

Columbia River Project Water Use Plan

Lower Columbia River

Reference: CLBMON #28 (Year 5 and Year 6)

***Lower Columbia River Adult White Sturgeon Monitoring
Program: 2012 and 2013 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 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 2012, conservation aquaculture broodstock targets were met with 8 females and 10 males being captured and successfully spawned at the Kootenay Sturgeon Hatchery (KSH). In 2013, 6 females and 3 males were captured and successfully spawned at the (KSH). Similar to the past several years of the program, 15.3% of the 655 White Sturgeon collected during the broodstock programs were first time captures supporting the need for a revised population estimate. In 2013, a population assessment program was initiated to improve abundance and survival rate estimates of the LCR White Sturgeon population. Additionally, data from this five-year program will be used to determine growth rates across females, males, and immature fish (<150 cm fork length), fish condition, age class structuring, and density dependent responses. Movement data indicated that activity generally occurred during the summer months for the assumed purposes of foraging or spawning. Adult White Sturgeon in the LCR are selecting deeper habitats of low flow, which do not appear to be limited under the current operational regime.

In 2012, spawning was estimated to have occurred from late June into late August at the downstream (Waneta) location. Spawning period was not estimated for the upstream locations as no live eggs or larvae were collected at these areas. In 2013, spawning was estimated to have occurred at Waneta between mid-June and mid-July, and downstream of Kinnaird (river kilometer (rkm) 14.5 and rkm 18.2) in late July. The timing and duration of spawning activity was similar to past years, with the majority of Waneta spawning days 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 18 and 12 spawning days occurred at Waneta in 2012 and 2013, respectively. Two spawning days were estimated to have occurred downstream of Kinnaird in 2013. For data collected in 2011 and 2012, genetic analyses were used to determine White Sturgeon spawning dynamics including number of spawning adults, effective breeding population size, and reproductive success

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 River as estimated by Irvine et al. (2007). A systematic stock assessment was initiated in 2013 and encompasses the entire Transboundary Reach of the lower Columbia River in Canada and the US. The goal of the stock assessment is to develop population and survival estimates to track recovery targets for this population. - Generally, the wild population remains dominated by adult age classes, with limited wild juveniles captured during sampling programs. 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 and are just reaching a size where they will start entering the adult population. - 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. A pilot aquaculture program that centers around using wild collected eggs and larvae is in development for 2014 and is based on results from genetic analyses presented in this report. |
| <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 days is unknown, it is estimated that multiple spawning days occur annually with eggs surviving to hatch. - Using genetic methods, it was found that 121.5 ± 34.7 adults (mean \pm SD) were spawning within the Canadian section of the lower Columbia River within each of two years (2011 and 2012). - Spawning occurs annually at the Waneta area, with the number of estimating spawning days varying by year. |

| Management Question | Status |
|--|--|
| | <ul style="list-style-type: none"> - Spawning has been identified through egg and larval captures downstream of Hugh Keenleyside Dam and Arrow Lakes Generating Station. 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 describe spawning frequency and duration. - An additional spawning location is used annually in the vicinity of Kinnaird but the exact location(s) of egg deposition remains unknown. - Additional spawning sites are used annually south of the international border. |
| <p>What is the degree of interaction among sub-populations of White 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 Columbia River. |
| <p>How do existing river operations affect adult movements, habitat preference, spawning site selection, or spawning activity?</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 assumed to be for either feeding or spawning. - Spawning related movements have been identified for a select number of mature males and females. 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 the use of 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 (Hildebrand and Parsley 2013) 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, spawning activity (i.e., 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 (before 2007) have identified White Sturgeon spawning sites at two primary locations in the mainstem Columbia, including the confluence with the Pend d'Orielle River (Waneta, river kilometer (rkm) 56.0; UCWSRI 2012) and in the vicinity of Northport, Washington (Howell and McLellan 2006). From additional work, other sites have been located in the Canadian portion of the LCR 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(s) of egg deposition remains unknown. These results have demonstrated that there are still spawning locations that are undocumented in the LCR, and that the continued monitoring is important to describing adult reproductive ecology, mechanisms influencing spawning site selection, and to understanding underlying mechanisms resulting in recruitment failure.

Reliable data on the actual number of adults contributing to annual recruitment (N_s) and estimates of successful reproduction at different spawning sites in the LCR is important for population management. However, it can be labour-intensive and difficult to obtain through traditional techniques of mark-recapture, tagging, or observational studies. Alternatively, genetic techniques can be used to answer questions related to White Sturgeon spawning and reproductive success, as well as evaluate population status and effects of management actions, that are otherwise hard to address using conventional methods (Anders et al. 2011). Genetic 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.

Understanding genetic diversity of White Sturgeon in the LCR is important when understanding long-term population viability and potential for adaptation to

environmental change (Reed and Frankham 2003). Effective population size (N_e) is defined as the number of individuals in an ideal population having the same magnitude of random genetic drift, inbreeding or loss of heterozygosity as the actual population (Wright 1931). The effective breeding number (N_b) represents a measure of effective size for a single reproductive season. This metric is important for understanding the ecological dynamics within a spawning season and is similarly influenced by factors affecting general estimates of N_e (Waples 2002). Therefore estimates of N_e , N_b , and annual recruitment are important variables to understand for endangered species (Charlesworth 2009; Waples 2010), as small populations are at risk of extinction through demographic stochasticity, genetic drift and environmental variation (Braude & Low 2010).

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 the 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 157 individual adults (72 females and 85 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 134,484 hatchery reared juvenile sturgeon into the LCR, 101,561 of which were released into the Canadian section (as of spring 2013).

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 days through the deployment of egg mats and drift nets.
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 White 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 the 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 White 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 days 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 White Sturgeon in the LCR will not be adversely affected by management response measures.
- 4) Of equal importance to the maintenance of the remaining White Sturgeon population; are there sufficient adults to continue the conservation aquaculture 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 program's management questions.

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, if deemed necessary, 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 White Sturgeon life history characteristics including size, growth, age structure, and condition, and population characteristics including abundance and trajectory, survival rates, genetic status, and reproductive potential are quantified with sufficient consistency to describe annual trends.
- 2) Biological characteristics including spawn monitoring to assess annual 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 monitoring program are summarized as follows.

1.2.1 Broodstock Acquisition

1. Provide eight to ten late-vitellogenic female and eight to ten mature males for transport to the Kootenay Sturgeon Hatchery (KSH).
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.

1.2.2 Spawn Monitoring

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

1.2.3 Larval Genetics

1. Assess the number, distribution, and timing of White Sturgeon spawning activity within the LCR.
2. Estimate the effective breeding number (N_b), number of adults contributing to offspring (N_s) and number of kin groups (N_k).
3. Assess reproductive ecology including individual reproductive success, spawning duration, and spawning group composition.
4. Evaluate the efficacy of empirical and genetic methods to estimate number of adults contributing to offspring.

1.2.4 Population Monitoring, Abundance, and Characteristics

Biological, mark-recapture, and related age structure data accumulated through bi-annual stock assessment program will be used to:

1. Assess population size and age structure, abundance, annual survival rates, and population trajectories.
2. Provide relative abundance and periodic updates to population estimates of the LCR White Sturgeon population.
3. Periodically compare 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 population.

1.2.5 Acoustic Tagging and Telemetry

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

1. Assist with directing broodstock acquisition efforts by following movements of fish of known sex or maturity.
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.
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 2012/2013 monitoring program consisted of a 57 km stretch of the LCR between HLK and the Canada/U.S. Border (downstream of the Pend d'Orielle River confluence; Figure 1). The study area also included a small section (~2.5 km) of the Kootenay River below Brilliant Dam extending to its confluence with the LCR. Specific areas of the LCR sampled under the various components of the program (e.g., broodstock, spawning, etc.) are described below.

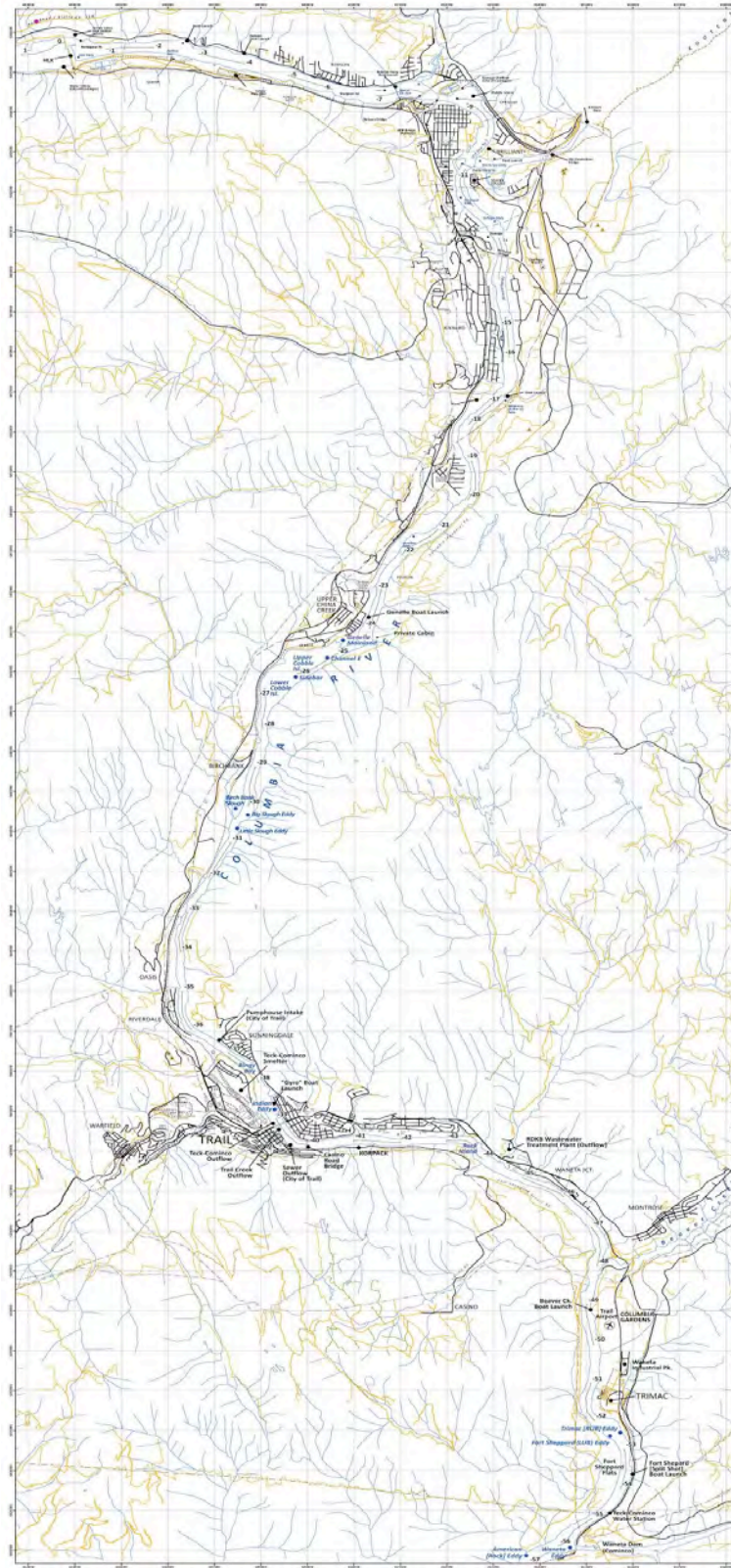


Figure 1. Overview of the study area between HLK (rkm 0.1) and the Canada/US border (rkm 57.0).

2.0 METHODOLOGY

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 LCR 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 2012/2013, discharge records for the LCR at Arrow Reservoir (combined HLK and ALH discharges from Arrow Lakes Reservoir), the Kootenay River (combined discharge from Brilliant Dam and the Brilliant Expansion facility), the LCR at Birchbank (combine discharge from Arrow Lakes Reservoir and Kootenay River; rkm 29), and the LCR at the Canada/United States border (combined discharge from Birchbank and the Pend d'Oreille River; rkm 57.0) were obtained from BC Hydro power records. Discharge data were recorded at one-minute intervals and averaged hourly in cubic meters per second (cms), cubic feet per second (cfs), and in thousands of cubic feet per second (kcfs) of passage flow.

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

2.1.2 Water Temperature

For the 2012/2013 study period, water temperatures were collected at several locations on the LCR including HLK (rkm 0.1), Kootenay River (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8) and Waneta (rkm 56.0). Water temperatures were recorded hourly at each location using thermographs (Vemco Minilog, accurate to $\pm 0.1^{\circ}\text{C}$).

2.2 Broodstock Acquisition

2.2.1 Study Design

Prior to 2008, adult White Sturgeon sampling efforts in the LCR for broodstock collection (BC Hydro 2007, 2008, 2013), mark recapture, 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 throughout the entire river (BC Hydro 2011a). In 2011 through 2013, sampling effort was not randomly distributed, 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.

2.2.2 Adult Capture

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 2012 and 2013, 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 - 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 10 to 12 circle halibut hooks attached at 6.0 m intervals. Hooks were attached to the mainline using a 0.95 cm swivel snap and a 0.7 m long ganglion line tied between the swivel and the hook. Halibut hook sizes used were 20/0 only to limit the capture of smaller juveniles on the set

lines. 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 2 m. Most set lines were deployed and remained in 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 removed from the set line were tethered between two anchor points to the port or starboard side of the boat. While tethered, the entire body of the fish was submerged. Once all fish were removed from the set line, the boat was idled into shore or anchored within a nearby back eddy and White Sturgeon were individually brought aboard for biological processing (described in Section 2.2.3).

