and averaged hourly in cubic meters per second (cms), cubic feet per second (cfs), and in thousands of cubic feet per second (kcfs) of passage flow.

Typically, the metric discharge measurement (cms) is used to discuss and present results of volumetric flow rates in technical reports and scientific publications; however, the non-metric discharge measurements of kcfs (typically used to describe flow rates of large magnitude) and cfs are more readily used by water planners and biologists to discuss flows from hydroelectric facilities. As such, all three units of measure (cms, cfs and kcfs) are also presented and referenced within the discussion section of this study report.

2.1.2 Water Temperature

For the 2011 study period, water temperatures were collected at several locations on the Columbia River including Norns Creek, Kootenay Eddy, Birchbank, and Waneta Eddy. Water temperatures were recorded hourly at each location using thermographs (Vemco Miniloggs, accurate to +0.1°C). Long-term water temperature monitoring stations are also maintained at HLK, Genelle, and Rivervale on the mainstem Columbia River and are available as alternatives should a monitoring station be lost or vandalized.

2.2 Adult Capture and Broodstock Acquisition

2.2.1 Study Design

Prior to 2008, previous sampling efforts for adult White Sturgeon in the LCR for broodstock collection (BC Hydro 2007, 2008, 2013), mark recapture and basic life history studies for population estimation (Hildebrand et al. 1999; Irvine et al. 2007) and acoustic tagging (Golder 2002 and 2006b) have focused on areas of known concentrations in order to maximize catch per unit effort given the short-term nature of the projects and budgetary limitations associated with many of the past studies. As this Water Licence Requirements (WLR) study is closely linked

to the other two LCR monitoring programs (CLBMON 29 and CLBMON 30), and as all three projects are considered long term (10 years) it is critical that sampling is designed to address both spatial and temporal factors across all sampling years to maintain consistency with related programs. Furthermore, it has been demonstrated that White Sturgeon in the LCR exhibit high site fidelity (BC Hydro 2011a; Hildebrand et al. 1999; van Poorten and McAdam 2010). Site fidelity further indicates the importance of ensuring that sampling strategies encompass the entire spatial distribution of habitats occurring throughout the entire LCR. Consistency between sampling designs is even more important given the transboundary nature of the population (Hildebrand et al. 1999; Irvine et al. 2007) and allows for direct comparison of results in future years.

In 2009 and 2010, sampling effort was randomly distributed with equal probability within and across each of the zones (BC Hydro 2011a). In 2011, sampling effort was not randomly distributed through the 5 zones, but was spatially balanced throughout the study area based on previous results. To achieve this we sampled lower, middle and upper river locations that were known as potential staging areas for adults in order to efficiently maximize the collection of mature adult White Sturgeon for conservation aquaculture broodstock. A setline stock assessment program to address uncertainties in the current population estimate is planned to begin in 2013 and will be coordinated between Canadian and US partners.

2.2.2 Broodstock Acquisition and Population Characteristics

The requirement for a consistent, well documented approach to adult White Sturgeon collection activities is a necessary component of the Upper Columbia River White Sturgeon Recovery Plan (UCSWRI 2012). The document, entitled “Upper Columbia River Adult White Sturgeon Capture, Transportation and Handling Manual” provides a very detailed and standardized methodology for the capture, transport, and handling of adult White Sturgeon broodstock (Golder 2006a). In 2011, the broodstock acquisition program employed two capture methods. The primary method of capture used to target adult White Sturgeon was set lines (a combination of both long lines and medium lines). Angling was used as a supplemental capture method when scheduling permitted.

Set Lines - Set lines were the primary method used to capture adult White Sturgeon. This method has been shown to provide higher White Sturgeon catch-rates, is less size selective compared to other sampling gear, and rarely captures non-target species (Elliot and Beamesderfer 1990). Set lines have been successfully used in the LCR to capture adult White Sturgeon for the past few decades (Irvine et al. 2007). A medium line configuration was the standard used for set lines, similar to that used by the Oregon Department of Fish and Wildlife (ODFW) and the Washington Department of Fish and Wildlife (WDFW) to capture White Sturgeon in the United States portion of the Columbia River (Nigro et al. 1988). Medium lines measured 54.0 m in length and consisted of a 0.95 cm diameter nylon mainline with 8 to 10 circle halibut hooks attached at 6.0 m intervals. Modified long line configurations for broodstock capture were also used in 2009 and 2010. Long lines measured 182 m in length and consisted of a 0.95 cm diameter nylon mainline with 30 circle halibut hooks attached at 5.6 m intervals. In 2010, long line configurations were occasionally used in large

eddies, and typically only 15 hooks were used and were attached at every second 5.6 m interval. This allowed researchers to access deeper portions of an eddy without having to use an overabundance of shore line. Hooks were attached to the mainline using a 0.95 cm swivel snap and a 0.7 m long ganglion line tied between the swivel and the hook. Halibut hook sizes used were 20/0 only to limit the capture of younger juveniles on the setlines. The barbs on all hooks were removed to reduce the severity of hook-related injuries and to facilitate fish recovery and release. All set line hooks were baited with kokanee (*Oncorhynchus nerka*) obtained from the Meadow Creek Hatchery (Meadow Creek, BC).

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

The set line retrieval procedure involved lifting the back anchor using the float line, until the mainline was retrieved. The boat was then propelled along the mainline and each hook line was removed. If a fish was captured on a hook, the boat was stopped while the fish was removed. White Sturgeon that were removed from the set line were tethered to the side of the boat. The 0.95 diameter tether line from the hook was attached between two anchor points along either the port or starboard side of the boat and allowed the entire body of the fish to remain submerged. Once all fish were removed from the set line, the boat was idled into shore or anchored within a nearby back eddy and White Sturgeon were individually brought aboard for biological assessment (described in section 2.2.3) and processing. All sturgeon were guided into a 2.5 m long by 1.0 m wide stretcher that was raised into the boat using a winch and davit assembly. The stretcher was secured on the boat and fresh river water was continuously pumped over the gills during the processing period. A hood on one end of the stretcher protected the head of the sturgeon from exposure to direct sunlight and also retained a sufficient amount of water allowing the fish to respire during processing. Wet towels were placed over the body of the fish to keep the skin cool and moist. White Sturgeon were returned to the water following processing and remained in the stretcher until they swam away under their own volition.

Catch per unit effort (CPUE) was used to compare numbers of sturgeon caught between sampling zones. CPUE is an expression commonly used to summarize set-line effort and is presented as the total number of fish captured per set line

hour. When overall catch rates are considered too be very low, CPUE is calculated the same way; however, it may be expressed by the mean or total number of fish captured by 100 hook hours of effort. The CPUE value expressed by set line hour is more relative for this study as sampling to date occurred in a more spatially balanced design relative to past studies and the number of hooks per set line was equalized. However, since previous estimates of CPUE for the LCR are presented by both hook hour and 100 hook hours of effort it is important to offer comparable results.

Angling - Angling was considered a supplemental and secondary capture method to set lines and was conducted from a boat (anchored to maintain position) in areas known to support White Sturgeon. Angling equipment consisted of a stiff action rod suitable for sturgeon, a level wind reel spooled with 45 to 58 kg test braided nylon line, a single-shanked barbless stainless steel hook (size 8/0), and a lead weight (510-680 grams) with sufficient mass to hold the baited hook on the bottom of the river. Baits used for angling included kokanee, kokanee marinated in garlic, kokanee marinated in anise, and brook trout marinated in garlic. Angling effort was calculated using hook-hours that were based on one baited hook fished for one hour. If a fish was hooked, all other participating anglers retrieved their lines and the boat either maintained position where anchored or was released from the in-stream anchor system to give chase (in the event that the sturgeon traveled considerable distance from where the fish was originally hooked). White Sturgeon that were successfully landed at the boat had the hook removed once successfully tethered to the side of the boat. Once the boat was securely anchored on shore or within a nearby back eddy, the White Sturgeon was brought aboard (described in section 2.2.3) and was biologically processed. Identical to the release methods following a set line capture, White Sturgeon were returned to the river following processing and remained in the stretcher until they swam away under their own volition.

2.2.3 Fish Handling, Transport, Hatchery Spawning and Release

Once on the boat, White Sturgeon were immediately checked for tags indicating if they had been previously captured and tagged. Recaptured White Sturgeon were identified by either: 1) the presence of a Passive Integrated Transponder (PIT) tag from Biosonics Inc. (400 kHz PIT tags or 134.2 kHz ISO PIT tag), 2) a missing section from the first ray on the left or right pectoral fin (a noticeable mark on White Sturgeon results from the removal of a section of the first pectoral fin ray for ageing purposes; the removal of the fin ray section results in an identifiable mark that persists for several years and can easily be identified by experienced samplers); or 3) the absence of lateral scutes. Unmarked fish were considered to be new captures (i.e., not previously handled by researchers) and had PIT tags injected subdermally in the tissue layer somewhere between the ventral edge of the dorsal fin and the mid-dorsal line, generally on the fishes right side. Prior to insertion, both the tag and the tagging syringe were immersed in an antiseptic solution (Germaphene). Care was taken to angle the syringe needle so the tag was deposited in the subcutaneous layer and not the muscle tissue. Pectoral fin ray section removal has been used on the Columbia River system since 1990 for ageing purposes. Unmarked fish received Oxytetracycline (OTC) injections which are used as a marker on bony structures (i.e., fin rays) for future age-validation studies. OTC was administered at a dosage of 0.2 mL

Liquamycin-LP per kilogram of body weight and was injected either through a surgical incision (Apperson and Anders 1991; R.L. & L. 1996); or administered intramuscularly posterior to the dorsal fin if surgery was not performed on the fish.

White Sturgeon were measured for fork length to the nearest 0.5 cm. Weight was determined by suspending the fish in the stretcher from the winch and davit assembly using a 250 kg capacity spring scale accurate to ± 2.2 kg. External examinations were conducted on each White Sturgeon to identify features such as colouration, deformities (either genetic or mechanical injury related), lesions, cysts, external parasites, and body form anomalies. All life history data were recorded in the field on standardized data forms and later entered into an electronic database.

The majority of adult White Sturgeon (>1.5 m fork length) were surgically examined to assess sexual maturity. This included fish that were new captures, candidates for acoustic tagging, or mature candidates for the aquaculture program. A 1.5 to 2.0 cm long incision was made through the ventral body wall just off the mid-line using a sterile scalpel. Maturity stages for both males and females were assessed according using an otoscope and classified based on qualitative histology (Bruch et al. 2001; Golder 2006a). Female developmental stages are usually more easily determined since ovary size, colour, average egg diameter, and egg colour can be used as indicators of maturity stage. Immature gonads or those in early stages of maturation are smaller and more difficult to find (especially in males). Following examination, the incision was closed using a half circle CP-2 reverse cutting-edge needle wedged to a 2-0 Polydioxanone violet monofilament suture (PDS). Sutures were spaced approximately 1 cm apart and sufficient slack (approximately 2.0 to 4.0 mm) was provided in the sutures to prevent tissue damage caused by swelling during the healing process.

For acoustic telemetry candidates, we used acoustic tags (Vemco, model V16) with a delay time of 60 to 180 seconds (120 sec. nominal delay). The life of these tags is estimated to be up to 10 years which will allow movements to be monitored across all years of the study period.

Finally, lateral scutes were removed using a sterilized scalpel in a manner consistent with the marking strategy employed by WDFW and ODFW. The 2nd right lateral scute was removed from new or recaptured sturgeon that received OTC injections. The 2nd left lateral scute was removed from new or recaptured sturgeon that did not receive OTC injections.

In 2011, all fish transportation efforts from the LCR to the Kootenay Sturgeon Hatchery in Wardner, B.C. were conducted by Freshwater Fisheries Society of BC (FFSBC) staff. White Sturgeon identified as being suitable for fish culture purposes were transferred from the capture boat directly into a 1.5 m deep aluminum holding tank (mounted on a 4.8 m flat deck trailer) filled with ambient river water. The transport trailer was equipped with oxygen tanks and diffusers to maintain appropriate levels of oxygenation (90-100%; Golder 2002). Rock salt was added to the water prior to and during transport in an effort to prevent osmotic stress (FFSBC 2010), to sterilize and aid with any

bacterial and/or fungal infections, and to treat any minor injuries (i.e., hook wounds and surficial rope abrasions) sustained during capture.

All of the adult sturgeon transported to the Kootenay Sturgeon Hatchery (KSH) were held in large (3.7 m in diameter) circular holding ponds with water temperatures regulated as close as possible to matching that of the Columbia River. Salt treatments (5-10 ppt) were applied to aid in the stress and minor injury healing process. Fluid samples (ovarian fluid and milt) were extracted from all contributing adults and were screened for virus and standard fish health culture purposes. Females were checked regularly (egg biopsies) to determine ripeness and to predict when they would be ready to be induced to spawn using standard fish culture hormone injections. Details regarding hatchery spawning of adults are provided in the FFSBC's annual reports (FFSBC 2010 and 2011).