Catch per unit effort (CPUE) was calculated for each year. 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 to 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 and the number of hooks per set line was equalized relative to past studies.

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 White Sturgeon; a level wind reel spooled with 45 to 58 kg test suitable 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 (*Oncorhynchus nerka*) obtained from the Meadow Creek Hatchery (Meadow Creek, BC). 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 fish traveled considerable distance from where it 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 and was biologically processed (described in Section 2.2.3).

2.2.3 Fish Handling, Transport, Hatchery Spawning, and Release

Captured White Sturgeon were individually guided into a 2.5 m by 1.0 m stretcher that was raised into the boat using a winch and davit assembly. The stretcher was secured on the boat and fresh river water was continuously pumped over the gills during the processing period. A hood on one end of the stretcher protected the head of the White Sturgeon from exposure to direct sunlight and also retained a sufficient amount of water allowing the fish to respire during processing. Wet towels were placed over the body of the fish to keep the skin cool and moist.

Once on the boat, White Sturgeon were immediately checked for tags indicating if they had been previously captured. 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 from the removal of a section of the first pectoral fin ray for ageing purposes); 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 between the ventral edge of the dorsal fin and the mid-dorsal line, generally on the fishes right side. A PIT tag was administered to any previously captured fish with no PIT tag present at time to capture. Prior to insertion, both the tag and tagging syringe were immersed in an antiseptic solution (Germaphene). Care was taken to angle the syringe needle so the tag was deposited in the subcutaneous layer and not the muscle tissue. The 2nd left lateral scute was removed from new captures (or recaptured White Sturgeon if present) using a sterilized scalpel in a manner consistent with the marking strategy employed by WDFW and ODFW.

White Sturgeon were measured for fork length 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 (>150 cm 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 using an otoscope and classified based on qualitative histology (Bruch et al. 2001; Golder 2006a). Female sexual maturity stage codes include: F0: females based on previous sex determination of unknown maturity (no surgical examination); F1: early developing white eggs; F2: early developing yellow eggs; F3: late developing yellow eggs; F4: black eggs of spawning maturity considered suitable candidates for broodstock; and F5: post spawn/spent. Male sexual maturity stage codes include: M0: males based on previous sex determination of unknown maturity (no surgical examination); M1: early reproductive; M2: late reproductive or ripe/flowing (see UCWSRI 2006 for details). Female developmental stages are usually more easily determined since ovary size, egg colour, and average egg diameter 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. White Sturgeon were returned to the water following processing and remained in the stretcher until they swam away under their own volition.

In 2012 and 2013, Freshwater Fisheries Society of BC (FFSBC) staff conducted all fish transportation efforts from the LCR to the Kootenay Sturgeon Hatchery (KSH) in Wardner, B.C. White Sturgeon identified as being suitable for fish culture purposes were transferred from the 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 White Sturgeon transported to the 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 LCR. 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 2013 and 2014).

Once spawned, each adult was implanted with an acoustic transmitter (Vemco, model V16) with delay time of 60 to 180 seconds (120 sec. nominal delay) and estimated operational life of 10 years. Adults were held at the KSH for a short recovery and observational period before transportation back to the LCR for release near the capture location.

2.2.4 Data Analysis

Biological data collected from adult and juvenile White Sturgeon caught in 2012 and 2013 analyzed in this report include sex ratios, fork length frequencies, mean weight, and mean relative weight (W_r). Relative weight (W_r) is a measure of fish plumpness allowing comparison between fish of different lengths, inherent changes in body forms, and populations (Wege and Anderson 1978). W_r is calculated with the following formula:

$$W_r = (W / W_s) * 100$$

where W is the actual fish weight (kg), and W_s is a standard weight for fish of the same length (Wege and Anderson 1978). We determined W_r for captured adults of known sex during broodstock acquisition for the years 2009 through 2013 according to the White Sturgeon standard weight-length equation developed by Beamesderfer (1993):

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

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

2.2.5 Adult Genetics

Though no genetic analyses using adult samples were planned in 2012 and 2013, tissue samples were collected for future genetic analysis from all adult White Sturgeon collected. A small piece of tissue (approximately 1.5 cm by 1.5 cm) from the tip of the dorsal fin was removed using surgical scissors, split into two sub samples, and archived in labelled scale envelopes.

2.3 Spawn Monitoring

2.3.1 Study Design

Monitoring of White Sturgeon spawning was carried out at several sites for this program based on previous data collection where White Sturgeon have been confirmed to have spawned, or have been suspected to spawn. LCR White Sturgeon cannot be observed congregating to spawn due to water depth and relatively high flow volume therefore spawning was documented through the collection of progeny.

Monitoring of spawning activity occurred at Waneta (rkm 56.0), which is located at the Pend d'Oreille River confluence immediately upstream of the Canada/US border (Figure 2). This site has been monitored for spawning activity since 1993 and is the main area of White Sturgeon spawning within the LCR in Canada (Hildebrand et al. 1999; Irvine et al. 2007; Golder 2009a). Secondary sites for spawn monitoring were also located in upstream sections of the LCR in 2012 and 2013. Spawning has been documented immediately downstream of ALH (rkm 0.1) with geographical boundaries previously described by Terraquatic Resource Management (2011) (Figure 2). Two additional sites downstream of Kinnaird

located at rkm 14.5 and rkm 18.2 were also monitored (Figure 2). These spawn-monitoring sites were selected based on past spawn monitoring surveys and White Sturgeon movement studies (BC Hydro 2013).

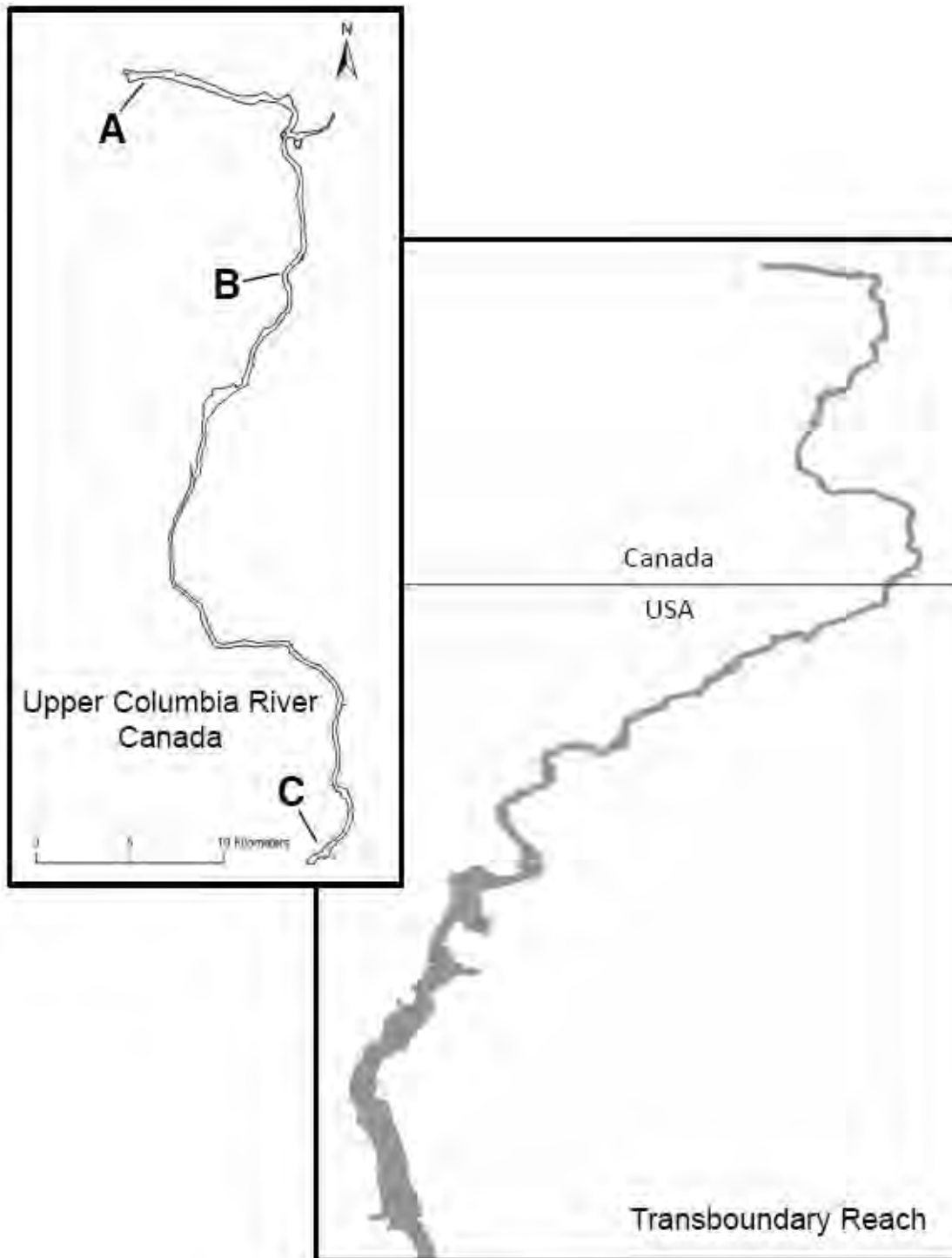


Figure 2. Egg mat and drift net deployment sites of ALH (rkm 0.1; A), Kinnaird (rkm 14.5, rkm 18.2; B), and Waneta (rkm 56.0; C) in the LCR in 2012 and 2013.

2.3.2 Egg Collection Mats and Drift Net Sampling Methods

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 since 1993 have proven that egg collection mats are effective at collecting White Sturgeon eggs at the Waneta site (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 collected 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; see Golder 2009a for details). Equipment used at other locations of the LCR were similar to the methods used for deployment and retrieval of drift nets deviating from the methods used in the Waneta area. A lead steel claw river anchor (30 kg) was used to hold the entire system to the river floor. Approximately 6 m of 3/8 galvanized chain was attached to the main anchor and was followed by a secondary steel anchor (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. An additional rope was attached from the back of the egg mat to a surface buoy to facilitate deployment and retrieval without dislodging the anchoring setup and ensured that sampling sites were consistent across the sampling program. 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. Alternatively, in areas of the river where flows allowed, a single egg mat (containing a 10 kg lead anchor fastened to a leading bridal) was deployed with a rope from the back of the egg mat to a surface buoy to facilitate deployment and retrieval. Upon retrieval, the entire system was removed from the river and brought into the boat for inspection. Both sides of the egg mats were inspected thoroughly by a minimum of 2 crewmembers before being reattached to the anchor system and redeployed.

Egg and larval sample collection, incubation, preservation, and developmental staging for estimation of fertilization date are described below (Sections 2.3.3, 2.3.4, and 2.3.5).

Drift Net Sampling - Drift net sampling has been used successfully to capture both fertilized eggs and passively dispersing yolk-sac larvae for many sturgeon species including White Sturgeon (Golder 2009a), Lake Sturgeon (*Acipenser fulvescens*; Auer and Baker 2002), and Shortnose Sturgeon (*Acipenser brevirostrum*; Moser et al. 2000). Drift net sampling has been added as a component to the adult spawn monitoring program in recent years and has

proven successful at documenting spawning days and egg dispersal patterns through the collection of eggs and larvae (BC Hydro 2013).

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. 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 (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 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. White Sturgeon eggs and larvae were enumerated by net for each sampling occasion. Deployment and retrieval times, water temperatures and depths at each net location were recorded.

Spawn-monitoring remained consistent with previously established locations of egg mat and drift net sampling (see Golder 2009b, 2010, 2012, 2013, 2014, and Terraquatic Resource Management 2011 for details). In 2012, egg mats were deployed at Waneta (n=7), and drift nets were deployed at Waneta (n=2), ALH (n=8) and rkm 18.2 (n=2) (Figure 2). In 2013, egg mats were deployed at Waneta (n=7), and drift nets were deployed at ALH (n=6), rkm 14.5 (n=2), and rkm 18.2 (n=4). Egg and larval sample collection, incubation, preservation, and developmental staging for estimation of fertilization date are described below (section 2.3.3, 2.3.4, and 2.3.5).

2.3.3 *In Situ Egg Incubation*

In 2012, a subsample of eggs (~20%) captured at Waneta were incubated *in situ* in egg incubation trays to obtain tissue for genetic analysis (see Section 2.4) but also to provide a general assessment of egg incubation success at Waneta. All eggs collected at upstream locations were incubated *in situ*. In 2013, eggs were not incubated *in situ* to hatch.

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 alive were placed in incubation trays. To load an incubation tray, 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 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 at a depth of 3.6 m. 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. Each incubation group was suspended in the water column by a small float to reduce sediment accumulation within the incubators. 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, water temperatures at the spawning area, and the rates of embryonic development provided in the literature (Beer 1981; Wang et al. 1985). The larvae that successfully hatched were preserved in 95% anhydrous ethanol and were archived for genetic analysis (see section 2.4).

2.3.4 Egg and Larvae Preservation

In 2012 and 2013, a random subsample of eggs (~20%) collected at Waneta was preserved in a Prefer solution (a buffered glyoxal/ethanol preservative) for developmental staging and estimation of fertilization date (see Section 2.3.5). At all other sites sampled in the upstream locations, eggs were developmentally staged immediately after capture and placed in incubation trays until hatch (see Section 2.3.3) to obtain a sufficient genetic tissue (see Section 2.4). A random subsample of larvae (~20%) collected at Waneta and all larvae collected at the upstream locations were preserved in 95% ethanol for developmental staging and genetic analysis. The disparity of sample preservation between locations is due to the large number of eggs and larvae collected at Waneta and relatively few samples obtained at the upstream locations.

2.3.5 Developmental Staging and Estimation of Fertilization Date

Preserved eggs and larvae were randomly examined with respect to date, stage, and site (to reduce observer bias) using a digital compound microscope (Nikon SMZ-745t Stereo Microscope with 10X eyepiece) and assigned a developmental stage. Enumeration of stages corresponded to the classification by Dettlaff et al. (1993), including embryonic stages (1 through 35; fertilization to pre-hatch) and

yolk-sac larval stages (36 through 45; hatch to exogenous feeding). Each developmental stage was associated with the appearance of at least one new feature therefore stages were not determined strictly by quantitative changes. No preserved samples had developed beyond stage 45.

Fertilization date for collected eggs and larvae was estimated by back-calculation from the recorded date and time of preservation based on developmental stage and mean incubation water temperature. The estimated age (hours; eggs, Parsley, U.S. Geological Survey, unpublished; yolk-sac larvae, Jay 2014) was subtracted from the preservation date and time to determine the estimated date and time of fertilization (i.e. spawning date). Calculated fertilization dates provided an estimation of spawning duration for each spawning site. However, the accuracy of egg developmental staging as a method to delineate spawning days 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).

2.4 Larval Genetics

Larval tissue samples used for genetic analysis were collected during the 2011 and 2012 spawn monitoring. Sampling and preservation methods used in 2011 were identical to those described in Sections 2.3.2, 2.3.3, and 2.3.4. Sampling locations included those of 2012 as well as HLK (rkm 0.1) and in the Kootenay River (see Jay et al. 2014, BC Hydro 2013 for details).

2.4.1 Genetic Analysis

The total number of 2011 larvae collected was subsampled for genotyping due to disparity in total sample sizes between spawning sites. In order of capture date, every other Waneta larval sample (~50%) and every fourth ALH larvae (~25%) were genotyped. Due to very low numbers ($n = 33$), all larvae collected at rkm 18.2 (100%) were selected for genotyping. All larvae collected in 2012 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 were diluted to a constant concentration (20 ng/μl) for use in Polymerase Chain Reactions (PCR). Individuals were genotyped using 12 microsatellite loci including *AciG-35*, *AciG-2*, *AciG-53*, *AciG-140* (Bork et al. 2008), *Atr-105* (Drauch and May 2007), *Atr-107*, *Atr-109*, *Atr-117*, *Atr-1101*, *Atr-1173*, *Atr-100*, and *Atr-113* (Rodzen and May 2002; Drauch and May 2007). PCR reactions were conducted to amplify 100 ng DNA in 25 μl reaction mixtures containing 2.5 μl of 10X PCR Buffer (0.1 M Tris-HCl, 15 mM MgCl₂, 0.5 M KCl, 0.1% gelatin, 0.1% NP-40, 0.1% Triton-X); additions of 1 μl MgCl₂ (25 mM) (0.5 μl MgCl₂ for *Atr-109*; 1.5 μl MgCl₂ for *Atr-107*; 2 μl MgCl₂ for *Atr-1101*) for all reactions excluding *Atr-105* and *Atr-117*; 2.5 μl deoxynucleotide triphosphates (dNTPs; 0.8 mmol/L); 1 μl of fluorescently labeled forward and unlabeled reverse primers (10 pmol/μl) and one unit of Taq DNA polymerase (5U/μl).

All PCR reactions were conducted using a Robocycler 96 thermal cycler (Stratogene). The PCR conditions were 94°C for 2 min, followed by 35 cycles

(33 cycles for *Atr-109*; 37 cycles for *Atr-107* and *AciG-2*) of 1 min at 94°C, 1 min for primer-specific annealing temperatures (55°C for *AciG-35*, *AciG-53*; 56°C for *Atr-100*, *Atr-105*, *Atr-107*, *Atr-109*, *Atr-113*, *Atr-117*, *Atr-1101*, *Atr-1173*; 57°C for *AciG-2*; 58°C for *AciG-140*), 72° for 2 min, and a final extension for 5 min at 72°C (excluding *Atr-105*, *Atr-107*, *Atr-109*, *Atr-117*, *Atr-1173*, and *AciG-35*). PCR products were run on 6% denaturing polyacrylamide gels and genotypes were visualized using a Hitachi FMBIO II scanner. Allele sizes were determined using commercially available size standards (MapMarker™, BioVentures Inc.) and based on several standard samples of known genotype. To minimize error, all genotypes were independently scored by two experienced lab personnel and verified again after data were entered into electronic databases. Errors in genotyping were empirically checked by blindly re-genotyping a random 10% of all samples within a year. Reported genotyping error was the ratio between observed number of allelic-errors and total number of alleles compared (Bonin et al. 2004).

Due to the polyploid nature of the White Sturgeon genome (Blackledge and Bidwell 1993), microsatellite alleles were treated as dominant data. Following Rodzen et al. (2004), each individual phenotype was converted into a $1 \times n$ vector, where n is the number of bands at the locus. Each band at a given microsatellite locus was indexed as 1 if the band was present (dominant) or indexed as 0 if the band was absent (recessive) within an individual's phenotype. Therefore, an individual phenotype showing bands 1, 3 and 7 at an 8-band microsatellite locus was converted to a $1 \times n$ vector of [1, 0, 1, 0, 0, 0, 1, 0], yielding eight dominant markers. This process was repeated for each microsatellite locus, and data were combined to produce a $1 \times n_T$ vector, where n_T is the total number of bands across all microsatellite loci for each individual.

2.4.2 Pedigree Analysis

Pedigree analyses were conducted using COLONY v2.0.4.0 (Jones and Wang 2010). This software uses a maximum likelihood method to estimate pedigree relationships among offspring belonging to a single cohort of the population by identifying networks of full-sibling and half-sibling families using their multi-locus genotypes inferred from dominant data while incorporating genotyping errors. Offspring may be inferred as full siblings who share two parents, half siblings who share a single parent, or non-siblings who share no parents. Analyses were conducted separately for each sampling site and year to estimate the number of kin groups (N_k ; groupings of inferred offspring sharing at least one common parent), N_s (the "actual" number of adults that contributed at least one offspring based pedigree reconstruction), and N_b (the "effective" number of breeding adults within a single reproductive season, estimated based on relative frequencies of full and half sibling dyads within a random sample of individuals with respect to kin; see Wang 2009). N_b is inversely related to the probability that two individuals drawn at random are siblings sharing one or two parents. Reproductive skew (e.g., unequal sex ratios, variance in reproductive success) increases the probability that two randomly selected individuals are full or half siblings, thereby decreasing N_b regardless of the estimated number of adults contributing offspring (N_s).

For each analysis, male and female polygamy was assumed. The full-likelihood method was used with most of the default parameter settings (e.g. dioecious, diploid, no inbreeding, a single run of medium length, medium likelihood precision, no sibship prior, no update of allele frequencies). The full-likelihood method assigns all sampled individuals to various inferred relationships (full-siblings, half-siblings, unrelated) jointly and is the most accurate COLONY method as verified by simulated and empirical data analyses (Wang 2004; Wang and Santure 2009). Due to sampling methods (collection of offspring of unknown parentage) COLONY parameters of sibship size, number of parent candidates, paternal sibships, maternal sibships and population allele frequency were unknown or zero. Additionally, the sex of the inferred adults is unknown.

The value for allelic dropout rate was set at 0 for all loci across both years. The values for rate of other kinds of genotyping errors (including mistyping and mutations) were empirically estimated to be 0.008 and 0.003 for the 2011 and 2012 data, respectively. Error rates were determined through the reanalysis of a ~10% random subset of individuals per year. The transformation of polyploidy codominant phenotypes to diploid dominant phenotypes could cause an apparent distortion of Mendelian segregation, and thus may lead to the split of large full sib families in the likelihood reconstruction (Wang and Scribner 2014). However, when genotyping error rates are permitted at each locus, rare phenotypes will be considered to be due to genotyping errors, and the large sibship will not be incorrectly split during pedigree reconstruction (Wang and Scribner 2014). To test whether higher genotyping error rates, relative to empirically calculated values, resulted in differences in sibship reconstruction, additional genotyping error rates (0.02 and 0.04; as suggested by Wang and Scribner (2014)) were used for the 2011 ALH data. To test whether subsampling biased results by underestimating N_s , N_b , and N_k , additional analyses were conducted for the 2011 ALH and Waneta data. Of the total samples collected, a subsample of the Waneta (25% and 12%) and ALH (12% and 6%) samples were systematically selected (i.e., every fourth sample collected in order of capture data to represent 25% of total capture) and analyzed in COLONY.

For each analysis, a replicate run was conducted using the same data and parameter values but different random number seeds allowing for the comparison of maximum likelihood estimates and best pedigree configurations as well as to evaluate program convergence for each data set. An analysis of variance (ANOVA) was used to test for differences in the number of kin groups (N_k) between sites and years.

With the combination of the estimated fertilization dates and genetic analyses data, the proportion of full-sibling individuals estimated to be fertilized within 24 and 48 hours of each other was calculated. Additionally, the duration of spawning per inferred adult, the mean and standard deviation of number of contributing adults per estimated spawning date, number of spawning partners per inferred adult, and number of estimated spawning days an inferred adult contributed progeny to were calculated.

2.4.3 Comparisons of Genetic and Empirical Estimates of Mature Adult Population

Estimates of spawning population size derived with the use of genetic and empirical data were compared. Spawning population size based on genetic data was estimated as described above (N_s). Empirical estimates of the LCR White Sturgeon population in spawning condition each year was calculated based on visual determination of maturation stages of adults captured during broodstock acquisition and corresponding sex ratios (see Section 2.2 for details).

The number of available annual spawners (N_c) and proportion of the total LCR White Sturgeon population (1,157 [414, 1889; 95% CI]; Irvine et al. 2007; 1:1 sex ratio) in spawning condition were estimated based on the proportion of total sexually mature adults captured. This method of estimation was then compared to inferred N_s determined by pedigree analysis using the 2011 genetic data. Comparisons were conducted only using the 2011 genetic data, since not all sampling sites were represented by the 2012 genetic data.

2.5 Population Monitoring, Abundance, and Characteristics

White Sturgeon life history information, population characteristics, and mark-recapture related information have been accumulated through the annual broodstock collection program since it was initiated in 2001 and through adult sampling conducted under CLBMON 28 (BC Hydro 2013). Starting in 2013, a systematic stock assessment program to address uncertainties in the current adult abundance and survival estimates was developed between Canadian and US recovery partners. This study represents the first systematic population estimate for the entire transboundary reach. The design of the stock assessment includes two annual surveys, one in the spring and one in the fall, and will continue for five years, ending in 2017.

Using standardized sampling methods, biological data collected from adult and juvenile White Sturgeon caught in 2013 are analyzed in this report for fork length frequencies, mean weight, and mean relative weight (W_r). After the completion of the stock assessment study, mark-recapture data will be used to estimate population abundance, age class structure, growth rates, density dependent responses, and survival rates of both wild adults and hatchery released juveniles.

2.5.1 Study Area and Design

The study area for the stock assessment program in 2013 started at HLK in Canada and extended downstream to Gifford Washington, USA (Figure 3). Set lines were the only method used to capture adult White Sturgeon during the stock assessment. All methods for fish capture and data analysis are consistent with those described for White Sturgeon caught during Broodstock Acquisition sampling and as described above in sections 2.2.2 and 2.2.4, respectively. During the stock assessment, four different hook sizes were used to select for different size classes of White Sturgeon. Hook sizes included 14/0, 16/0, 18/0, and 20/0 that are known to select for both adult and juvenile White Sturgeon.

Hooks were systematically attached to the mainline in 3 sets of each hook size in descending order of size. The barbs on all hooks were removed to reduce the severity of hook-related injuries and to facilitate fish recovery and release. Set line effort was consistent at 1.6 hooks per hectare of river throughout the entire study area and setline sample sites were distributed randomly and spatially balanced using the Generalized Random-Tessellation Stratified Design (GRTS). All set line hooks were baited with pickled squid obtained from Gilmore Fish Smokehouse, Dallesport, WA USA.

Data collected during the stock assessment surveys included: PIT tag number, fork length (cm), and weight (kg). All life history data were recorded in the field on standardized data forms and later entered into an electronic database. After the completion of the stock assessment study, mark-recapture data will be used to estimate population abundance, age class structure, growth rates, density dependent responses, and survival rates of both wild adults and hatchery released juveniles. Catch records are analyzed across all years of broodstock collection and stock assessment in an effort to provide recommendations to annual conservation aquaculture breeding plans and to maximize the genetic diversity available for culture practices.