Once spawned, each adult was implanted with an acoustic transmitter (Vemco, model V16) and held at the Kootenay Sturgeon Hatchery for a short recovery and observational period. Adults were then transported back to the Columbia River for release near their capture location.

2.2.4 Adult Genetics

Though no genetic analyses using adult samples were planned in 2011, tissue samples were collected for future genetic analysis from all adult White Sturgeon collected. A small piece of tissue (approximately 1.5 cm x 1.5 cm) from the tip of the dorsal fin was removed using surgical scissors, and archived in labelled scale envelopes. The individual DNA samples were then split into two sub samples and preserved in 95% denatured ethanol.

2.3 Spawn Monitoring

2.3.1 Study Design

Monitoring of sturgeon spawning was carried out at several sites for this program, and was based on previous data collection where sturgeon have been confirmed to have spawned, or have been suspected to spawn.

Monitoring of spawning activity occurred at Waneta, which is located where the Pend d'Orielle River enters the Columbia River near the US border. This site has been monitored for spawning activity since 1993 and is the main area of sturgeon spawning within the LCR in Canada (Hildebrand et al. 1999; Irvine et al. 2007; Golder 2009a). The Waneta spawning area was again sampled in 2011 and both egg mat and drift net sites remained consistent with previously established locations. These sampling sites have been described in detail in other reports (Golder 2009b)

Secondary sites for spawn monitoring were also located in the upper river in 2011. Drift nets and egg mats were deployed at HLK/ALH (rkm 0.1), while only drift nets were deployed downstream of Kinnaird (rkm 13.5 and 18.2), and in the Kootenay River (Figure 2).

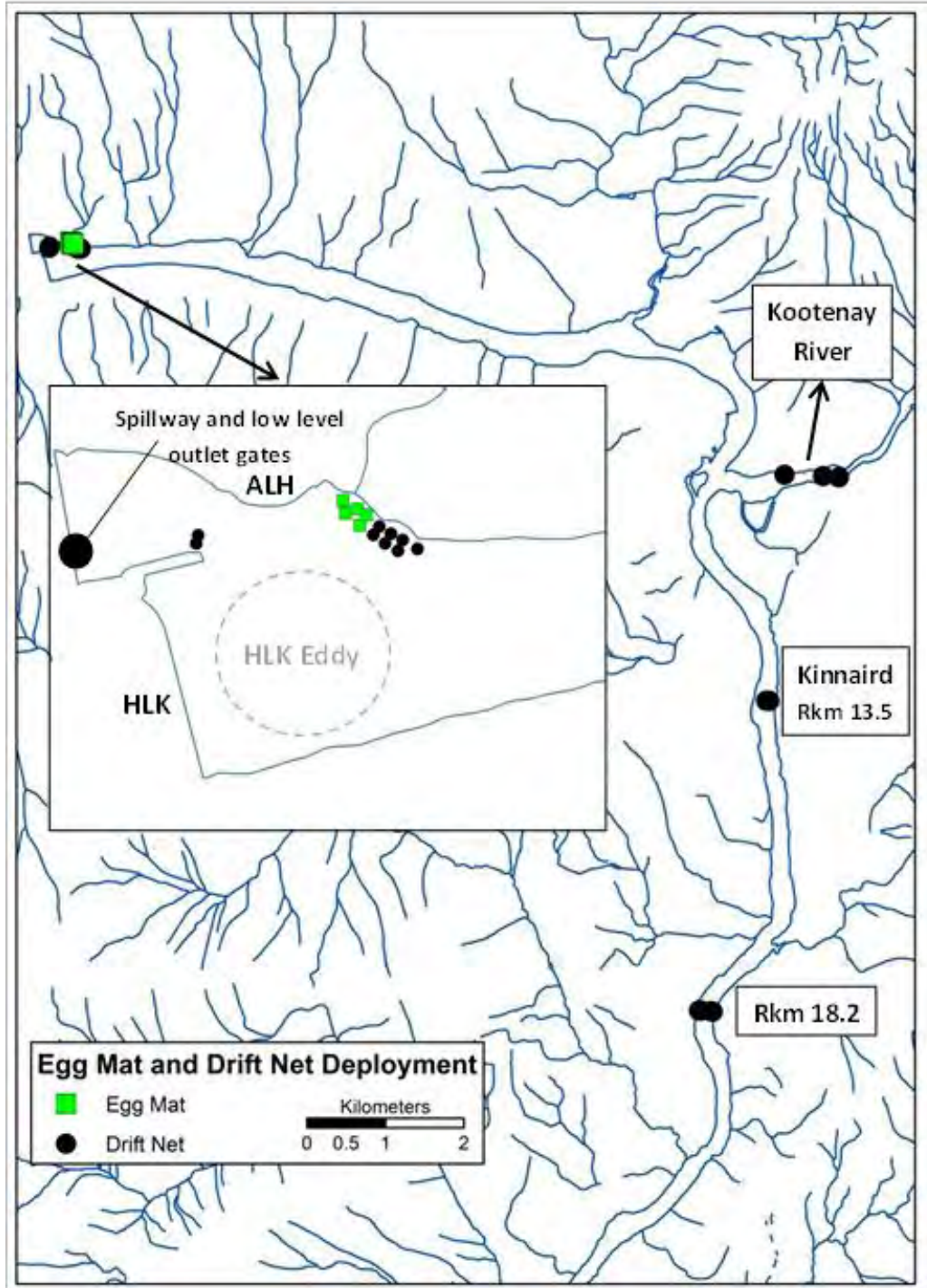


Figure 2. Egg mat and drift net deployment sites in the lower Columbia River in 2011.

2.3.2 Egg Collection Mats and Drift Net Sampling

Egg Collection Mats - White Sturgeon are broadcast spawners which allows for the collection of eggs using passive sampling techniques. Egg collection mats are a proven method of collecting White Sturgeon eggs (McCabe and Beckman 1990; McCabe and Tracey 1993). Studies conducted in the Waneta area of the Columbia River since 1993 have proven that egg collection mats are effective at collecting White Sturgeon eggs (Golder 2002, 2010). Mats consisted of a 0.76 by 0.91 m steel frame with latex coated animal hair filter material fastened to frame. Egg mats were deployed on the river substrate and collect drifting or deposited eggs that became entrapped in the filter material.

The type of equipment deployed and the procedure for deployment and retrieval in the Waneta area mimicked past monitoring protocols (i.e., paired egg collection mats retrieved from the river bottom and inspected in metal trays filled with river water; Golder 2009a). The type of equipment used to deploy egg mats in other locations of the LCR deviated from the proven methods used in the Waneta area and were very similar to the methods used for deployment and retrieval of drift nets. A lead steel claw river anchor (30 kgs) was used to hold the entire system to the river floor. Approximately 6 m of 3/8 galvanized chain is attached to the main anchor and is followed by a secondary steel anchor (also 30 kg) to ensure the anchor remained flat on the river bottom. Two 30 m sections of 0.95 cm diameter 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 egg mat. We attached an additional rope from the back of the egg mat to a surface buoy to facilitate deployment and retrieval. Alternatively, a single egg mat (containing a 10 kg lead anchor fastened to a leading bridal) with a rope from the back of the egg mat to a surface buoy to facilitate deployment and retrieval was deployed in areas of the river where flows allowed. When retrieving the egg mat, the buoy attached directly to the back of the egg mat would be picked up from the boat and the mat would be brought to the surface. Once at the surface, the egg mat would be detached from the anchor system and brought into the boat for inspection and analysis. Both sides of the egg mats were inspected thoroughly by a minimum of 2 crew members before being reattached to the anchor system and redeployed. The buoy attached directly to the back of the egg mat allowed the retrieval of the net without dislodging the anchoring setup and ensured that sampling sites were consistent across the sampling program.

Upon detection of a spawning event through the collection of either eggs, a proportion (20%) of the samples collected were preserved so that the timing of individual spawning events could be estimated (based on egg developmental stage estimated in the field) and the predicted timing of hatch could be calculated (see section 2.3.3 and 2.3.4 for detailed procedure).

Drift Net Sampling - Drift net sampling has been used successfully to capture both fertilized eggs and passively dispersing free embryos for many sturgeon species including White Sturgeon in the LCR (Golder 2009a), Lake Sturgeon (*Acipenser fulvescens*; Auer and Baker 2002), and Shortnose Sturgeon

(*Acipenser brevirostrum*; Moser et al. 2000). Drift nets are deployed on the bottom of the river and are designed to passively capture sturgeon larvae (a primary objective of the CLBMON 29 Lower Columbia River Juvenile White Sturgeon Detection Program) dispersing downstream from spawning areas. Drift net sampling has been added as a supplemental component to the adult spawn monitoring program in recent years and has proven successful at documenting spawning events and egg dispersal patterns through the collection of eggs and larvae.

Drift nets used in this program consisted of a 1.3 cm rolled stainless steel frame (D shape) with a 0.6 m x 0.8 m opening that is trailed by a 4 m tapered plankton net (0.16 cm delta mesh size) with a collection cup device. Deployment and anchor system specifications were consistent between sampling locations in the LCR are described as follows. A lead steel claw river anchor (30 kg) was used to hold the entire system to the river bottom. Approximately 6 m of 3/8 galvanized chain was attached to the main anchor and was followed by a secondary steel anchor (14 -30 kg depending on site river velocities) to ensure the anchor remained flat on the river bottom. Two 30 m sections of 0.95 cm diameter 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 frame on the drift net to a surface buoy for both 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.

Typically, drift nets were deployed and retrieved from the bow of the boat using an electronic winch. 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 sampling sites were consistent across the sampling program. 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 eggs or larvae. Numbers of sturgeon eggs and larvae were enumerated by net for each sampling occasion. A proportion (20%) of the larvae collected were preserved so that estimates could be developed for the time of hatch and the time egg fertilization occurred (see section 2.3.4). We also recorded deployment and retrieval times, water temperatures and depths at each net location.

2.3.3 Egg and Larvae Preservation and Staging

As part of the Waneta Spawn Monitoring Program completed by in 2011, a random sample (1 in 5) of the total number of eggs and larvae captured were preserved in a Prefer solution (a buffered glyoxal/ethanol preservative) for developmental staging. At all other sites sampled in the upper river in 2011, all eggs and larvae captured were preserved in a Prefer solution for developmental staging.

Following field collection activities, all preserved eggs and larvae were then inspected using a stereo microscope (Nikon, model: SMZ745T) to assess egg developmental stages and aid in the back calculation process that allows one to predict the time and number of potentially different spawning events based on published rates of White Sturgeon egg development (Beer 1981; Wang et al. 1985).

Once a spawning event was estimated, a range of time in which each spawning event likely occurred was assigned based on the developmental stages of the eggs associated with timing of that specific event. The accuracy of egg developmental staging as a method to delineate spawning events and estimate time of spawning can be affected by individual White Sturgeon spawning behaviour, egg maturation rates, and more importantly the fluctuation in daily thermal regimes (Parsley et al. 2010).

Preservation, staging and genetic analysis (see section 2.4.2) was also done for all eggs and larvae that were collected at other sites (ALH and rkm 18.2) in 2011.

2.4 In Situ Egg Incubation

2.4.1 Egg Incubation

In 2011, the remaining 80% White Sturgeon eggs captured on egg mats from the Waneta spawning area were incubated *in situ* in egg incubation trays to obtain tissue for future genetic analysis (as a means to determine parental contributions to the eggs captured) but also to provide a general assessment of egg incubation success at Waneta. Eggs collected at ALH were all incubated *in situ*.

Based on previous study results in the Waneta area, incubation trays have been effective in incubating eggs to hatch (Golder 2010). The incubation trays consisted of an 18 cm long by 9 cm wide piece of 6 mm thick plexiglass middle sheet with 50 perforations (6 mm wide) distributed in a rectangular grid pattern. Two 3 mm thick sheets of similarly sized and perforated plexiglass, with 1 mm plastic screen glued to one side, were placed on either side of the middle sheet to seal the eggs within the incubator. Only collected eggs that were assessed to be developing were placed in incubation trays. To load the incubation trays with eggs, the bottom and middle plates of the incubator were placed in a shallow tray of fresh river water and a single White Sturgeon egg was placed in each of the 50 perforations. The top sheet was then placed over the other two sheets and the entire unit was sealed by bolting all three sheets together. The incubation trays were returned to the river near the capture site and incubated *in situ* until hatch.