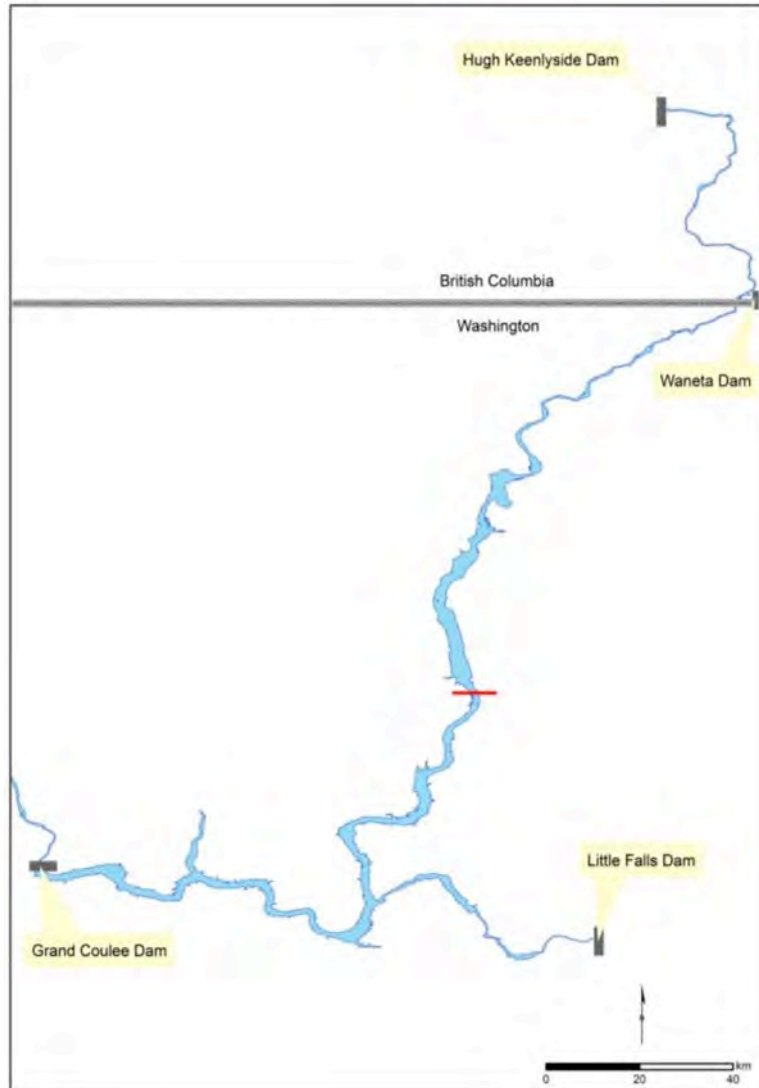


Figure 3. Study area for White Sturgeon stock assessment survey occurring from 2013-2017 in the transboundary reach of the Columbia River. Upstream extent of the study area is Hugh Keenleyside Dam in Canada and the downstream extent of the study area ends at Gifford Washington USA (indicated by the horizontal red line).

2.6 Acoustic Tagging and Telemetry

Acoustically tagging White Sturgeon within the LCR is required to monitor movement trends such as seasonal habitat use, and spawning site selection, timing, and duration. Additionally, unknown spawning habitat locations within the LCR have been identified through spawn related movements (BC Hydro 2013). Spawn related movements are defined as rapid movements from one area of long-term residency to an area of short-term residency during the spawning season (July/August), and returned movements to the original area of long-term

residency. In 2012 and 2013, movements of multiple fish were examined to provide additional support when identifying a possible spawning location.

Vemco model V16 acoustic tags (operational life of 10 years) were allocated to adult White Sturgeon predicted to spawn within the following 1-3 years (based on sex maturity examinations) in 2009, 2011, and 2013 (BC Hydro 2011a, 2013). In 2007 through 2012, all adults collected for broodstock were implanted with an acoustic tag prior to their post spawning release (BC Hydro 2013; Section 3.2.2.). In 2013, only one female that did not successfully spawn was implanted with an acoustic tag prior to release in order to monitor post release movements related to spawning. Total number of White Sturgeon acoustically tagged is provided in Table 1.

Table 1. Acoustic tags implanted by year for female and male adult White Sturgeon in the LCR.

| Year | Wild | | Broodstock | | Total |
|-------|--------|------|------------|------|-------|
| | Female | Male | Female | Male | |
| 2007 | 0 | 0 | 5 | 6 | 11 |
| 2008 | 0 | 0 | 8 | 7 | 15 |
| 2009 | 11 | 8 | 10 | 12 | 41 |
| 2010 | 0 | 0 | 9 | 10 | 19 |
| 2011 | 4 | 1 | 9 | 11 | 25 |
| 2012 | 0 | 0 | 8 | 10 | 18 |
| 2013 | 0 | 2 | 1 | 0 | 3 |
| Total | 15 | 11 | 50 | 56 | 132 |

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.

Since being initially deployed in 2003, the spatial extent of the array encompassing the LCR from HLK (rkm 0.1) southward to the Canada/U.S. International Border (rkm 57.0) 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 a 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 (e.g., cable ties, rope, float, sufficient extra float line to accommodate fluctuating water levels, remaining battery life) during each quarter annual 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 2.1.3) 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 2.7.2).

2.6.2 Telemetry Data Analysis

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 the telemetry array. For all 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 are echoes generated by the system’s environment (e.g., bathymetric profile, substrate, narrow river) or pings of multiple tags colliding resulting in detections that were not linked to an active transmitter, or does not align with movement data for an active transmitter. 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 LCR between HLK 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 tag that automatically generated a spreadsheet file containing the total number of times each tag was detected by 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 too fine scale for this species. The detection record was examined for each individual, and observed false detections were removed.

Detection data from 2012 and 2013 were summarized and proportional habitat use throughout the LCR was examined as a function of individual fish and sex. We calculated the proportional spawning site use as a function of individual fish and sex based on suspected spawn related movements (defined in Section 2.6).

Additionally, we examined migration trends from site of residency to suspected spawning site including total distance travelled (rkm), travel time (days) and time spent at a spawning location (days).

3.0 MONITORING RESULTS

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

3.1 Physical Parameters

3.1.1 Discharge

Mean daily discharge (cms; cfs) measured from Arrow Reservoir, Kootenay River, Birchbank, and Canada/U.S. International Border for the 2012 and 2013 study periods are presented in Figure 4 and Figure 5, respectively. Minimum and maximum discharge (cms; cfs) for each location and year is given in Table 2.

White Sturgeon spawning in the LCR typically occurs when water temperatures exceed 14.0°C and flows are on a descending pattern (Hildebrand et al. 1999; BC Hydro 2013). The timing and duration of White Sturgeon spawning period is annually estimated to occur between June 1 and August 15 based on egg and larval collections (see Section 2.3.5). Peak freshet flows of 7,940 and 5,720 were reached on June 28, 2012 and July 1, 2013, respectively, coinciding with the estimated initial spawning date for each year (2012, Figure 4; 2013, Figure 5). Considerable variation in hourly mean discharge occurred within the predicted spawning period.

Table 2. Minimum and maximum discharge (cubic meters per second, cms; cubic feet per second, cfs) at four locations on the LCR in 2012 and 2013.

| Location (Year) | Minimum Discharge | Maximum Discharge |
|------------------------|------------------------|-------------------------|
| Arrow Reservoir (2012) | 568 cms (20,065 cfs) | 3,258 cms (115,056 cfs) |
| Arrow Reservoir (2013) | 590 cms (20,859 cfs) | 2,146 cms (75,779 cfs) |
| Kootenay River (2012) | 230 cms (8,130 cfs) | 3,424 cms (120,930 cfs) |
| Kootenay River (2013) | 448 cms (15,824 cfs) | 2,420 cms (85,451 cfs) |
| Birchbank (2012) | 1,078 cms (38,093 cfs) | 6,043 cms (213,410 cfs) |
| Birchbank (2013) | 1,092 cms (38,581 cfs) | 4,434 cms (156,601 cfs) |
| Border (2012) | 1,407 cms (49,720 cfs) | 7,940 cms (280,400 cfs) |
| Border (2013) | 1,343 cms (47,440 cfs) | 5,720 cms (202,000 cfs) |

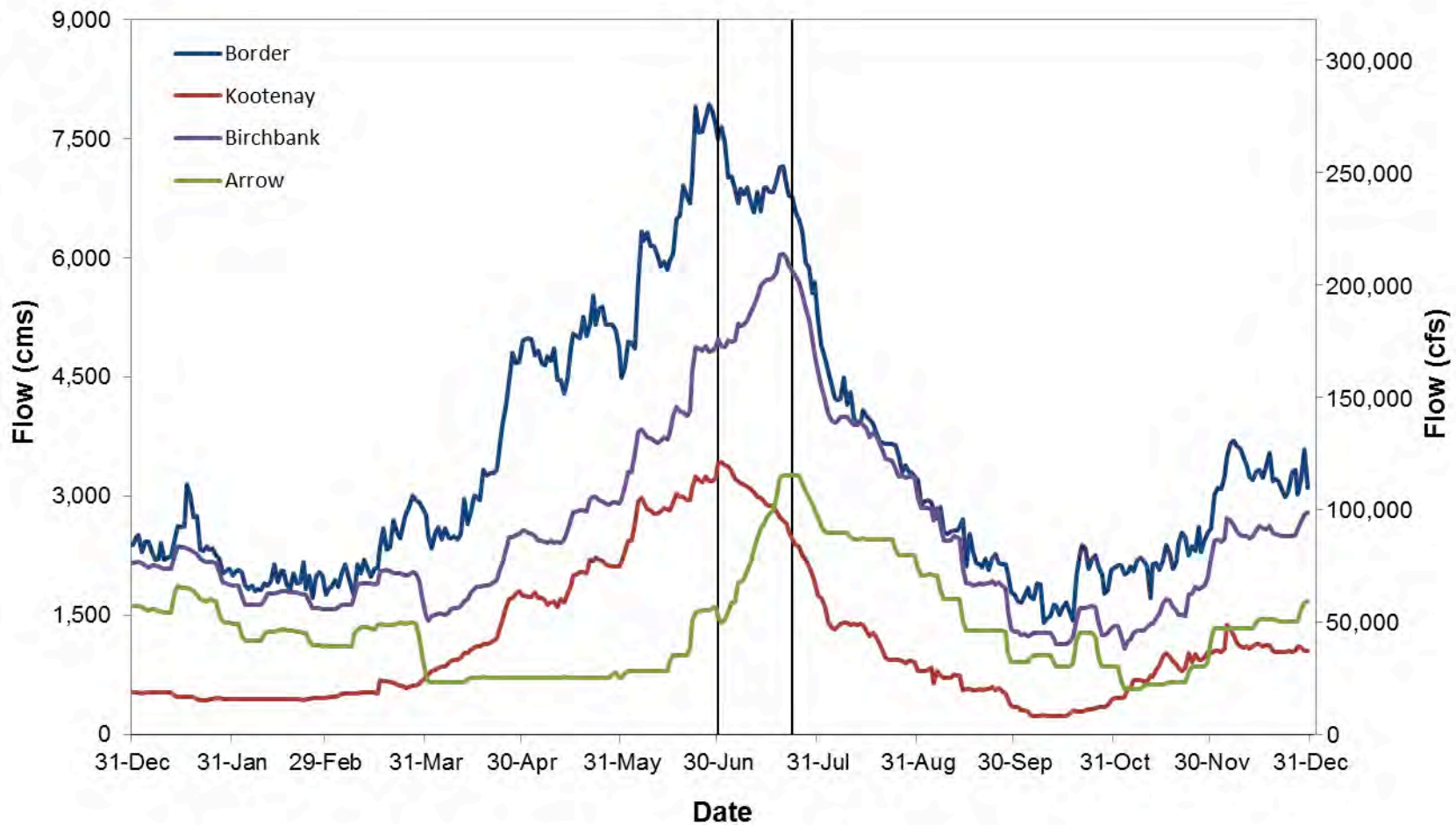


Figure 4. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada/U.S. International Border on the LCR from January 01, 2012 – December 31, 2012. The solid vertical bars represent the first and last estimated spawning dates at Waneta in 2012, either based on the collection of fertilized eggs or larvae. Despite sampling effort, estimated spawning dates were not calculated for the upstream locations.

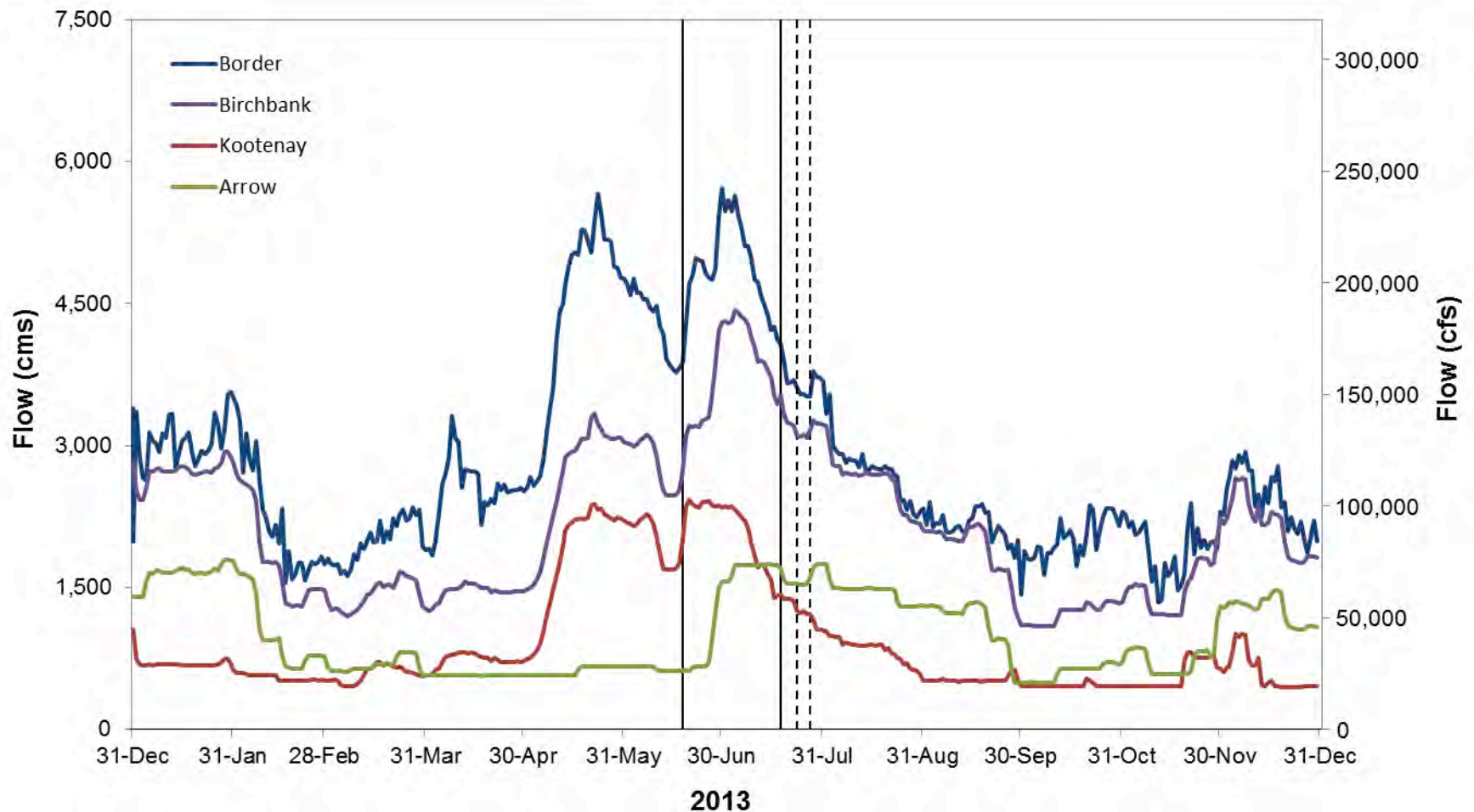


Figure 5. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada/U.S. International Border on the LCR from January 01, 2013 – December 31, 2013. The solid vertical bars represent the first and last estimated spawning dates at Waneta in 2013, either based on the collection of fertilized eggs or larvae. Vertical dashed bars represent the first and last estimated spawning dates in the upper portion of the LCR (at or above rkm 18.2).