The incubation trays were generally deployed in incubation groups consisting of one or two crab bait cages (one incubator per cage) attached to a weighted 25 m length of mainline (the incubation array) and originally set at 3.6 m depth. Concrete anchors at each end of the mainline were used to maintain position on the river bottom. The upstream end of the array was tethered to shore. A buoy attached to the downstream anchor served as a backup method of retrieval in case the shoreline tether failed. To reduce sediment accumulation within the incubators, they were suspended in the water column by attaching the bait cages (containing the incubators) to a loop on a 0.5 m tether equipped with a small

float. For additional ballast and stabilization, the end of the tether was attached to metal weight which was in turn attached to the mainline with a carabineer. The incubation groups on the array were left undisturbed until a sufficient amount of time had elapsed for the eggs to hatch. Incubation tray retrieval timing was determined based on the approximate developmental stage of the eggs at capture and the rates of embryonic development provided in the literature (Beer 1981; Wang et al. 1985) and water temperatures at the spawning area. The larvae from eggs that successfully hatched were preserved in 99% anhydrous ethanol and were archived for future genetic analysis (see section 2.4.2).

2.4.2 Larval Genetics

A subsample of larvae was selected to be genotyped. In order of capture date, every other larval sample for Waneta (50%; n=232) and every 4th larval sample for ALH (25%; n=104) were selected for DNA extraction and genotyping. The percentage subsampled was determined by estimating the number of spawning events that occurred at each location. This was done by estimating the time of fertilization through back calculation based on time of capture, water temperature, and developmental stage of the collected egg/larvae. A larger subsample of Waneta was genotyped compared to ALH since there was a higher estimated number of spawning events and therefore potentially more adults contributing to recruitment. Due to low numbers of samples collected, all larvae collected at rkm 18.2 were genotyped.

DNA was extracted from larval tissue samples using QIAGEN DNeasy® kits (QIAGEN Inc.) according to manufacturers' protocols. DNA was quantified using a Nanodrop spectrophotometer and all samples will be diluted to a constant concentration (20ng/μl) for use in Polymerase Chain Reactions (PCR). Individuals were genotyped using 12 microsatellite loci AciG35 (Bork et al. 2008), AciG2, AciG53, AciG140, Atr105 (Drauch and May 2007), Atr107, Atr109, Atr117, Atr1101, Atr1173, Atr100 and Atr113 (Rodzen and May 2002, Drauch and May 2007). PCR reactions were conducted to amplify 100ng DNA in 25μl reaction mixtures containing 10X PCR Buffer (1M Tris-HCl, 1M MgCl₂, 1M KCl, 10% gelatin, 10% NP-40, 10% Triton-X), 2mM of each dNTP, 10pmol of forward and reverse primer and 0.5μl Taq DNA polymerase (5U/μl). PCR conditions followed protocols determined for each individual locus. PCR products were run on 6% denaturing polyacrylamide gels and genotypes will be visualized using a Hitachi FMBI0II scanner. Allele sizes were determined using commercially available size standards (MapMarker™, BioVentures Inc.) and based on several standard samples of known genotype. Due to the polyploidy nature of the White Sturgeon genome, microsatellite alleles were treated as dominant data by scoring each allele as either present or absent within individuals (Rodzen and May 2002; Hardy 2003). To minimize error, all genotypes were independently scored by two experienced lab technicians and verified again after data were entered into electronic databases. As an additional measure of quality control and assurance of accurate scoring, ~10% of all individuals were randomly selected and reanalyzed.

Likelihood methods were used to partition offspring in each sample into sibling clusters using microsatellite data without parental information. Analyses were implemented in program COLONY 2.0 using algorithms allowing for polygamous

mating by both males and females (Wang and Santure 2009). This approach can determine that an un-sampled adult contributed to a group of offspring produced during the same reproductive event based on inferred pedigree relationships among the larvae from the same and different inferred full- and half-sibling pedigree. In 2011, likelihood methods were used to estimate the number of contributing adults at ALH, site 18.2, and Waneta.

2.5 Population Monitoring and Abundance

White Sturgeon life history information, population characteristics and mark-recapture related information were accumulated primarily through the annual broodstock collection program of each year and through adult sampling conducted under CLBMON 30 (BC Hydro 2011a).

Biological data collected from adult sturgeon sampled in 2011 are analyzed in this report for characteristics such as length frequency, length-weight relationship, sex ratio, and seasonal timing of spawning. In future years, mark-recapture data will be used to estimate population abundance and mortality rate. Catch records are analyzed across all years of broodstock collection in an effort to provide recommendations to annual conservation aquaculture breeding plans and to maximize the genetic diversity available for culture practices.

2.6 Acoustic Tagging and Telemetry

As biological characteristics of the White Sturgeon population in the LCR including spawn timing and trends, and movements to seasonal habitat use and spawning site selection are poorly understood under the current range of operating conditions, the tagging and tracking of fish is required.

Vemco model V16 acoustic tags (operational life of 10 years) have been allocated to adult White Sturgeon predicted to spawn within the next 2-3 years (based on sex maturity examinations) in 2008, 2009, and 2010 (BC Hydro 2011a, 2013) in addition to broodstock sturgeon used for aquaculture. In 2011, acoustic transmitters were implanted in 21 adult sturgeon that were used as broodstock at the KSH. These fish received an acoustic transmitter prior to their post spawning release to their original capture location in the LCR.

2.6.1 Acoustic Receiver Array

We used an array of fixed station remote receivers (Vemco, model VR2 and VR2W) already deployed within the LCR as the primary method of detecting spatial and temporal movements of tagged White Sturgeon.

The spatial extent of the array encompassed the LCR from HLK Dam Lake southward to the Canada/U.S. International Border has not changed since being initially deployed in 2003 and remained constant until 2009. In early May of 2010, the array was repositioned to 3 km intervals starting at HLK and moving downstream to the international border. This was done to improve spatial coverage throughout the study range (as indicated through increased detectability of individual fish exhibiting site fidelity). We also increased the

spatial coverage of the array by adding receivers in areas that were previously not covered, improving our ability to detect movements on a finer spatial scale.

The receivers were deployed approximately 3 m below the water surface on a weighted mainline consisting of either 0.95 cm diameter nylon or 0.64 cm stainless steel cable. A large pyramid shaped concrete reinforced anchor (55-80 kg; varied depending on receiver station location within the river channel) was attached at one end of the mainline and highly buoyant low drag float (Model LD-2 or LD-3) was attached to the opposite end to the anchor. The receiver was fastened to the mainline (using cable ties) with the hydrophone orientated towards the river bottom. Stations were checked for wear and tear (cable ties, rope, float, sufficient extra float line to accommodate fluctuating water levels, remaining battery life) during each download and repair/replacement was conducted as necessary.

Raw data from the receivers were downloaded using the latest versions of Vemco User Environment (VUE) software (version 1.8) which was installed on a weather resistant laptop computer. Due to the volume of data collected, telemetry station downloads were split into separate VUE databases for each year of the study and the data was then exported into a separate database (Microsoft Access) for further analyses (see section 2.6.2).

2.6.2 Telemetry Data Analysis

Raw detection data recorded on receivers were uploaded frequently (>4 times/year) into a telemetry database and software (Vemco, VUE) for management and long term storage. Although the acoustic array was originally intended to track the movements of White Sturgeon, multiple research projects involving other fish species are ongoing in the LCR, and as such, user agreements with other agencies and researchers have been developed for the utilization of this telemetry array. For White Sturgeon projects and all other projects combined we often recorded more than 4 million detections annually. Over a period of the last several years, this has resulted in a larger amount of data than anticipated and has resulted in issues regarding tag collisions which have increased the total number of “false” detections occurring in the database. False detections were detections in the database that were not linked to an active transmitter, or that were the same ID as an active transmitter but does not align with movement data for that fish. They can be generated by echoing due to the system (bathymetric profile, lots of rock, narrow river) or due to tag collisions when multiple tags ping at once. Finally, our ability to upload, store, and analyze raw data collected from the multitude of acoustic receivers has become more labour intensive with the large numbers of active acoustic transmitters at large (>400) in the Columbia River between HLK Dam in Canada and Grand Coulee Dam in WA.

We developed a telemetry database using a Client-Server model in Microsoft Access to help address data requirements related to examining White Sturgeon movements, to assist with identifying “false” detections, and to filter out unwanted/unnecessary tag data (e.g., non sturgeon species). The database was designed as a filtering tool that allows the organization and summary of data in a manner that results in outputs suitable for analyses. Queries were generated

for each individual sturgeon tag that automatically generated a spreadsheet file containing the total number of times each tag was detected, each day, at a particular station or river kilometer. Data were binned in 24 hour periods as site fidelity is known to be high in this system and hourly observations of movement proved to be to fine scale for this species. The detection record was examined for each individual and in cases where there were false detections, these detections were removed.

A main objective of this program is to identify spawning related movements to help identify alternate spawning locations used in the system. We defined spawning movements in this study as rapid movements from one area during the spawning window, a residence period in an area for a short period of time, and then a migration to another location where residency time is long. In past years, fish appearing to make spawning related movements tended to return to their original location following time spent on the presumed spawning area. Further, other fish movements (timing and locations) that aligned with that individual were examined to provide additional support when identifying a possible spawning area.

Once the data were screened and all false detections removed, we summarized the 2008 through 2011 detection data and evaluated general movement patterns throughout each year and across years both by individuals and by sex. Proportional habitat use throughout the river was examined for all adults and then at the level of sex. We determined movements (spawning related and otherwise) on an individual basis and examined habitat use based on the proportion of detections of tagged White Sturgeon at each receiver location. Movements (distance travelled, km) between receiver stations were calculated by taking the difference in river kilometers between successive detections. The amount of distance travelled by month was calculated separately by sex, to help determine if either sex made movements to staging areas prior to spawning. We calculated the proportion of time an individual spent at a single location by dividing the number of detections per station by the total number of detections for that individual. This was conducted by monthly and by year for both sexes. Residence time, or site fidelity, was expressed by sex as the maximum amount of time spent at a single location over the study period.

3.0 MONITORING RESULTS

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

3.1 Physical Parameters

3.1.1 Discharge

Mean daily discharge measured from Arrow Reservoir (combined flows from HLK and the ALH facility), the Kootenay River (combined discharge from Brilliant Dam (BRD) and the Brilliant Expansion (BRX) facility), at the Columbia River at Birchbank (combined Arrow Reservoir and Kootenay River discharge at rkm 29), and at the Columbia River at the Canada/U.S. International Border (combined discharge from Birchbank and the Pend'Oreille River) for the 2011 study period are presented in Figure 3.

The White Sturgeon spawning period is generally estimated to occur between May 01 - July 31, annually, and is based on a number of factors including egg and larval collections, historical river temperatures, and the timing peak freshet flows. For 2011, mean daily discharge measured from Arrow Reservoir, the Kootenay River, at Birchbank, and at the Canada/U.S. International Border on the Columbia River during the predicted spawning period is summarized in Table 1. Peak freshet flows were reached on June 14 in 2011. Considerable variation in hourly mean discharge occurred within the predicted spawning period.

Table 1. Mean and maximum flow (in cubic meters per second; cms) at four locations on the Columbia River during the projected White Sturgeon spawning period in 2009, 2010, and 2011.

Location (Year)	Mean Minimum Flow	Mean Maximum Flow
Arrow Reservoir (2009)	527.9 cms (18642.2 cfs)	1519.7 cms (53668.0 cfs),
Arrow Reservoir (2010)	550.4 cms (19437.0 cfs)	1482.2 cms (52343.4 cfs)
Arrow Reservoir (2011)	897.3 cms (31689.0 cfs)	1813.5 cms (64043.9 cfs)
Kootenay River (2009)	526.6 cms (18595.6 cfs)	1960.2 cms (69222.6 cfs)
Kootenay River (2010)	520.8 cms (18392.1 cfs)	2112.4 cms (74599.1 cfs)
Kootenay River (2011)	806.5 cms (28482.1 cfs)	2906.3 cms (102636.7 cfs)
Birchbank (2009)	1176.9 cms (41562.2 cfs)	2727.9 cms (96334.6 cfs)
Birchbank (2010)	1227.5 cms (43349.6 cfs)	2360.7 cms (97493.6 cfs)
Birchbank (2011)	1550.5 cms 54755.3478	4155.4 cms (46746.2 cfs)
Border (2009)	1969.2 cms (69542.2 cfs)	4925.7 cms (173947.9 cfs),
Border (2010)	1287.7 cms (45473.9 cfs)	5132.3 cms (181244.8 cfs)
Border (2011)	2687.2 cms (94900 cfs)	7560.5 cms (267000 cfs)