3.1.2 Water Temperature

Mean daily river temperatures (°C) during 2012 and 2013 are illustrated in Figure 6 and Figure 7, respectively. Annual mean (\pm SD), minimum, and maximum water temperatures (°C) at locations HLK (rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle Eddy (rkm 26.0), Rivervale (rkm 35.8), and Waneta Eddy (rkm 56.0) for 2012 and 2013 are summarized in Table 3. The date of occurrence of spawning temperature threshold (14°C) at each location is provided in Table 3. Variations in water temperatures experienced during the study period can be attributed to warm/cold water influences caused in the Arrow Reservoir system (i.e., combined HLK and ALH discharges from Arrow Lakes Reservoir), and other cold-water tributary influences.

Table 3. Mean (\pm SD) daily, minimum, and maximum water temperatures (°C) recorded within the LCR during 2012 and 2013. Data was recorded at locations of HLK (rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle Eddy (rkm 26.0), Rivervale (rkm 35.8), and Waneta Eddy (rkm 56.0).

| Location | RKM | Year | Temperature | | | Date of Suspected Spawning Threshold (14°C) |
|-----------|------|------|------------------|---------|----------|---|
| | | | Mean \pm SD* | Minimum | Maximum* | |
| HLK | 0.1 | 2012 | 9.07 \pm 4.62 | 2.79 | 17.09 | 12-07-08 |
| Kootenay | 10.5 | 2012 | N/A | 2.24 | N/A | 12-07-10 |
| Kinnaird | 13.4 | 2012 | N/A | 1.76 | N/A | N/A |
| Genelle | 26.0 | 2012 | 8.89 \pm 4.62 | 2.70 | 17.04 | 12-07-10 |
| Rivervale | 35.8 | 2012 | N/A | 2.98 | N/A | N/A |
| Waneta | 56.0 | 2012 | 9.31 \pm 5.34 | 2.35 | 18.83 | 12-07-09 |
| HLK | 0.1 | 2013 | 9.97 \pm 5.05 | 3.99 | 18.97 | 13-06-08 |
| Kootenay | 10.5 | 2013 | N/A | 3.40 | N/A | N/A |
| Kinnaird | 13.4 | 2013 | 9.8 \pm 5.14 | 3.87 | 19.64 | 13-07-02 |
| Genelle | 26.0 | 2013 | 9.79 \pm 5.11 | 3.75 | 19.29 | 13-07-01 |
| Rivervale | 35.8 | 2013 | N/A | 3.88 | N/A | N/A |
| Waneta | 56.0 | 2013 | 10.09 \pm 6.04 | 2.35 | 20.83 | 13-06-11 |

*N/A: data unavailable due to lost or damaged temperature loggers

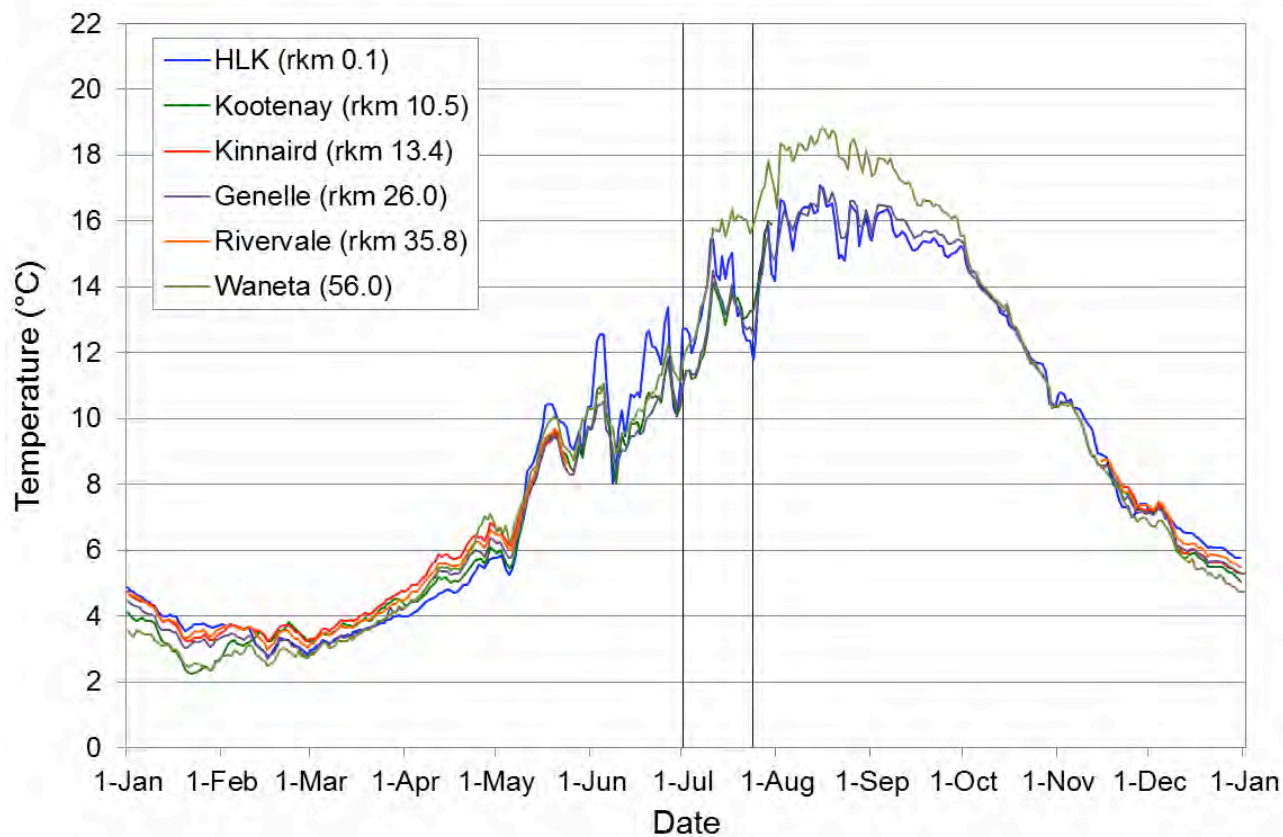


Figure 6. Mean daily water temperature (°C) of the LCR in 2012. Data was recorded at locations of HLK (rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8), and Waneta (rkm 56.0). Missing data is due to lost or damaged temperature loggers. Vertical solid lines represent estimated spawning days at the Waneta spawning area, either based on the collection of fertilized eggs or larvae. Despite sampling effort, estimated spawning dates were not calculated for the upstream locations.

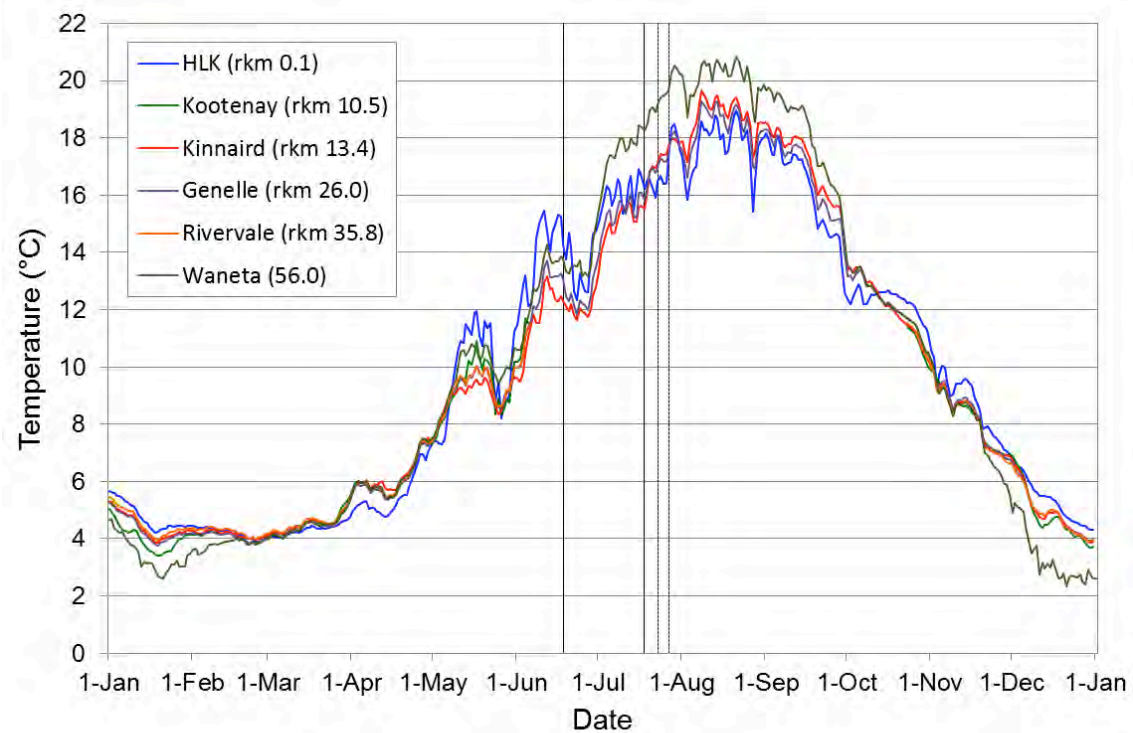


Figure 7. Mean daily water temperature (°C) of the LCR in 2013. Data was recorded at locations of HLK (rkm 0.1), Kootenay (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8), and Waneta (rkm 56.0). Missing data is due to lost or damaged temperature loggers. Vertical solid lines represent estimated spawning days at the Waneta spawning area while vertical dashed lines represent estimated spawning events near Kinnaird. Estimated spawning days were either based on the collection of fertilized eggs or larvae.

3.2 Broodstock Acquisition

3.2.1 Adult Capture

Set Lines

In 2012, total White Sturgeon captures were 222 over 3,332 hours (138.8 days) of effort extended over 22 days (June 4 – 28) at a mean water temperature of 11.17°C. CPUE was 0.067 captures/set line hour. A total of 144 adults and 71 juveniles were captured with 7 fish (6 adults, 1 juvenile) recaptured over the sampling effort period.

In 2013, total White Sturgeon captures were 403 over 4,130.5 hours (174.2 days) of effort extended over 24 days (June 10 – July 11) at a mean water temperature of 14.29°C. CPUE was 0.096 captures/set line hour. A total of 200 adults and 199 juveniles were captured. Three adults were captured twice on set lines, three adults were captured using both set lines and angling techniques, and one juvenile was captured three separate times using both set line and angling techniques.

Angling

In 2012, total White Sturgeon captures were 46 over 22.5 hours of effort. CPUE was 2.00 captures/angling hour. A total of 13 adults and 32 juveniles were captured with one juvenile captured twice.

In 2013, total White Sturgeon captures were 32 over 13.25 hours of effort. CPUE was 2.42 captures/angling hour. A total of 13 adults and 18 juveniles were captured with three adults and one juvenile captured on set lines as well. One juvenile was captured twice via angling.

3.2.2 Fish Handling, Transport, Hatchery Spawning, and Release

2012

Of the 260 White Sturgeon captured, 18 fish (8 females, 10 males) captured on set lines were transported to the KSH to be used as broodstock. No fish captured by angling were in spawning condition. The remaining 242 White Sturgeon were assessed and released alive at their capture locations. A total of 39 fish (15.0% of total capture; 37 and 2 by means of set lines and angling, respectively) were first time captures (hatchery released juveniles were considered recaptures). Of the first time capture fish, 5 (1 female, 4 males) were considered to be sexually mature and transported to the KSH. All fish selected for broodstock were spawned successfully and family crosses were determined based on a full factorial mating design. However, eggs of three of the females had 0% survival to hatch resulting in 5 maternal families (see FFSBC 2013 for details). After the induced spawning event, all White Sturgeon were released into the LCR. In the spring of 2013, 4,037 juveniles were stocked in the LCR.