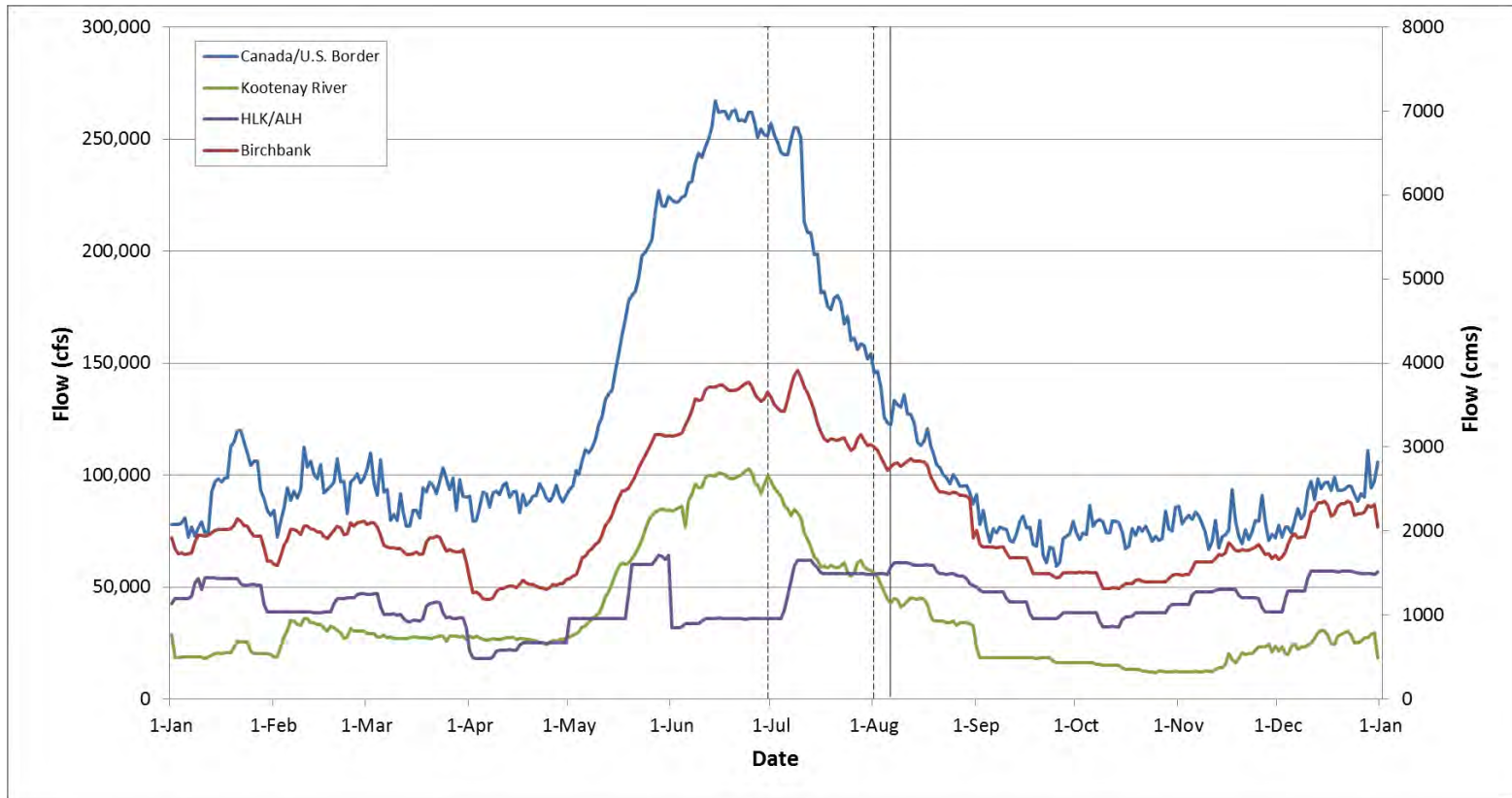


Figure 3. Mean daily discharge measured from Arrow Reservoir, the Kootenay River, at Birchbank, and at the Canada/U.S. International Border on the Columbia River from January 01, 2011 – December 31, 2011. The solid vertical bars represent the first and last estimated spawning dates at Waneta Eddy in 2011, either based on the collection of fertilized eggs or larvae. Vertical dashed bars represent the first and last estimated spawning date in the upper portion of the Columbia River (at or above rkm 18.2).

3.1.2 Water Temperature

In 2011, daily average water temperature at the Norns Creek, Kootenay Eddy, Birchbank, and Waneta Eddy ranged from 2.1 °C to 18.2 °C, 2.3 °C to 18.3 °C, 2.4 °C to 17.7 °C, and 1.1 °C to 18.4 °C, respectively. River temperatures reached the suspected spawning threshold of 14 °C at Norns Creek on July 4, 2011 and the remainder of the sampling locations by July 17 (Figure 4). Variations in water temperatures experienced during the study period can be attributed to warm/cold water influences caused in the Arrow Reservoir system (i.e., combined HLK and ALH discharges from Arrow Lakes Reservoir), and other coldwater tributary influences.

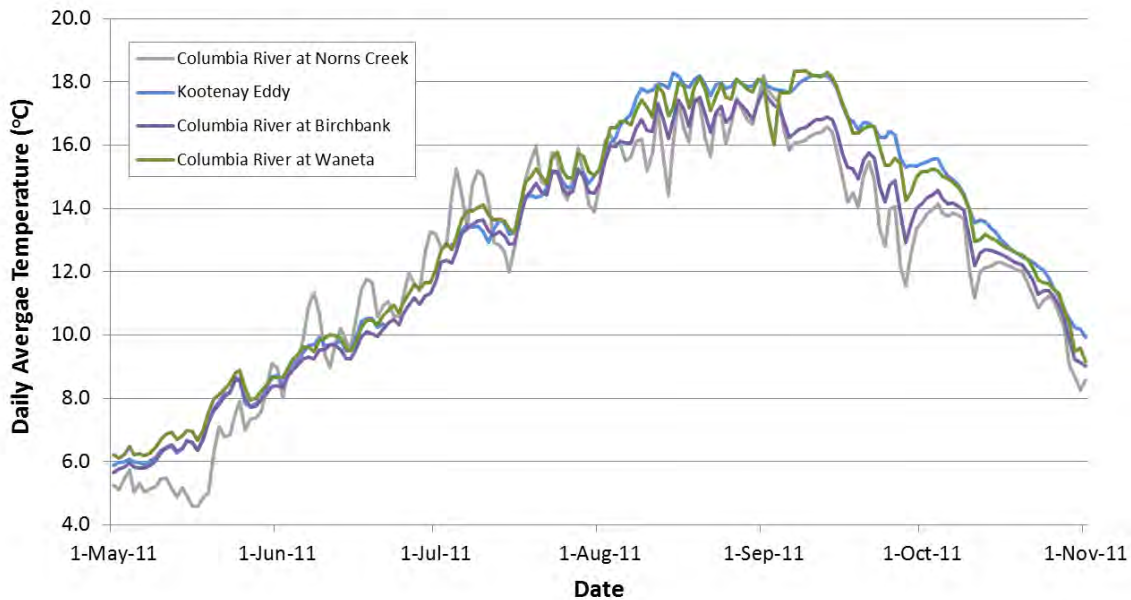


Figure 4. Mean daily water temperature (°C) recorded at four different locations within the lower Columbia River from May 01 until November 01, 2011. Locations are presented from most upstream (Columbia River at Norns Creek) to most downstream (Waneta).

3.2 Adult Capture and Broodstock Acquisition

3.2.1 Broodstock Acquisition and Population Characteristics

Set Lines - In 2011, a total of 162 White Sturgeon were captured in 1768 hours of set line effort expended over 16 field days during the broodstock acquisition program (June 5-28). Only a single fish was caught twice during the program. Mean CPUE, as expressed as the number of fish captured per set line hour and incorporating all sampling zones, was 0.09.

Angling - In 2011, a total of 13.5 hook-hours of angling effort were expended over the 16 day broodstock sampling period; resulting in the capture of 40 White Sturgeon (CPUE 2.96 fish/hook-hour). Of these, 55% (n=22) of the fish were captured in Fort Shepherd Eddy (rkm 52.3). Angling resulted in moderate rates

of capture for adults (n=16; 40%) with the remainder of the catch being represented by hatchery released juveniles from 2001-2005 brood years. One of the 16 adult fish captured during the angling component of this program was a suitable hatchery candidate. Finally, four individual sturgeon caught angling were also captured on setlines during the program.

3.2.2 Fish Handling, Transport, Hatchery Spawning and Release

During the 2011 White Sturgeon broodstock acquisition program, 202 White Sturgeon (5 were recaptured during the study) were captured and assessed for marks that would indicate previous capture (presence of a tag, evidence of removal of a lateral scute, or removal of a section of a pectoral fin ray). Of the 197 White Sturgeon captured, 21 (males n=11; females n=10) were transported to the Kootenay Trout Hatchery (for possible contribution to the aquaculture program) and the remaining 176 were assessed for maturity, had biological information recorded, and were released at their capture locations. All White Sturgeon captured in this program were released alive. Of these fish, a total of 56 fish (27.8%) were first time captures (hatchery released juveniles are considered recaptures). Of the 56 first time captured fish, 49 were processed and released and 7 were determined to be sexually mature adults suitable for potential contribution to the conservation aquaculture program (1 male and 6 females), and were transported to the Kootenay Trout Hatchery.

In 2011, of the 21 White Sturgeon (11 males, 10 females) were transported to Kootenay Trout Hatchery in Ft. Steele, B.C. for use as potential broodstock, eight males and six females were spawned successfully, contributing to six (FFSBC 2012).

From 2001 to 2011, the proportion of adults broodstock captured and used for conservation aquaculture from different sections of the LCR has been dominated by the lower section near Waneta eddy (70%) and the upper section near HLK (18%; Table 2). The length frequency distribution of all mature adult White Sturgeon used for the conservation aquaculture program from 2001-2011 shows that females are on average larger than males (see Figure 5).

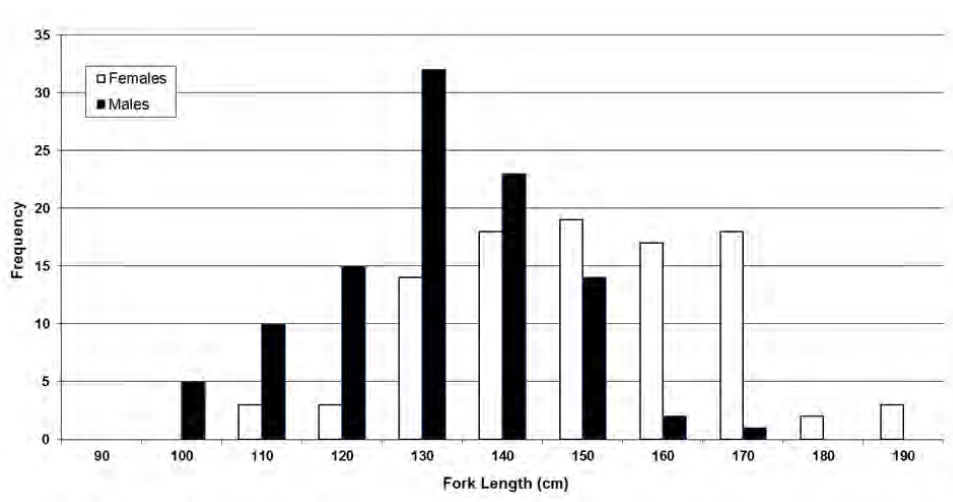


Figure 5. Length-frequency of mature male and female White Sturgeon captured in the lower Columbia River Canada and used in the conservation aquaculture program, 2001 to 2011.

Table 2. The proportion of adult White Sturgeon broodstock selected from different sections of the lower Columbia River for use in the conservation aquaculture program from 2001-2011.

Reach	Proportion
HLK* to Norns	0.18
Kootenay Eddy	0.09
Kinnaird to Trail	0.04
Trail to Border	0.70

*Hugh Keenlyside Dam

3.2.3 Adult Genetics

During the early years of the program, tissue samples are being preserved for genetic analyses in later years. This includes fin clips from adults and juveniles as well as subsamples of eggs (incubated to hatch) and larvae collected each year. Using these genetic samples to provide insight into adult breeding dynamics of the population, including estimates of variance in reproductive success, which can be used to guide aquaculture programs. Genetic data obtained from fertilized naturally produced eggs or dispersing larvae may be used to estimate genetic relationships among adults spawning at different locations to determine whether evidence exists for spatial genetic structure among sub-populations that spawn in different locations. Evidence for reproductive isolation among adults spawning in different locations would indicate spawning site fidelity at a fine spatial scale and could indicate that management of different sub-populations which occupy different areas of the river is warranted. No results exist to date as the tissue samples for all years have been archived.

3.3 Spawn Monitoring

3.3.1 Egg Collection Mats and Drift Net Sampling

Waneta Area - A total of seven egg mat stations (two mats per station; all seven tied to shore) were repeated in the Waneta spawning area in 2011 to facilitate comparisons with previous studies. These stations have been consistently sampled since 2000 (R.L. & L. 2001; Golder 2002, 2003, 2004, 2005, 2006c, 2007, 2009b), and general monitoring has occurred in this area since 1993 (Tables 3 and 4). High flows in 2011 reduced the number of suitable locations within the Waneta spawning area where a drift net could safely be deployed and retrieved. Based on hydraulic conditions of the study area, only one site was deemed suitable for deployment of a drift net.