2013

Of the 426 White Sturgeon captured, 14 fish (7 females, 7 males) captured on set lines and 2 fish (1 female, 1 male) captured via angling were transported to the KSH to be used as broodstock. The remaining 410 White Sturgeon were assessed and released alive at their capture location. A total of 61 fish (14.3% of total capture; 60 and 1 by means of set lines and angling, respectively) were first time captures (hatchery released juveniles were considered recaptures). Of the first time capture fish, 6 (2 females, 4 males) were assessed as sexually mature and transported to the KSH. Of the 16 fish selected for broodstock, 9 (6 females, 3 males) were spawned successfully and 6 maternal families were crossed using a modified full factorial design. The remaining 7 fish were not used due to immature gametes/gonads (see FFSBC 2014 for details). One immature female was implanted with an acoustic transmitter (Vemco Model V16) to monitor possible post release movements related to spawning. All White Sturgeon held at the hatchery were released to the LCR.

From 2001 to 2013, the majority of adults used as broodstock for conservation aquaculture have been captured in the downstream section (67.8%; Trail (rkm 36.0) to Waneta (rkm 56.0)) while the upstream sections have had a lower percentage of broodstock representation (Table 4).

Table 4. The proportion of adult White Sturgeon broodstock selected from different sections of the LCR for use in the conservation aquaculture program from 2001-2013.

| Reach | Proportion |
|---|------------|
| HLK (rkm 0.1) to Norn's Creek (rkm 8.0) | 0.16 |
| Kootenay Eddy (rkm 10.5) | 0.13 |
| Kinnaird (rkm 13.4) to Trail (rkm 36.0) | 0.03 |
| Trail (rkm 36.0) to Border (rkm 57.0) | 0.68 |

3.2.3 Sex and Maturity

During broodstock acquisition, sex of White Sturgeon was determined from previous capture records or through surgical examination (Section 2.2.3; see UCWSRI 2006 for sex determination details). In 2012, sex was determined for 118 captured fish consisting of 49 males and 69 females (male:female sex ratio of 0.7:1) (Table 5). Male captures consisted of 15 M0 (0.31; proportion of total male capture), 24 M1 (0.49), and 10 M2 (0.20). Female captures included 24 F0 (0.34), 24 F1 (0.34), 6 F2 (0.09), 7 F3 (0.10), 8 F4 (0.12), and 0 F5 (0.00). In 2013, the White Sturgeon of known gender (n=164) consisted of 71 males and 93 females making for a male:female sex ratio of 0.8:1 (Table 5). Male captures consisted of 22 M0 (0.31), 39 M1 (0.5), and 10 M2 (0.14), and female captures consisted of 43 F0 (0.46), 33 F1 (0.35), 7 F2 (0.08), 2 F3 (0.02), 8 F4 (0.09), and 0 F5 (0.00). Table 5 outlines the sex ratios (male:female) observed for most years between 1992 and 2013.

Table 5. Sex ratios for White Sturgeon captured from 1992-1998 and from 2001-2013 in the LCR.

| 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 |
| 2012 | 49 | 69 | 0.7:1 |
| 2013 | 71 | 93 | 0.8:1 |
| Total | 608 | 636 | 1:1 |

3.2.4 Fork Length (FL) Frequency and Weight

Mean (\pm SD) FL (cm) of all fish captured during the 2012 and 2013 broodstock acquisition was 148.5 ± 42.1 and 141.1 ± 45.2 , respectively (Figure 8). The mean FL of adults captured in 2012 and 2013 was 179.3 ± 19.3 and 183.2 ± 18.8 , respectively. Mean FL of juvenile captures in 2012 and 2013 was 100.7 ± 12.9 and 99.6 ± 16.4 , respectively. White Sturgeon captured on set lines were larger (2012, 154.6 ± 40.9 ; 2013, 141.7 ± 45.2) than fish captured angling (2012, 119.3 ± 35.0 ; 2013, 133.3 ± 46.8) (Figure 8). Across both years, females were larger (2012, 190.5 ± 13.5 FL; 2013, 193.1 ± 16.6 FL) than males (2012, 177.5 ± 14.2 FL; 2013, 182.6 ± 13.3) (Figure 9). The length frequency distribution of all sexually mature adult White Sturgeon used for the conservation aquaculture program from 2001-2013 shows that females are on average larger than males (Figure 10).

During the 2012 and 2013 broodstock acquisition, the mean (\pm SD) weight (kg) of captured females was 55.9 ± 13.9 and 57.7 ± 16.9 , and mean weight of captured males was 43.3 ± 12.5 and 47.9 ± 11.1 , respectively (Table 6). Mean weight for specific maturation stages (Section 2.2.3; see UCWSRI 2006 for details) are given in Table 6.

In 2012, mean (\pm SD) W_r of females and males was 86.0 ± 8.8 and 83.5 ± 9.5 , respectively (Table 7). In 2013, mean (\pm SD) W_r of females and males was 84.4

± 9.3 and 85.1 ± 8.6 , respectively (Table 7). Variation in W_r was best described by sex, with females having slightly higher W_r compared to males. Further, female W_r was highest for individuals in spawning condition (F4; Table 7). W_r for White Sturgeon in the LCR, Canada, is less than reported in Columbia River populations downstream of Grand Coulee Dam, USA (Devore et al. 2000; Howell and Mclellan 2007).

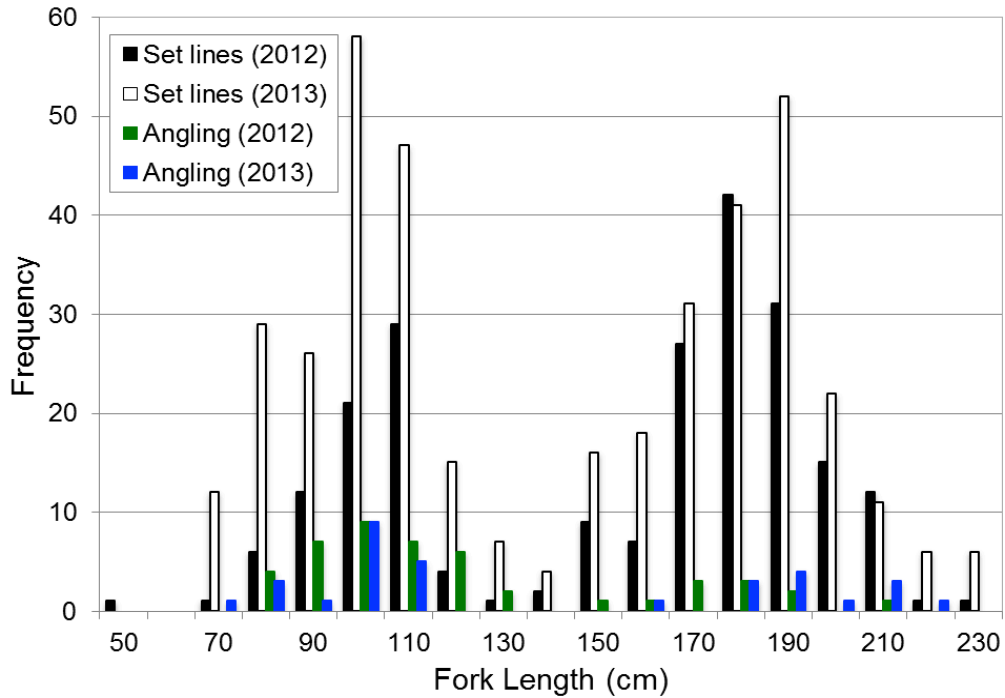


Figure 8. Fork length (cm) frequency of White Sturgeon captured using set lines and angling techniques during broodstock acquisition conducted on the LCR in 2012 and 2013.

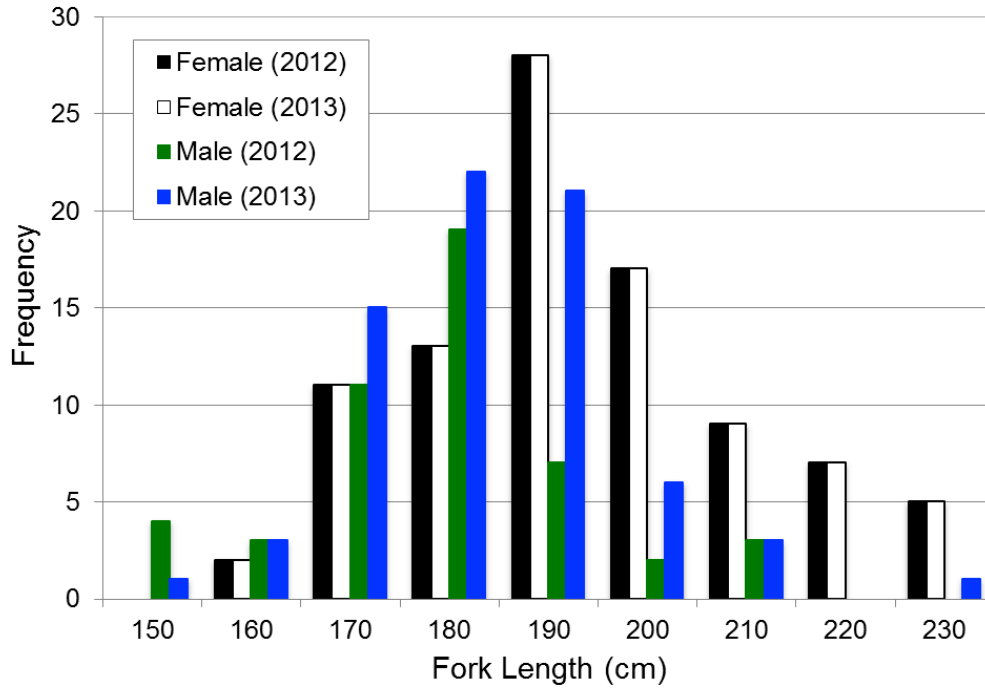


Figure 9. Fork length (cm) frequency of adult White Sturgeon of known sex captured during broodstock acquisition conducted on the LCR in 2012 and 2013.

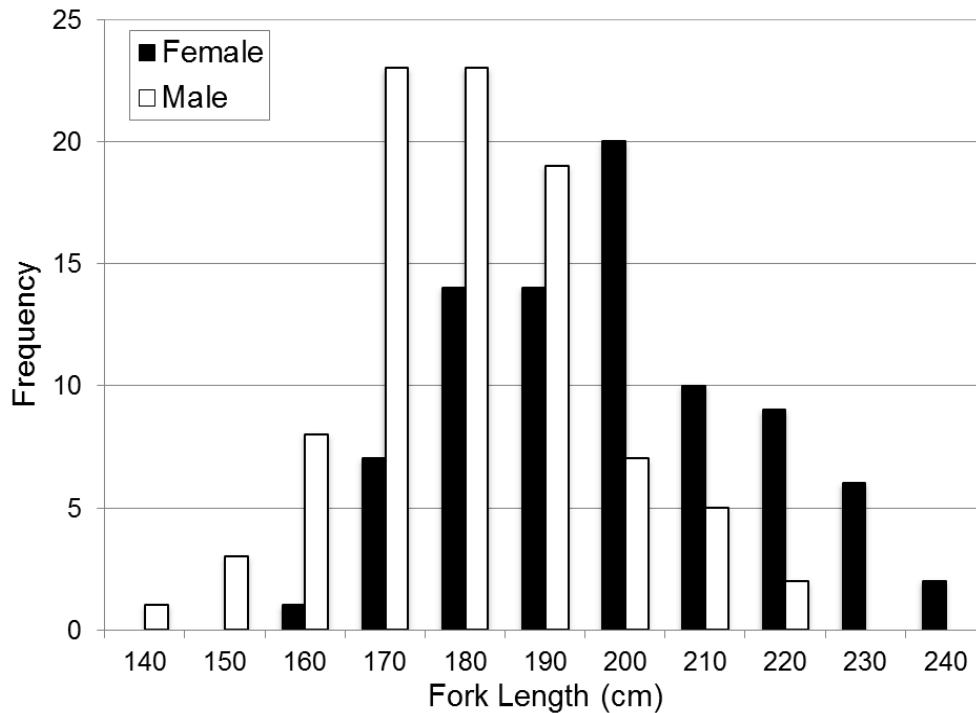


Figure 10. Fork length (cm) frequency of sexually mature female and male White Sturgeon captured and used as broodstock in the LCR conservation aquaculture program during the years 2001 through 2013.

Table 6. Weight (kg; mean \pm SD) for female and male adult White Sturgeon collected during broodstock acquisition on the LCR in 2012 and 2013. Weights are provided for specific maturation stages as described in Section 2.2.3 and UCWSRI (2006).

| Sex | 2012 | 2013 |
|--------|-----------------|-----------------|
| Female | 55.9 \pm 13.9 | 57.7 \pm 16.9 |
| F4 | 68.0 \pm 17.7 | 69.3 \pm 21.4 |
| F3 | 65.1 \pm 13.2 | 56.0 \pm 0.0 |
| F2 | 69.5 \pm 14.1 | 55.7 \pm 9.1 |
| F1 | 50.6 \pm 9.1 | 59.3 \pm 15.7 |
| F0 | 51.8 \pm 11.7 | 54.7 \pm 16.5 |
| Male | 43.3 \pm 12.5 | 47.9 \pm 11.1 |
| M2 | 54.4 \pm 14.7 | 48.2 \pm 12.6 |
| M1 | 40.3 \pm 10.2 | 48.4 \pm 11.8 |
| M0 | 40.8 \pm 10.8 | 45.6 \pm 8.7 |

Table 7. Relative weights (W_r ; mean \pm SD) for female and male adult White Sturgeon collected during broodstock acquisition on the LCR in 2009 through 2013. Relative weights are provided for specific maturation stages as described in Section 2.2.3 and UCWSRI (2006).

| Sex | 2009 | 2010 | 2011 | 2012 | 2013 |
|--------|------------------|----------------|-----------------|-----------------|-----------------|
| Female | 90.4 \pm 20.1 | 85.9 \pm 9.0 | 86.0 \pm 13.2 | 86.0 \pm 8.8 | 84.4 \pm 9.3 |
| F4 | 105.5 \pm 11.3 | 95.3 \pm 7.7 | 90.7 \pm 8.5 | 95.4 \pm 4.6 | 90.8 \pm 12.1 |
| F3 | 90.1 \pm 8.4 | 89.6 \pm 8.7 | 89.6 \pm 6.2 | 91.4 \pm 11.9 | 88.4 |
| F2 | 84.9 \pm 7.4 | 84.3 \pm 6.1 | 86.4 \pm 8.5 | 94.1 \pm 11.9 | 89.3 \pm 7.3 |
| F1 | 85.5 \pm 6.6 | 82.9 \pm 8.5 | 86.6 \pm 17.1 | 83.5 \pm 7.0 | 83.4 \pm 10.1 |
| F0 | 83.0 \pm 8.8 | 81.3 \pm 7.4 | 79.6 \pm 8.7 | 82.2 \pm 7.3 | 83.0 \pm 8.3 |
| Male | 90.3 \pm 22.8 | 83.3 \pm 7.5 | 83.1 \pm 8.5 | 83.5 \pm 9.5 | 85.1 \pm 8.6 |
| M2 | - | - | - | 90.7 \pm 6.0 | 86.1 \pm 10.4 |
| M1 | - | - | - | 81.2 \pm 9.5 | 86.1 \pm 9.1 |
| M0 | - | - | - | 82.3 \pm 9.6 | 83.0 \pm 7.0 |

3.2.5 Adult Genetics

The collection of tissue samples, in the form of dried fin clips, of all captured adults was continued and archived. Additionally, tissue samples were collected from wild juvenile, drifting larvae and eggs (incubated to hatch) during other White Sturgeon monitoring programs. Future genetic analysis of all samples will provide insight into population genetic diversity, adult breeding dynamics including number of breeding adults, variation in reproductive success through parentage and pedigree analysis, and spatial genetic structuring among spawning sub-populations. Pedigree analysis using wild larval samples collected in 2011 and 2012 has been completed and results are discussed in Section 3.4. Current and future results will be applied to recovery planning and aquaculture programs for LCR White Sturgeon.

3.3 Spawn Monitoring

3.3.1 Egg and Larval Sampling: Sampling Effort and Sample Preservation

2012

Downstream Location – Waneta (rkm 56.0)

Egg mats (n=7; 48-hour sets) and drift nets (n=2; 3 hour sets) were deployed on June 11 and sampling continued until August 3 with water temperatures ranging from 9.6 to 18.3°C (Figure 6). Total sampling effort for egg mats and drift nets were 16,627.2 hours (692.8 days) and 48.2 hours (2.0 days), respectively, for a cumulative effort of 16,675.4 hours (694.8 days) (Table 8). The mean (\pm SD) daily effort was 59.8 ± 18.8 hours and 2.3 ± 0.8 hours, and mean water depth was 5.2 ± 2.4 m and 7.1 ± 1.8 m for egg mats and drift nets, respectively.

A total of 360 eggs and 17 larvae were captured at Waneta between the dates of July 4 and July 27 (Table 8). Of the total capture, 86 eggs (33 from drift nets and 53 from egg mats) were preserved and 98 eggs (28 from drift nets and 70 from egg mats) were incubated, successfully hatched and preserved. All larvae collected in drift nets (n=15) and on egg mats (n=2) were preserved. The day of largest sample collection was July 16 with 73 samples (15 preserved eggs, 51 incubated eggs and 7 larvae) representing 37% of total collection (38% of egg capture; 41% of larval capture). The next largest sampling collection dates were July 9 and July 25 each representing 16% of the total collection.

Upstream locations – ALH (rkm 0.1) and downstream of Kinnaird (rkm 18.2)

Sampling at the upstream locations was delayed until July 26 due to high water flows (50 year flood level; see Section 3.1.1) that prevented gear deployment. Once permitted, drift nets were deployed for 24-hour sets at ALH (n=8) on July 26 and on August 12 at rkm 18.2 (n=2) with water temperatures ranging from 13.1 to 16.7 °C (Figure 6). Sampling was terminated at both sites on August 16. Across all sites, the cumulative effort for entire study period was 3,126.0 hours (130.3 days) (Table 8). Total sampling effort completed at ALH and rkm 18.2 was 2,929.2 hours (122.1 days) and 196.8 hours (8.2 days), respectively. The mean (\pm SD) daily effort at ALH and rkm 18.2 was 21.2 and 24.6 hours, respectively. Mean (\pm SD) water depth was 8.9 ± 4.8 m at ALH and 7.4 ± 0.7 m at rkm 18.2.

Six dead eggs were captured at ALH, however, there were no live eggs or larvae collected and preserved at ALH or rkm 18.2 (Table 8). This is expected to be a result of the hydrology of the spawning areas in 2012 (see Section 3.1.1). Both temperature and flow have been shown as important environmental predictors of White Sturgeon spawning. Hildebrand et al. (1999) found that spawning primarily occurred at the Waneta area following temperatures exceeding the 14°C threshold. In 2012, water temperatures at ALH and rkm 18.2 rarely rose above this threshold (14.3 ± 1.0 °C; mean \pm SD) and did not remain above 14°C for extended periods of time during the sampling period. Further, high flows increasing the riverbed area could have potentially provided additional spawning

areas that were not sampled. Due to high flows (50 year flood level; Figure 4), nets were deployed three weeks later in 2012 compared to the 2011 spawn-monitoring program (BC Hydro 2013). However, it is believed spawning activity did not occur prior to deployment, as drift nets were set while water temperatures were below optimal spawning temperatures.

2013

Downstream Location – Waneta (rkm 56.0)

Egg mats (n=7; 48-hour sets) were deployed on June 17 and sampling continued until July 31 with daily mean water temperatures ranging from 13.1 to 20.5°C (Figure 7). Total sampling effort for egg mats was 14,739 hours (614.1 days) (Table 8). Additional details and results are summarized in Golder and LGL (2014).

Spawning was first detected on June 21 on the descending arm of the first freshet peak that occurred on May 9. Flows increased in June and spawning was not detected again until the descent of the second peak after June 23 (Figure 5). Over the sampling period, a total of 410 White Sturgeon eggs were captured at Waneta (Table 8). Of the total capture, 119 eggs and 0 larvae were preserved for developmental staging. *In situ* incubation was not conducted in 2013 therefore no eggs were collected for incubation. The day of largest sample collection was July 8 with 195 eggs representing 47.6% of the total sample collection at the Waneta site.

Upstream locations – ALH (rkm 0.1) and downstream of Kinnaird (rkm 14.5, rkm 18.2)

Egg and larval sampling was conducted from July 11 to August 9 with water temperatures ranging from 13.9 to 19.4 °C (Figure 7). Prior to July 19, drift nets were deployed for 24 hours (long-set). After July 19, drift nets were deployed for short sets (approximately 4 hours; short-set) between the hours of 8:00 and 15:00. Across all upstream sites, the cumulative effort for entire study period was 1,197.9 hours (49.9 days) (Table 8). During the long-set sampling methods, the mean (\pm SD) daily effort was 23.8 ± 1.3 hours. For the short-set sampling methods, drift nets were set at an average daily time of 4.4 ± 0.25 hours. Sampling at ALH occurred between July 11 and August 9. Total sampling effort conducted at ALH was 680.4 hours (28.4 days) with a mean daily effort of 24.6 ± 2.2 and 4.6 ± 0.7 hours for long- and short-sets, respectively. Cumulative sampling effort at rkm 14.5 was 154.3 hours (6.4 days) between the dates of July 18 and August 9. The mean daily effort at rkm 14.5 was 22.3 ± 0.0 and 4.2 ± 0.7 hours for long- and short-sets, respectively. Sampling at rkm 18.2 occurred through the dates of July 15 and August 9 for a total effort of 363.2 hours (15.1 days) with a mean daily effort of 24.4 ± 1.6 and 4.2 ± 0.6 for long- and short-sets, respectively. Mean (\pm SD) water depth was 6.3 ± 2.6 m at ALH, 4.3 ± 0.6 m at rkm 14.5, and 3.9 ± 0.9 m at rkm 18.2.

A total of 5 yolk-sac larvae were collected and preserved at the upstream locations (Table 8). No eggs were collected at any of the three monitoring sites. Zero yolk-sac larvae were collected at ALH (CPUE = 0), 1 yolk-sac larvae was

collected at rkm 14.5 (CPUE= 0.006) on July 29, and 4 yolk-sac larvae were collected at rkm 18.2 (CPUE = 0.011) between the dates of July 29 and August 2.

Table 8. White Sturgeon egg and larval collection and sampling effort for monitoring locations in the LCR including Waneta (rkm 56.0), downstream of Kinnaird (rkm 18.2, rkm 14.5), Kootenay (rkm 10.5), downstream ALH (rkm 6.0), ALH (rkm 0.1) and HLK (rkm 0.1) for years 2008 through 2013.

| 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 |
| | rkm 18.2 | - | - | - | 0 | 5 | 976 |
| | rkm 6.0 | - | - | - | 0 | 0 | 3,091 |
| 2010 | Waneta | 4,003 | 16 | 18,204 | 888 | 89 | 113 |
| | 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 | 50 |
| | rkm 18.2 | - | - | - | 2 | 32 | 1,400 |
| | rkm 14.5 | - | - | - | 0 | 0 | 154 |
| | rkm 10.5 | - | - | - | 0 | 0 | 993 |
| | HLK | - | - | - | 0 | 0 | 461 |
| | ALH | 2 | 0 | 3,614 | 183 | 308 | 2,538 |
| 2012 | Waneta | 226 | 2 | 16,627 | 134 | 15 | 48 |
| | rkm 18.2 | - | - | - | 0 | 0 | 197 |
| | ALH | - | - | - | 6 | 0 | 2,929 |
| 2013 | Waneta | 410 | 0 | 14,739 | - | - | - |
| | rkm 18.2 | - | - | - | 0 | 4 | 363 |
| | rkm 14.5 | - | - | - | 0 | 1 | 154 |
| | ALH | - | - | - | 0 | 0 | 680 |

3.3.2 *In Situ Incubation*

2012

In situ incubation was only conducted at the Waneta site as no live eggs were captured at the upstream locations. A total of 228 eggs were incubated *in situ* in seven incubation groups between the dates of July 4 and July 27 at water temperatures ranging from 11.3°C to 20.3°C (Table 9). Mean (\pm SD) hatch rate was 51.1 \pm 16.8% with a range of 30.0% to 80.8%. Mean hatch rates for eggs collected by egg mats and drift nets were 56.1 \pm 20.4% and 46.1 \pm 12.2%, respectively. Post-hatch larval survival ranged from 27.3% to 100.0% with a mean of 86.6 \pm 24.2%.

2013

In situ incubation was not conducted at any of the spawn monitoring locations in 2013.

Table 9. Mean daily water temperature (°C), *in situ* incubation hatch rate (%), and larval survival (%) for White Sturgeon eggs from egg mat and drift net sampling at Waneta in 2012. Developmental stages are based on Dettlaff et al. (1993).

| Incubation Period | n | Stage | Water Temp (°C) | Larvae | | Eggs | | Hatch Rate (%) | Larval Survival (%) |
|-------------------|------------|--------------|-----------------|-----------|-----------|----------|------------|----------------|---------------------|
| | | | | Live | Dead | Live | Dead | | |
| Egg Mat | | | | | | | | | |
| July 4 - 9 | 32 | Neurulation | 16.0 | 3 | 8 | 0 | 21 | 34.4 | 27.3 |
| July 9 - 16 | 16 | Cleavage | 18.2 | 11 | 0 | 0 | 5 | 68.8 | 100.0 |
| July 11 - 16 | 14 | Gastrulation | 18.5 | 2 | 2 | 0 | 10 | 28.6 | 50.0 |
| July 13 - 16 | 39 | Yolk Plug | 18.7 | 25 | 0 | 0 | 14 | 64.1 | 100.0 |
| July 20 - 25 | 26 | Cleavage | 17.5 | 21 | 0 | 0 | 5 | 80.8 | 100.0 |
| July 25 - 27 | 5 | Neurulation | 17.9 | 3 | 0 | 0 | 2 | 60.0 | 100.0 |
| Total | 132 | | 17.8 | 65 | 10 | 0 | 57 | 56.8 | 86.7 |
| Drift Net | | | | | | | | | |
| July 9 - 16 | 7 | Cleavage | 18.2 | 4 | 0 | 0 | 3 | 57.1 | 100.0 |
| July 11 - 16 | 50 | Gastrulation | 18.5 | 13 | 2 | 0 | 35 | 30.0 | 86.7 |
| July 13 - 16 | 11 | Yolk Plug | 18.7 | 6 | 0 | 0 | 5 | 54.5 | 100.0 |
| July 18 - 25 | 12 | Cleavage | 17.9 | 4 | 0 | 0 | 8 | 33.3 | 100.0 |
| July 20 - 25 | 9 | Cleavage | 17.5 | 4 | 0 | 0 | 5 | 44.4 | 100.0 |
| July 25 - 27 | 7 | Neurulation | 17.9 | 3 | 1 | 0 | 3 | 57.1 | 75.0 |
| Total | 96 | | 18.1 | 34 | 3 | 0 | 59 | 38.5 | 91.9 |
| Combined | 228 | | 18.0 | 99 | 13 | 0 | 116 | 49.1 | 88.4 |

3.3.3 Developmental Staging and Estimated Spawning Dates

All preserved eggs and larvae were assigned a developmental stage based on Dettlaff et al. (1993) to calculate an estimated date of fertilization. Samples ranged from newly fertilized eggs to yolk-sac larvae (Table 10).