Sampling in 2011 occurred over a period of 61 field days commencing on June 13 and ending on August 12. In total, 2,318 eggs and 9 free embryos were captured during 19,882 mat-hours of egg mat sampling; and an additional 234 eggs and 16 larvae were captured during 49.8 hours of drift net sampling (Table 4).

In the majority of sampling years, spawning has occurred primarily during the descending limb of the Pend d'Oreille River hydrograph and commenced after mean daily water temperatures in that system exceeded 14 °C. In 2011, an estimated 8 discrete spawning events occurred between June 30 and August 01. All occurred at water temperatures above 14 °C, and 7 of 8 on the descending limb of the Pend d'Oreille hydrograph (Table 5; Golder 2012).

Table 3. The number of White Sturgeon eggs and larvae collected annually at the Waneta spawning area on the lower Columbia River, 1993-2007.

Year	Eggs	Larvae
1993 (Low effort)	61	4
1994 (Low Effort)	33	0
1995	762	4
1996	1680	13
1998	1621	2
2000	474	1
2001	620	1
2002	2058	15
2003	3829	1
2004	2038	0
2005	4815	5
2007	1528	2

Table 4. The number of White Sturgeon eggs and larvae collected by sampling effort, sampling location, and year on the lower Columbia River, 2008-2011.

Year	Location	Egg Mats			Drift Nets		
		Eggs	Larvae	Effort (Hrs)	Eggs	Larvae	Effort (Hrs)
2008	Waneta	3,456	7	19,428	494	220	72
	rkm 18.2	0	0	16,493	0	1	164
2009	Waneta	1,715	2	21,964	77	39	90.1
	rkm 18.2	0	0	0	0	5	976.1
	Robson	0	0	0	0	0	3091.3
2010	Waneta	4,003	16	18,204	888	89	113.4
	rkm 18.2	0	0	10,600	1	8	2,104
	ALH**	12	0	3,608	30	115	2,084
2011	Waneta	2,318	9	19,882	234	16	49.8
	rkm 18.2	0	0	0	2	32	1,400
	rkm 13.5	0	0	0	0	0	154
	Kootenay	0	0	0	0	0	993
	HLK*	0	0	0	0	0	461
	ALH	2	0	3,614	183	308	2,538

*Hugh Keenlyside Dam

**Arrow Lakes Generating Station

Table 5. Total numbers of White Sturgeon eggs collected and the estimated number of spawning events (based on staged eggs) at the Waneta spawning for sampling that has occurred from 1993 through 2011. The percentage of spawning events occurring on the descending limb of the hydrograph is also presented as a comparison by year. Table reproduced from Golder 2012.

Year	Peak Discharge (cfs)	Peak Freshet Date	Total Number Eggs Sampled	Estimated Minimum Number of Spawning Events	% of Spawning Events Occurring on Descending Limb of Freshet Hydrograph
1993	62154 ^a	17-May	61	5	100
1994	52266 ^a	05-Jun	33	4	100
1995	67804 ^a	10-Jun	762	9	100
1996	98457 ^a	14-Jun	1680	12	100
1998	71971 ^a	02-Jun	1621	5	100
2000	60388 ^a	03-Jun	474	5	100
2001	114651 ^b	26-May	620	7	100
2002	230412 ^b	30-Jun	2058	9	56
2003	150526 ^b	05-Jun	3829	9	100
2004	135089 ^b	14-Jun	2038	9	100
2005	166521 ^b	10-Jun	4815	12	100
2007	185984 ^b	09-Jun	1528	10	100
2008	216651 ^b	04-Jun	3456	17	100
2009	173948 ^b	02-Jun	1715	15	100
2010	181245 ^b	21-Jun	4891	27	63
2011	278856 ^b	20-Jun	2318	8	88

^a discharge records from 1993 to 2000 only measured discharge from the Pend d'Oreille River at Waneta Dam

^b discharge records from 2010 to 2011 indicate combined discharge from the Pend d'Oreille River at Waneta Dam and the Columbia River at the Canada/U.S. International Border

Other Locations - In addition to sampling at Waneta in 2011, additional mats and nets were deployed in other areas that were suspected White Sturgeon spawning locations. In 2011, Egg mats and drift nets were strategically placed in other areas of the LCR (HLK, ALH, rkm 13.5, rkm 18.2, Kootenay River) in an effort to potentially locate alternate spawning locations. Egg mat sampling occurred at ALH over a period of 37 field days between June 28 and August 3, and drift net sampling occurred over a period of 26 field days between July 11 and August 17. At HLK, rkm 13.5, rkm 18.2, and Kootenay River, drift net sampling occurred over a period of 26 field days between July 11 and August 17.

In total, 3,614 mat-hours of egg collection mat sampling; and 5,546 hours of drift net sampling resulted in the capture of 187 eggs and 340 larvae (Table 4). 493 were captured by both egg mats and drift nets in the ALH tailrace site and 34 were captured in a drift net at rkm 18.2 (Table 4).

3.3.2 Egg and Larvae Preservation and Staging

Waneta Area - In 2011, the developmental stage of approximately 10% (n=318) of the total eggs captured at Waneta during egg collection mat and drift net sampling was determined (see Table 6). Based on the time of egg capture, developmental differences among eggs captured, and the presence of recently spawned eggs, it is estimated that 14 spawning events occurred in the Waneta spawning area in 2011 (see Figure 6). Only one (7%) of the spawning events in 2011 occurred in June, which is less than the average from past years (50%). This event occurred on June 29 which is among the latest date recorded. The last spawning event was on August 2.

Spawning events are typically estimated from the developmental stage of eggs. However, starting in 2011 we estimated spawning events separately from collected eggs and larvae in the event one collection technique represented spawning events that the other did not. From the larvae (n=400) that were staged, an additional 5 spawning events were estimated at Waneta on days where there were no spawning events identified through staged eggs (Figure 5). This brought the total number of estimated spawning events at Waneta to 19 (Figure 6).

Other Locations - In 2011, the developmental stage of all eggs (n=112; see Table 6) captured at ALH during egg mat collection and drift net sampling was determined. Based on the development stage of the eggs it was estimated that 4 spawning events occurred at ALH between July 30 and August 3 (see Figure 6).

From the larvae (n=142) that were staged, one additional spawning event was estimated at ALH when there were no spawning events identified through staged eggs (Figure 6), bringing the total number of estimated spawning events to 5.

Table 6. The proportion of White Sturgeon eggs collected across different developmental stages from wild spawning events at the Waneta spawning area and the Hugh Keenleyside/Arrow Lakes Generating Station (HLK/ALH) spawning area in 2011.

Egg Stage	Waneta		HLK/ALH	
	Number	Proportion	Number	Proportion
1 to 5	26	0.08	0	0.00
6 to 10	28	0.09	1	0.01
11 to 15	53	0.17	1	0.01
16 to 20	72	0.23	20	0.18
21 to 25	14	0.04	2	0.02
26 to 30	7	0.02	38	0.34
31 to 35	101	0.32	29	0.26
Dead	15	0.05	16	0.14
Fungus	2	0.01	5	0.04
Total	318		112	

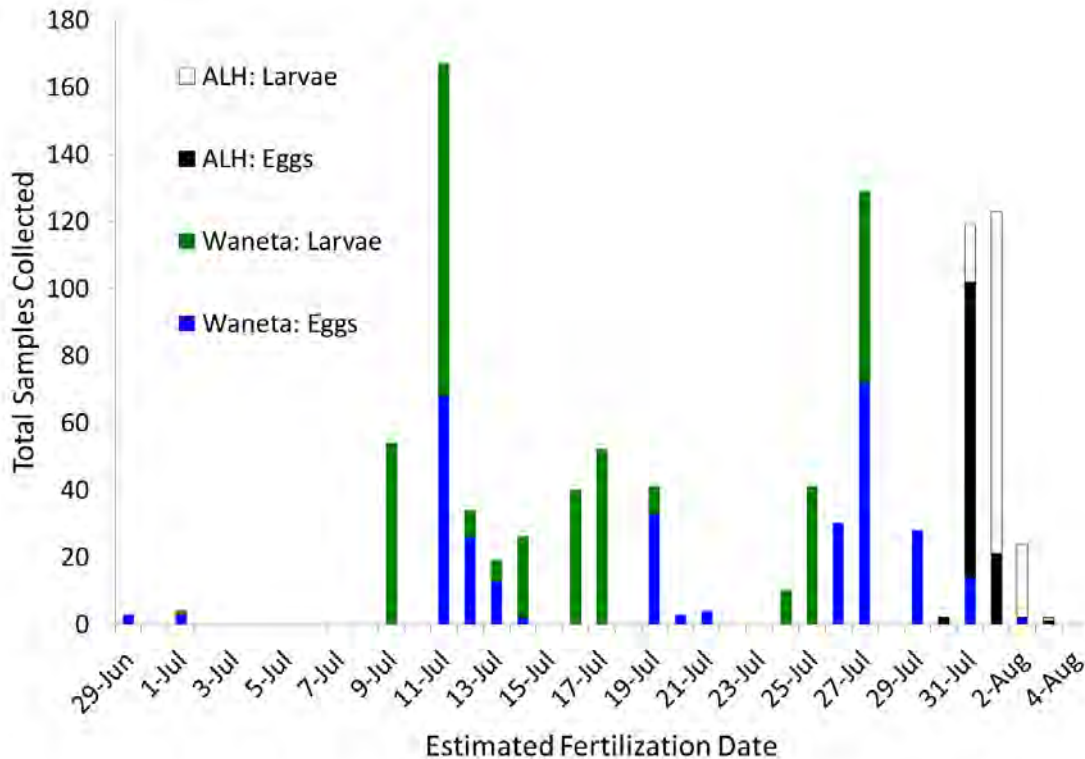


Figure 6. The number of White Sturgeon eggs and larvae developmentally staged and assigned back to the spawning event they were estimated to originate from for Waneta and Hugh Keenleyside/Arrow Lakes Generating Station (HLK/ALH) spawning areas in 2011.

3.4 *In Situ* Egg Incubation

3.4.1 *Egg Incubation*

In 2011, 781 collected eggs were incubated in stream at the Waneta spawning area using an *in situ* approach, of which 59% successfully hatched (Table 7). At ALH, 168 collected eggs were incubated of which 112 successfully hatched (66% hatch rate; Table 7).

Table 7. Survival to hatch for White Sturgeon eggs collected from wild spawning events and incubated *in situ* at the Waneta spawning area in 2011.

Date	Total Eggs Incubated	Total Live Eggs	Total dead Eggs	Live Larvae	Dead Larvae	Survival to Hatch
6-15 Jul	1	0	0	1	0	100
13-20 Jul	150	0	37	112	1	75.3
15-22 Jul	118	0	87	24	7	26.3
18-22 Jul	8	0	2	5	1	75
20-27 Jul	19	0	8	11	0	57.9
22-29 Jul	200	0	79	119	2	60.5
29 Jul – 3 Aug	197	0	83	111	3	57.9
3-4 Aug	88	0	22	65	1	75
Total	781	0	318	448	15	59.3

3.4.2 *Larval Genetics*

This report provides a summary of preliminary genetic analyses as genotyping was not complete for all individuals across all loci at the time of this report. We report on sib cluster groupings for all individuals sampled regardless of estimated probability of group inclusion. In 2012, offspring will be collected from known full and half-sibling pairings to use to validate the accuracy of pedigree assignment and to assess the accuracy of likelihood-based estimates of confidence in pedigree assignment.

A total of 163 alleles were documented at the 12 microsatellite loci in the LCR White Sturgeon larval samples (n=369). The number of alleles per locus ranged from 4 (AciG53) to 21 (Atr117) (Table 8). The average number of alleles per individual at each locus ranged from 1.89 (Atr113) to 6.15 (AciG35). Preliminary analysis of the 104 individuals for the ALH location included 9 loci (Atr100, Atr117, Atr1173, Atr113, Atr1101, Atr107, Atr109, Atr105 and AciG35). Preliminary analysis of 1.82RKM of the 33 individuals included 6 loci (Atr100, Atr117, Atr1173, Atr113, Atr1101, and Atr107). For this report, all estimated pedigree relationships are reported regardless of statistical support. Estimated pedigrees are illustrated using Pedigree Viewer 6.5b (written by Brian and Sandy Kinghorn 2011). Assuming random mating, polygyny and polyandry (males and females mate with multiple partners, respectively), the effective population size (N_e), at the spawning sites of ALH and near Kinnaird (rkm 18.2) were 32 (95% C.I. 20-53) and 31 (95% C.I. 18-54) respectively. Analyses are still underway for Waneta. The estimated number of contributing adults was 42 (20 males and 22

females) at ALH and 29 (14 males and 15 females) at rkm 18.2. It is important to note that actual sex of the adults is unknown. Differences in the estimation of N_e and the number of contributing adults are likely due to the variation in reproductive success. Figures 7 and 8 illustrate the variation in relative estimates of reproductive success at ALH and rkm 18.2 respectively based on assignment of putative parents (top of each figure) to sampled offspring (bottom of each figure).

Table 8. The total number of alleles per locus (N_T), size range (in base pairs (bp)) and average number of alleles per individual per locus (N_I) for the 12 microsatellite loci used for genotyping 2011 samples collected in the lower Columbia River. N_T and N_I are based on the larval samples selected for genotyping (n=369).

Locus	N_T	Size Range (bp)	N_I
Aci2	6	236 - 274	3.45
AciG35	15	248 - 316	6.15
AciG53	4	216 - 240	1.9
AciG140	8	162 - 186	2.55
Atr105	6	140 - 160	2.85
Atr107	20	180 - 264	4.57
Atr109	18	242 - 314	3.58
Atr117	21	196- 280	3.79
Atr1101	5	134 - 154	2.31
Atr1173	19	264 - 340	3.38
Atr100	13	96 - 156	2.19
Atr113	14	184 - 260	1.86

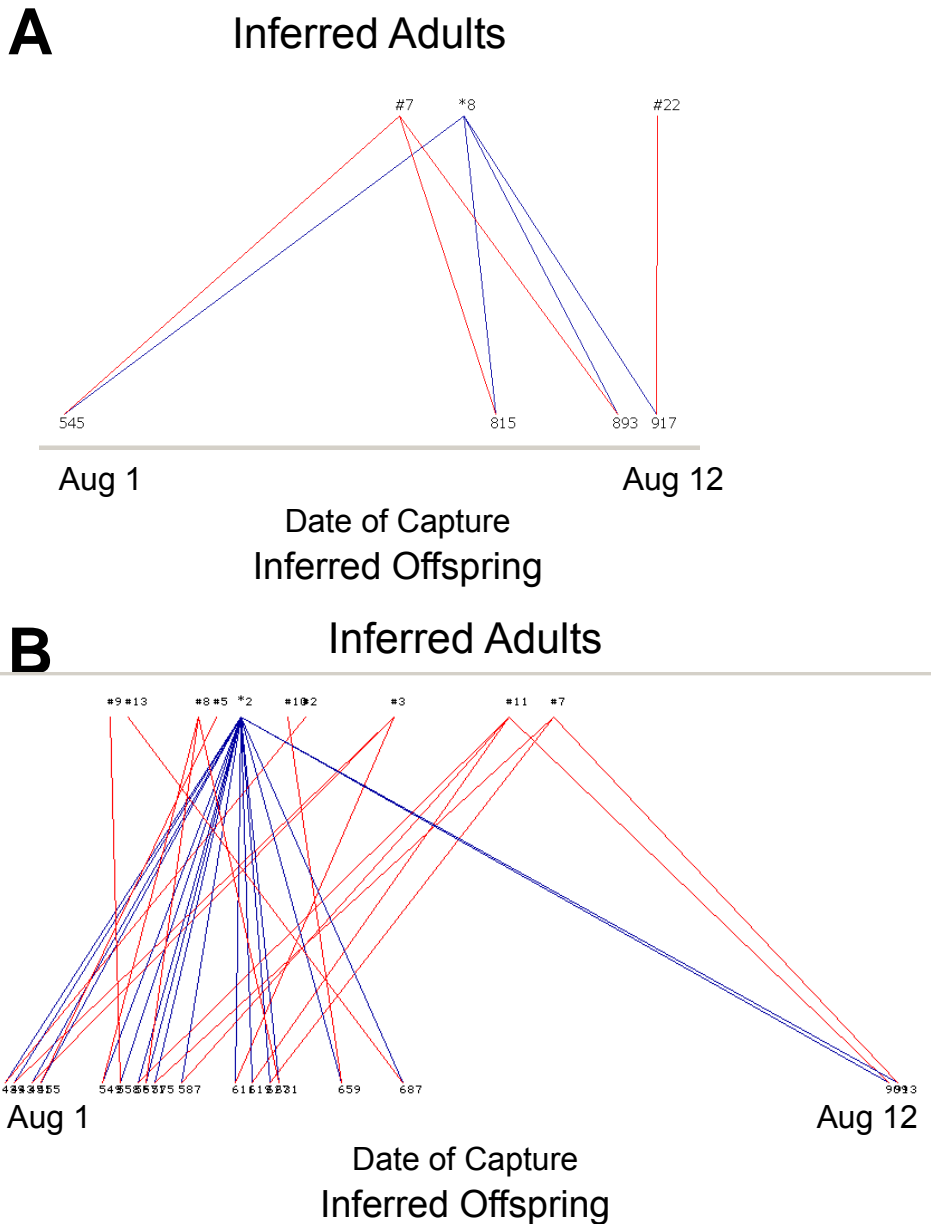


Figure 7. Simplified pedigree graph of a subset of adults to demonstrate the varying relative reproductive success of adults at ALH. Individual #22 (red) (A) produced one of the sampled larvae where as individual *2 (blue) (B) produced 18 sampled larvae. Individual *8 (blue) (A) mated with two individuals where *2 (blue) (B) mated with 9 individuals. Based on relative reproductive success and the sampling methods, the duration of spawn also varied between adults with most spawning throughout the entire collection period (August 1 – 12) where others (#22 red) only spawned in the latter half of the collection period.

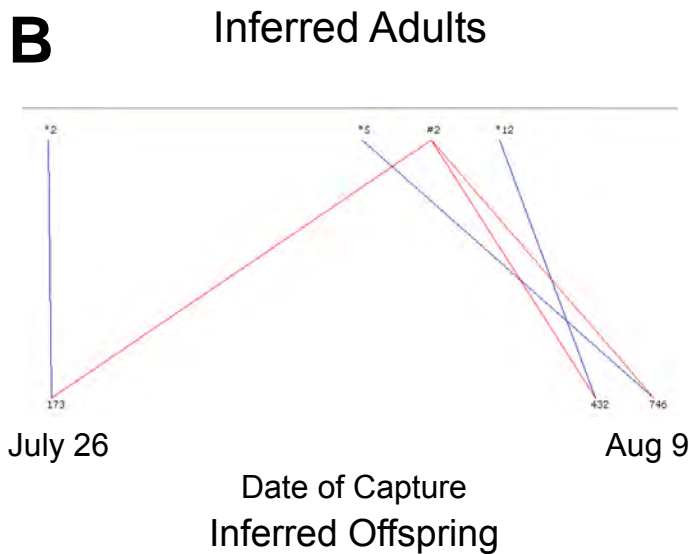
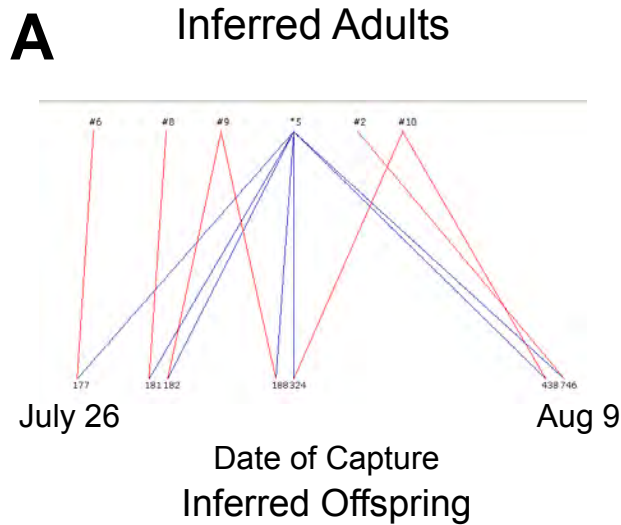


Figure 8. Simplified pedigree graph of a subset of adults to demonstrate the varying relative reproductive success of adults at rkm 18.2. Most individuals produced one of the collected larvae and therefore mated with one other individual (for example, #6 red, #8 red, #2red, *5 blue) where as individual *5 (blue) (A) produced 7 sampled larvae and mated with 5 individuals. Based on relative reproductive success and the sampling methods, the duration of spawn also varied between adults with most spawning once where others (*5 blue) spawned during the entire period of July 26 to August 9 or at the beginning and end of the spawning period (#2 red).

3.5 Population Monitoring and Abundance

3.5.1 Length Frequency Distribution

The average fork length of all fish collected in 2011 (n=201; Figure 9) was 162.2 ± 38.4 cm (± 1 Standard Deviation; SD). Fish in the 70-130 cm range primarily represent juvenile White Sturgeon released through the conservation aquaculture program since 2001. The average fork length of males (confirmed through maturation staging during surgical examinations or from previous capture history records of recaptured fish) captured in 2011 (n=45) was 181.7 ± 15.4 cm (Figure 11). The average fork length of females was marginally larger compared to males and was 188.2 ± 19.2 cm (Figure 11). The average weight of all fish (n=201) was 37.6 ± 21.0 kg (± 1 SD). The average weight of known males (n=45) and females (n=64) was 47.5 ± 13.5 kg and 51.7 ± 15.8 kg, respectively. Similar to previous broodstock capture programs, differences in size selectivity were observed again in 2011 between the two capture methods, with set line sampling resulting in catching larger fish when compared to angling (Figure 10).

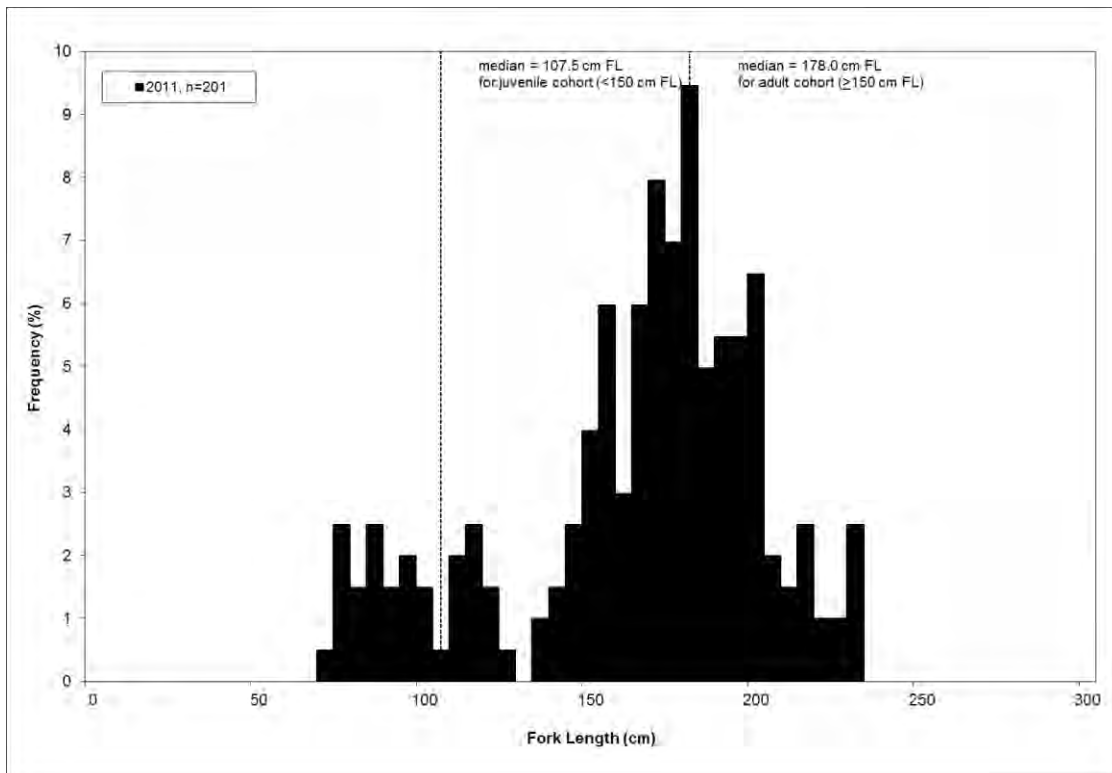


Figure 9. Length frequency of White Sturgeon captured during assessments in the lower Columbia River during 2011.

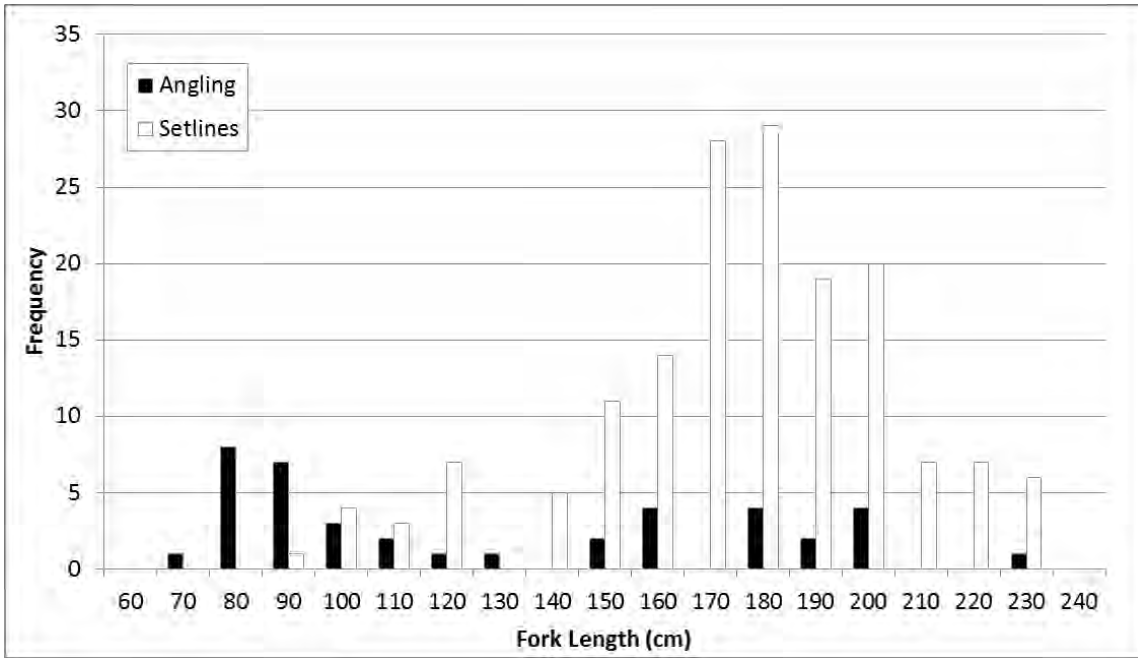


Figure 10. Length frequency of White Sturgeon captured using two gear types, angling and setlines, during assessments conducted during 2011 in the lower Columbia River.

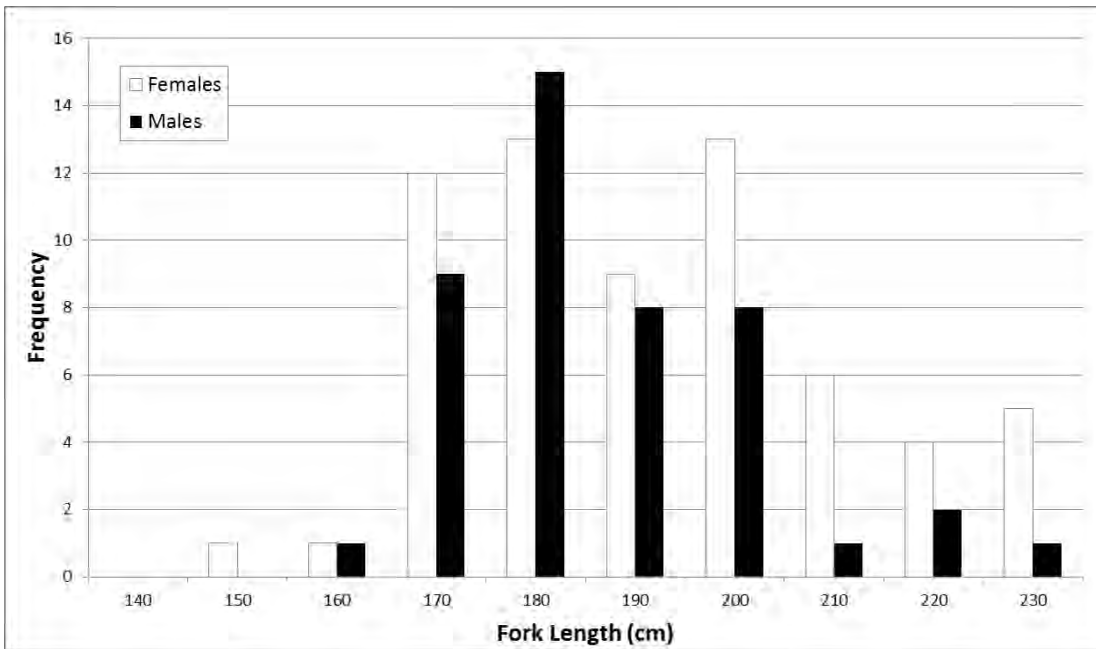


Figure 11. Length frequency of adult White Sturgeon of known sex (female and male) captured during assessments in the lower Columbia River during 2011.

Since tagging programs began in the early 90's, a large number of individuals have been captured 4 or more times (Table 9) allowing for detailed look at growth over time. Growth, as described by changes to fork length by year, was highly variable across females, males, and sub-adults (Table 10; Figure 12). Mean growth in fork length per year ranged from 2.2 to 2.9 depending on sex (Table 10). Comparatively, the mean annual growth of adult wild White Sturgeon >150 cm FL in the Roosevelt Reach was 2.8 cm/yr (UCWSRI 2012).

Relative weight (W_r ; Beamesderfer 1993) for White Sturgeon in the LCR is less than reported in downstream populations (Devore et al. 2000; Howell and McLellan 2007) and was calculated to be 90.4, 85.9, and 86.0 for adult females captured during broodstock collection efforts in 2009, 2010, and 2011, respectively (Table 11). Variation in relative weight was best described by sex, with females having slightly higher relative weights compared to males of a similar size class. Further, female relative weights were highest for individuals in spawning condition, or developmental stage of F4 (Described in UCWSRI 2006; Table 11).

Table 9. The number of recapture events for individual adult White Sturgeon marked and released in the lower Columbia River, Canada between 1993 and 2011.

Recaptures	Adults >150 cm
13	1
12	1
11	3
10	4
9	4
8	6
7	9
6	16
5	51
4	84

Table 10. Mean (± 1 SD) growth in fork length (cm) per year for individual White Sturgeon captured 4 or more times in the lower Columbia River.

Sex	Fork Length	Growth in Fork Length (cm)/Year	Sample Size
Female	177.8 \pm 27.7	2.2 \pm 2.4	209
Male	163.3 \pm 25.7	2.4 \pm 2.9	227
Unknown	133.1 \pm 20.5	2.9 \pm 2.7	189

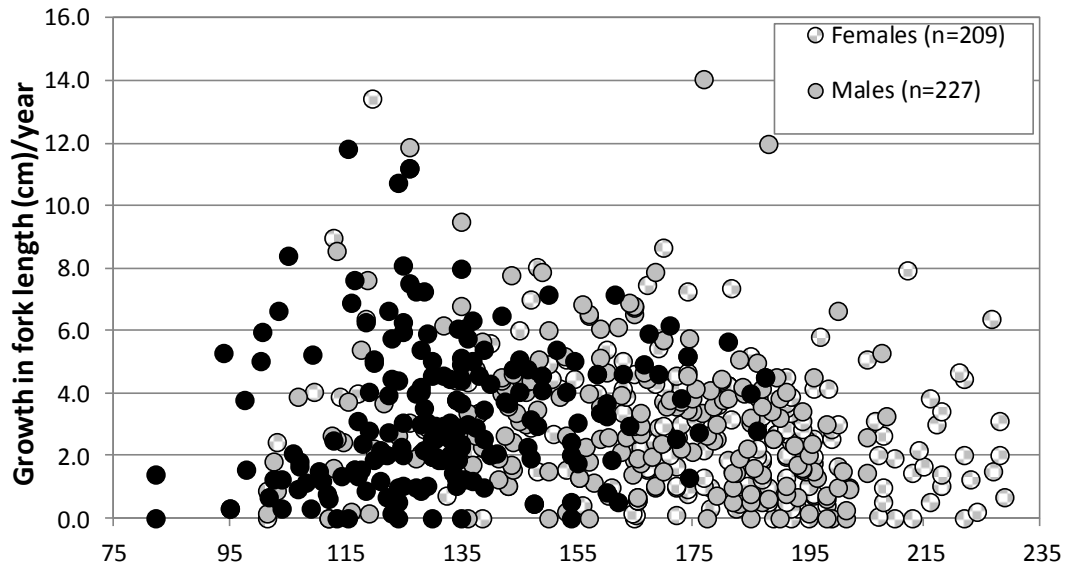


Figure 12. Mean (± 1 SD) growth in fork length (cm) per year between capture events for individual White Sturgeon captured 4 or more times in the lower Columbia River.

Table 11. Mean (± 1 SD) relative weights for female and male adult White Sturgeon collected during broodstock collection efforts on the lower Columbia River during June of 2009-2011. Relative weights are provided for specific female maturation stages, as described in UCWSRI 2006.

Sex	2009	2010	2011
Female	90.4 \pm 20.1	85.9 \pm 9.0	86.0 \pm 13.2
F4	105.5 \pm 11.3	95.3 \pm 7.7	90.7 \pm 8.5
F3	90.1 \pm 8.4	89.6 \pm 8.7	89.6 \pm 6.2
F2	84.9 \pm 7.4	84.3 \pm 6.1	86.4 \pm 8.5
F1	85.5 \pm 6.6	82.9 \pm 8.5	86.6 \pm 17.1
F0	83.0 \pm 8.8	81.3 \pm 7.4	79.6 \pm 8.7
Male	90.3 \pm 22.8	83.3 \pm 7.5	83.1 \pm 8.5

3.5.2 Sex and Maturity

In 2011 for the 109 White Sturgeon whose gender was known (through records from past captures) or determined through surgical examination, 45 were males and 64 were females (male:female sex ratio of 0.7:1). Table 12 outlines the sex ratios observed for most years in the 1990's and since the conservation aquaculture program was initiated in 2001.

Of the 45 male White Sturgeon captured in 2011, 6 (13%) were of unknown maturity, 28 (62%) were early reproductive, and 11 (25%) were late reproductive or ripe (flowing). Of the 64 female White Sturgeon captured in 2011, 12 (20%) were of unknown maturity, 32 (49%) were early developing "whitish eggs", 7 (11%) were early developing "yellow egg", 5 (8%) were late "yellow egg", 8 (12%) were black eggs of spawning maturity and considered to be suitable candidates for the conservation aquaculture program, and 0 (0%) were post spawning/spent.

Table 12. Sex ratios for White Sturgeon captured from 1992-1998 and from 2001-2011 upper Columbia White Sturgeon broodstock acquisition program.

Year	Number of Males	Number of Females	Sex Ratio (Males:Females)
1992	45	28	1.6:1
1993	42	18	2.3:1
1994	23	22	1.1:1
1995	12	4	3.5:1
1996	25	8	3.1:1
1997	3	3	1.0:1
1998	7	6	1.2:1
2001	58	46	1.3:1
2002	21	31	0.7:1
2003	25	36	0.7:1
2004	39	50	0.8:1
2005	33	41	0.8:1
2006	26	17	1.5:1
2007	35	32	1.1:1
2008	15	18	0.8:1
2009	38	51	0.7:1
2010	41	63	0.7:1
2011	45	64	0.7:1
Total	488	474	Mean 1.0:1

3.6 Acoustic Tagging and Telemetry

The movements of 78 adults, 43 females and 35 males, tagged with acoustic transmitters were examined during the period of spring 2008 through December of 2011. Analysis of the movements of all individuals resulted in the mean proportion of time spent at a single location (residency time) was 0.65 ± 0.21 (mean \pm 1 SD). Though not significantly different ($df = 75, t = 1.99, P = 0.30$), females had slightly higher residency time (0.67 ± 0.20) compared to males (0.62 ± 0.22). Habitat use for fish tracked as part of this work was highest in the upper section of the river (e.g., Robson reach; Figure 13) and there were only marginal differences between females and males (Figure 14).

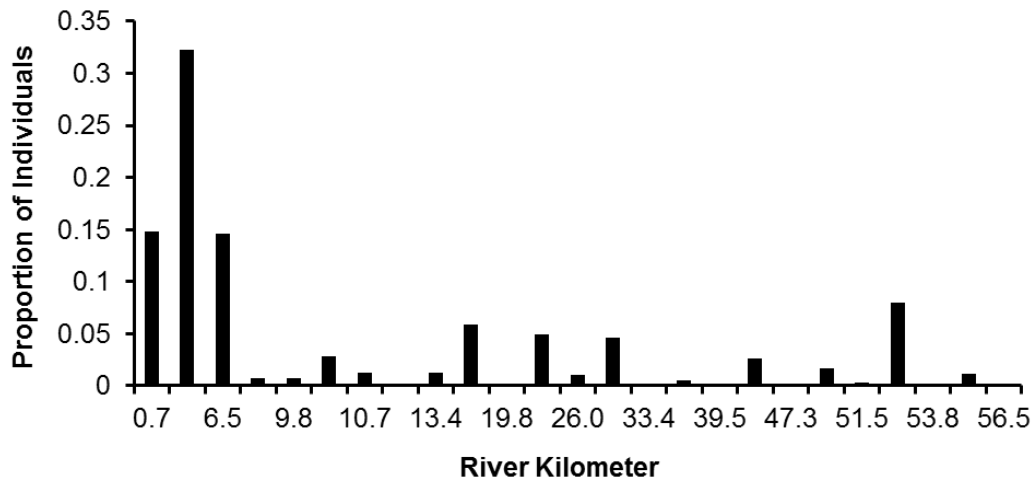


Figure 13. The proportion of individual adult White Sturgeon with acoustic transmitters detected by river kilometer in the lower Columbia River, 2008-2011.

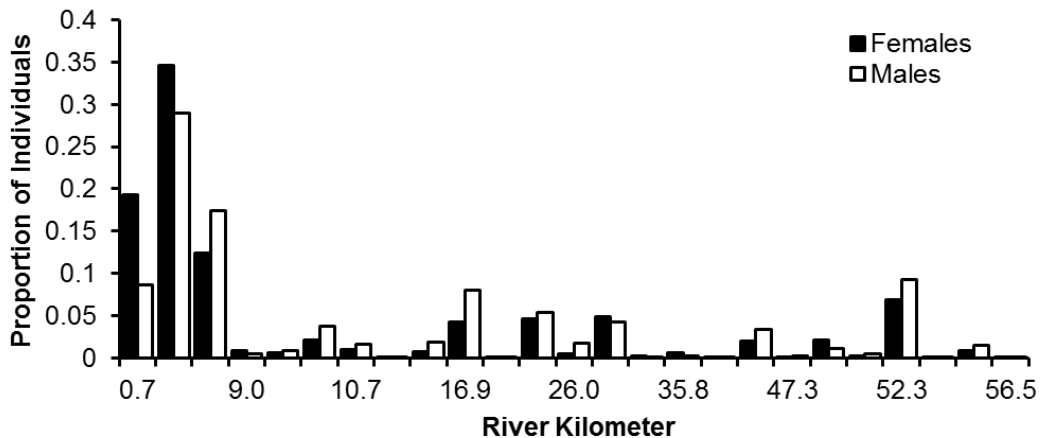


Figure 14. The proportion of individual female and male adult White Sturgeon with acoustic transmitters detected by river kilometer in the lower Columbia River, 2008-2011.

A number of adult White Sturgeon (n=44) were identified to have made movements that appeared to be spawning related during June-August from 2008 to 2011. Spawning related movements tended to remain within the section of river the individual was originally detected in (Table 13). However, a proportion of individuals in each river section exhibited putative spawning migrations to adjoining river sections (Table 13). Individuals suspected to spawn in the middle section of the LCR (Kootenay-Columbia confluence to Trail BC) travelled further to spawning areas compared to those spawning in the upper (Robson Reach) or lower (e.g., Waneta) sections (Table 14). Time spent on the spawning grounds was similar across the different suspected spawning sites and averaged about a month in duration (Table 14).

Table 13. The proportion of White Sturgeon adults (n=44) with acoustic transmitters that undertook suspected spawning movements (June to August) within and outside the river section they were originally detected in within the lower Columbia River, Canada, 2008-2011.

River Section where Movement Originated ^a	River Section (Known or Suspected Spawning Area)		
	Upper (Keenleyside)	Middle (Suspected – Kinnaird)	Lower (Waneta)
Upper	0.80	0.20	0.00
Middle	0.06	0.59	0.35
Lower	0.08	0.00	0.92

^a Upper = HLK to Kootenay River mouth; Middle = Downstream of Kootenay R. mouth to Birchbank; Lower = Trail to Waneta

Table 14. Summary of movements made to suspected spawning sites for adult sturgeon detections originating in three different river sections. The mean (\pm 1 SD) distance travelled (km) to suspected spawning sites, the travel time (days) it took the individual to arrive at the site, and the total time (days) spent at the site are presented for movements made in the lower Columbia River during the period of June to August, 2008-2011.

River Section*	Distance Travelled	Travel Time	Time Spent on Location
Upper	6.20 \pm 5.35	6.73 \pm 10.35	27.69 \pm 24.92
Mid	12.78 \pm 13.35	6.13 \pm 7.38	34.50 \pm 25.66
Lower	6.68 \pm 14.06	1.44 \pm 1.74	30.56 \pm 18.05
Overall	9.08 \pm 11.57	5.30 \pm 8.04	31.24 \pm 22.35

*Upper = HLK to Kootenay River mouth; Middle = Downstream of Kootenay R. mouth to Birchbank; Lower = Trail to Waneta

4.0 DISCUSSION

The primary objectives of this study are to document the timing, duration and locations of White Sturgeon spawning events in the LCR. This includes identifying spawning cues and describing spawning habitat. This program is also responsible for the collection of up to 20 mature adult White Sturgeon to serve as broodstock for the conservation aquaculture program. Through the fourth year of this work we have been successful in documenting spawning at existing spawning areas, identifying new spawning areas, and estimating the timing and duration of spawning across all areas studied. Further, we have identified movements of adults to known or suspected spawning areas which has helped guide annual sampling strategies. For White Sturgeon throughout their range, it is generally thought that the spawning period is protracted and occurs in the late spring and early summer months (May to July) with specific timing dependent on environmental cues (e.g., temperature, flows; Parsley and Beckman 1994). In the LCR, in 2011, spawning was estimated to have occurred from late June into early August, with spawning in the upper portion of the river (i.e., near HLK/ALH) being later (e.g., early August) compared to downstream areas (i.e., Waneta; Figure 6). Further, spawning has been identified in the vicinity of Kinnaird (rkm 13.0) through the capture of dispersing larvae but the exact location of the spawning area remains unknown. The timing and duration of spawning activity is similar to past years, with the majority of Waneta spawning events occurring on the descending limb of the hydrograph and at water temperatures above 14 °C (Golder 2012).

In the Upper Columbia River, annual reproductive success of spawning adult sturgeon has been measured by estimating numbers of spawning events since monitoring began in the early 1990's (UCWSRI 2012). This has been done by developmentally staging of eggs collected on egg mats and estimating when fertilization occurred based on known rates of development across different temperature regimes. Eggs at early developmental stages are known to provide the most accurate estimates of when spawning events occurred (Parsley et al. 2004). However, it is known that egg and larval captures using different capture techniques (e.g., egg mats vs drift nets) may disproportionately represent different spawning events. When developing eggs were used to estimate spawning events in 2011, it was estimated that 8 events happened at Waneta (Golder 2012) and 4 events happened in the ALH tailrace (Terraquatic Resource Management 2011). For the first time in 2011 we staged captured White Sturgeon larvae and estimated when spawning occurred using known development rates at different water temperatures (Katy Jay, unpublished data). This more than doubled the estimated number of spawning events at Waneta to 19, and increased the number of spawning events at ALH to 5 (Figure 6). Although this result is not totally unexpected, given the fact that sampling methodologies only sub-sample a proportion of the habitat in spawning areas, it demonstrates that the number of spawning events may have been underestimated in the past. We acknowledge that assigning larvae back to the date they hatched and then assigning the incubation period at the egg stage for that individual could result in increased error and decreased accuracy in the true date that spawning occurred. Therefore, in addition to empirical estimates using developmental stages of eggs and larvae, we are incorporating molecular analyses using the collected samples to determine if genetically, the estimates of when spawning occurred align for samples collected at different life stages. These analyses are novel and incorporate new analytical techniques only recently applied to long-lived iteroparus species like sturgeon (Duong et al. 2013). Results from this work will help inform the most appropriate means of estimating the number of annual spawning events and will hopefully allow for comparisons across sampling years.

In addition to determining efficiencies between sampling methods in representing eggs and larvae from different spawning events, capture efficiency between gear types is important when identifying spawning areas where the exact location is unknown. At Waneta the use of egg mats has been the consistent methodology used for the collection of White Sturgeon eggs since the spawning location was first described. At the HLK/ALH area and at other locations in the upper sections of the river, the use of drift nets has been more effective in collecting eggs or larvae (Table 4). For spawning areas where the exact geographical location is uncertain, drift nets are more effective as they can represent all areas upstream of the sampling location. Though egg mats are effective when the main areas of egg deposition have been identified, drift nets should be used primarily when attempting to assign a general location where spawning may be occurring. To address the objectives of this program as it relates to describing new spawning areas it is recommended that egg mats be restricted to use at Waneta, and that drift nets are the primary technique used in areas where spawning locations are uncertain (e.g., Kinnaird).

White Sturgeon in the LCR tend to select deep slow moving sections of the river and these habitats do not appear to be limited under the current operating regime of the river. Similar to past years, movement data indicated that activity generally occurred during the summer months for foraging or spawning. Site fidelity remains high (> 60%) to specific river locations and underlies the importance of maintaining spatial balance when sampling for adults. This is especially important for sampling programs planned in the upcoming years where results will be used to generate a new population estimate. Spawning related movements of adults with acoustic transmitters revealed that adults tended to migrate to spawning areas within the same river area (Table 13) they were exhibiting high fidelity to. These movements were from a large sample size of adults and differ from previous work that identified adults making longer migrations from upstream areas (e.g., Robson reach) to downstream spawning areas (e.g., Waneta; UCWSRI 2012). However, a portion of adults tracked in this study exhibited putative spawning migrations to adjoining river areas (Table 13) indicating mixing of adults throughout the transboundary stretch of river. Though results from telemetry monitoring the first few years of this program reveal patterns of habitat use and possible spawning related movements, they should be interpreted with some caution as the longer term movement patterns of this species are poorly understood. Additional data through the duration of this program are needed to address how the operation of the river may influence habitat use or movements. At the present time, there are sufficient numbers of adults with active acoustic transmitters so additional telemetry tagging is not planned in the coming years. Data will continue to be collected in a systematic fashion using the longitudinal array of receivers in the LCR.

The primary focus of the broodstock capture program is to provide adults that can contribute to progeny stocked from the conservation aquaculture program. Although the target of 10 mature males and 10 mature females has been met annually through the program (FFSBC 2011, 2012), including in 2011, not all fish sent to the hatchery are successfully used in crosses as some fish that are mature at the time of capture do not fully mature once in the hatchery. To date, adults have not been reused in the program other than a single female who contributed eggs for production (2001) the first time she was spawned and for experimental purposes (2010) the second time she was caught in spawning condition. Given the number of adults captured annually that have not been used in the hatchery program remains high, the goal remains to not reuse adults to

contribute to production across multiple years. The majority of the adults taken to the hatchery since the program began have been from downstream areas (70%; Table 2) reinforcing statements above regarding the importance of spatially balanced sampling due to high site fidelity.

Additional to the capture of mature adults for the aquaculture program, the broodstock program has also served as sole method of providing information on the biology of the population (e.g., length frequency, growth rates, population estimates). Importantly, approximately 30% of the individuals captured during the broodstock program had not been captured and tagged previously. This is similar to previous years and indicates the importance of a conducting sampling to revise population estimate as confidence in the baseline numbers of sub adults and adults present in the LCR is needed for recovery planning. Using life history data from multiple captures of the same individual, we were able to estimate growth across females, males, and immature fish (<150 cm fork length). Growth (cm/year) was highest for immature fish (2.9) compared to both males (2.4) and females (2.2). Growth of adults (>150 cm fork length) was marginally lower compared to mean annual growth of adult wild White Sturgeon in the Roosevelt Reach (2.8 cm/year; UCWSRI 2012) but higher compared to adults in the Kootenay River (0.6 cm/year; Paragamian and Beamesderfer 2003). Other metrics such as relative weight, sex ratios, and maturity information have been collected, though additional years of data collection are required to assess trends.

5.0 RECOMMENDATIONS

1. Set lining provides a methodology for the capture of mature White Sturgeon that enables conservation aquaculture targets to be met in a timely manner. To minimize the capture of sub adults, large hook size (20/0) should be employed exclusively on the set lines. In addition, this work has shown that angling primarily results in the capture of sub adult White Sturgeon, and as such should only be employed as a capture methodology for broodstock collection if scheduling permits. Otherwise, the additional effort should be placed on deploying extra set line effort.
2. 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 (e.g., in the vicinity of Kinnaird).
 - a. Egg mats should continue to be used at Waneta and HLK/ALH in the same consistent fashion as previous years sampling.
 - b. Additional drift net stations should be deployed downstream of Kinnaird to determine where larvae may be originating from.
3. Tissue samples should be collected from offspring at the different spawning areas to determine how many adults are contributing using molecular methods. If possible, genetic analyses should address which sampling method, egg mats or drift nets, better represents the spawning population (e.g., number of contributing adults).
4. Additional range testing should be conducted throughout the LCR to describe detection probabilities for each unique receiver station.
5. Work towards the development of a coordinated stock assessment program with US agencies to improve our confidence in the numbers of fish in the transboundary reach.
6. Development of a database that could store all life history data and telemetry data among researchers and industries.

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