Table 10. Proportion of White Sturgeon eggs and larvae collected across different developmental stages from spawn monitoring locations of Waneta, rkm 14.5, and rkm 18.2 in 2012 and 2013. In 2012, samples were only collected at the Waneta site. No samples were collected at ALH in 2012 or 2013. Developmental stages are based on Dettlaff et al. (1993).

| Development Category | Stage | Waneta (2012) | | Waneta (2013) | | rkm 14.5 (2013) | | rkm 18.2 (2013) | |
|--------------------------|---------|---------------|--------------|---------------|--------------|-----------------|--------------|-----------------|--------------|
| | | <i>n</i> | <i>Prop.</i> | <i>n</i> | <i>Prop.</i> | <i>n</i> | <i>Prop.</i> | <i>n</i> | <i>Prop.</i> |
| Cleavage | 1 - 6 | 12 | 0.08 | 38 | 0.42 | 0 | 0.00 | 0 | 0.00 |
| Gastrulation | 7 - 14 | 17 | 0.11 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Yolk Plug | 15 - 18 | 4 | 0.03 | 7 | 0.08 | 0 | 0.00 | 0 | 0.00 |
| Neurulation | 19 - 26 | 8 | 0.05 | 15 | 0.17 | 0 | 0.00 | 0 | 0.00 |
| Elongation of Pronephros | 27 | 0 | 0.00 | 9 | 0.10 | 0 | 0.00 | 0 | 0.00 |
| Heart Formation | 28 - 33 | 14 | 0.09 | 7 | 0.08 | 0 | 0.00 | 0 | 0.00 |
| Pre-Hatch | 34 - 35 | 17 | 0.11 | 14 | 0.16 | 0 | 0.00 | 0 | 0.00 |
| Yolk-sac Larvae | 36 - 45 | 78 | 0.52 | 0 | 0.00 | 1 | 1.00 | 4 | 1.00 |

2012

Downstream Location – Waneta (rkm 56.0)

An estimated 18 discrete spawning days (24-hour periods) occurred at Waneta between the dates of June 28 and July 22 (Figure 11). Three peaks of spawning activity were identified to have occurred during late June/early July (June 28 – July 4) and mid-July (July 7 – 13; July 15 – 22). Of the estimated spawning days, collected larval samples represented 10 days (July 1 – 21) and collected egg samples represented 14 days (June 28 – July 22). Six estimated spawning days were represented by both egg and larval samples (July 2, 7, 8, 9, 17, and 18).

Upstream locations – ALH (rkm 0.1) and downstream of Kinnaird (rkm 18.2)

Estimated spawning days were not calculated for ALH or rkm 18.2 since there were no live eggs or larvae collected.

2013

Downstream Location – Waneta (rkm 56.0)

An estimated 12 discrete spawning days occurred at Waneta between the dates of June 18 and July 18 with the majority of spawning activity between July 1 and July 11 (Figure 12). The two peaks in spawning activity is a reflection of the LCR discharge with estimated spawning days occurring on the descending limbs of each freshet peak (Figure 5).

Upstream locations – ALH (rkm 0.1) and downstream of Kinnaird (rkm 14.5, rkm 18.2)

Two discrete spawning days were estimated to have occurred at rkm 14.5 and 18.2 rkm on July 23 and July 27 (Figure 12). Larvae collected at rkm 14.5 (n=1) and 18.2 rkm (n=3) represented the estimated spawning date of July 23. One larvae collected at rkm 18.2 represented the spawning date of July 27.

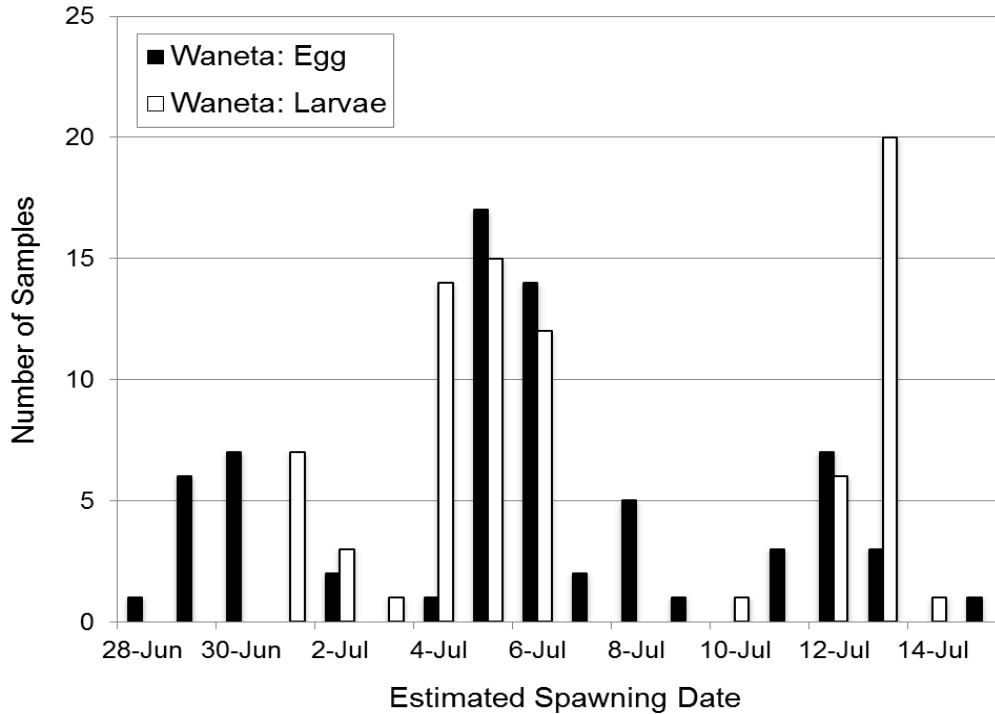


Figure 11. Estimated spawning dates in the LCR during 2012 at Waneta. Dates are determined through back calculation from date of capture based on developmental stage of each sample. No live eggs or larvae were collected at the upstream locations.

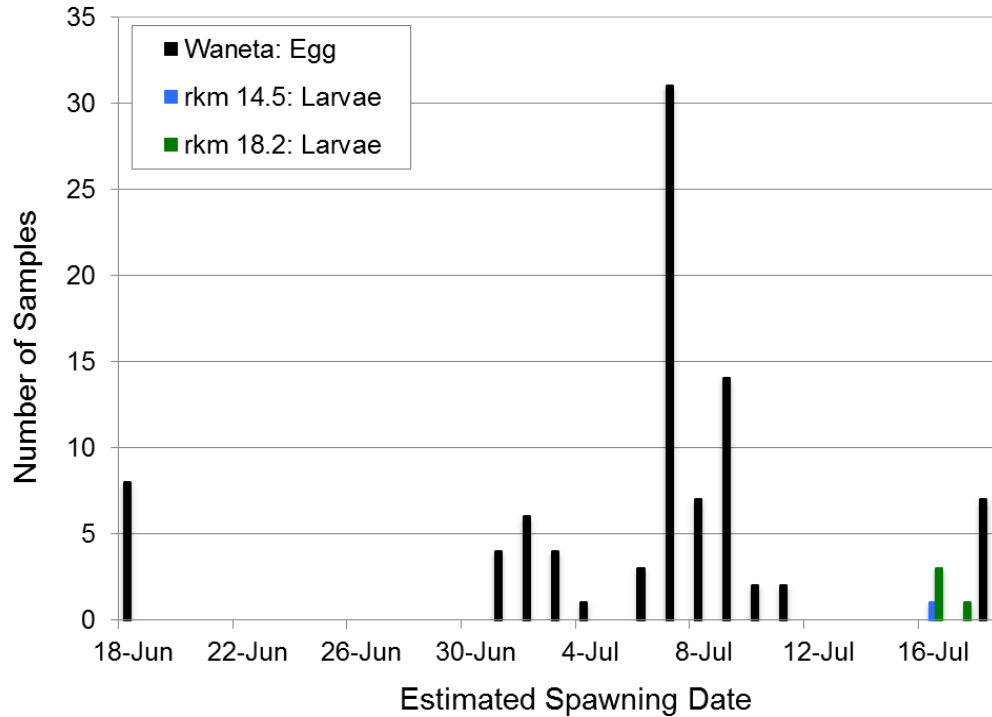


Figure 12. Estimated spawning dates in the LCR during 2013 at locations of Waneta, rkm 18.2, and rkm 14.5. Dates are determined through back calculation from date of capture based on developmental stage of each sample.

3.4 Larval Genetics

3.4.1 Genetic Analysis

Across the 12 microsatellite loci, the number of alleles per locus varied from 5-21 (12.4 ± 6.4 ; mean \pm SD). The total number of alleles observed was similar in 2011 and 2012 (143 and 139 total alleles, respectively).

3.4.2 Pedigree Analysis

The number of kin groups (N_k) varied among sites and between years (Table 11; Figure 13 and 14). The number of full-sibling families nested within each kin group was significantly different between sites and years (Figure 13; $F=10.181$, $P<0.001$). In 2011, the Waneta site was estimated to have had the greatest number of kin groups ($N_k = 60$) with 4.75 ± 2.61 (mean \pm SD) full-sibling families nested within a kin group. Twenty kin groups were identified at the ALH site in 2011. However, the mean number of full-sibling families nested within a kin group (4.75 ± 2.79) was similar to Waneta (2011). Additionally, inferred kin groups at ALH exhibited greater variability in numbers of full-sibling families per group compared to the other sites. Comparatively lower number of full-sibling families per kin group were estimated to have occurred at the sites of Waneta in 2012 (2.94 ± 1.49 ; $N_k = 49$) and rkm 18.2 in 2011 (2.44 ± 0.62 ; $N_k = 18$), indicating spawning individuals at these sites had a lower number of reproductive

partners relative to ALH (2011) and Waneta (2011). In 2011, the proportion of full-sibling individuals estimated to be fertilized within 24 and 48 hours of each other was 0.792 and 0.917 at ALH and 0.711 and 0.844 at Waneta, respectively. In 2012, 0.286 and 1.000 of full-sibling individuals were estimated to be fertilized within 24 and 48 hours at Waneta, respectively.

In 2011, the estimated effective breeding number (N_b) for the Waneta site was 46 (31, 70; 95% CI) representing 48.9% of the total UCR estimated N_b , while ALH and rkm 18.2 had an estimated N_b of 16 (9, 34) and 32 (19, 58) contributing 17.0% and 34.0% of the total estimated N_b , respectively (Table 11). Over the sections of UCR surveyed, the Waneta site was the major contributor to the estimated number of adults contributing offspring (N_s) with 89 inferred spawning adults representing 61.0% of the total estimated N_s , while ALH and rkm 18.2 were estimated to have 29 and 28 spawning adults contributing to progeny sampled, respectively; both representing 19% of the total N_s . N_s and N_b remained relatively constant when the number of samples used within an analysis was reduced for ALH and Waneta while N_k decreased (Table 13). Subsampling 50%, 25% and 12% of the Waneta larvae resulted in estimated N_s of 89, 87, and 48, and estimated N_b of 46, 52, and 43, respectively. N_k reduced from 61 with a subsample of 50% of the total larvae to 46 and 28 when 25% and 12% subsampling occurred, respectively. Subsampling 25%, 12% and 6% of the total ALH larvae collected resulted in estimated N_s of 29, 24, and 21 and estimated N_b of 16, 17, and 24, respectively. A reduction in N_k (20, 15, and 13) was also observed within the ALH data when a subsample of larvae was analyzed (25%, 12%, and 6%, respectively). In 2012, N_b and N_s were estimated to be of 79 (56, 110) and 97, respectively. However, results only represent adults spawning at the Waneta site since no samples were collected at the ALH or rkm 18.2 sites (Table 11).

Estimated fertilization dates of progeny assigned to adults were used to infer variation in individual adult reproductive success within spawning sites and between spawning sites and years (Table 12; Figure 14). At the ALH site in 2011, the number of inferred adults that contributed to an estimated spawning day was 10.4 ± 7.7 , the number of spawning partners per adult was 3.6 ± 2.9 , and the number of estimated spawning days an inferred adult contributed to was 2.1 ± 1.1 . In 2011, the number of inferred adults per estimated spawning day at Waneta was 17.9 ± 12.9 , the number of spawning partners was 3.6 ± 2.8 , and number of estimated spawning days an inferred adult contributed to was 2.4 ± 1.2 . During the 2012 spawning season, the number of inferred spawning adults within a given estimated spawning day was 12.4 ± 11.9 , inferred adults had 2.0 ± 1.5 spawning partners, and the number of estimated spawning days an inferred adult contributed to was 1.4 ± 0.6 . COLONY is unable to determine sex of inferred adults through pedigree analysis. However, based on the pedigree data, both sexes were estimated to have spawned over multiple days, with multiple partners, and multiple individuals of each sex contributed to spawn within an estimated spawning day.

Table 11. Estimates of White Sturgeon effective breeding number (N_b), number of adults contributing to offspring (N_s), and number of kin groups (N_k) based on pedigree analyses of wild larvae of unknown parentage collected by means of egg mats and drift nets in the LCR in 2011 and 2012.

| | Number genotyped | N_b | 95% CI | N_s | N_k |
|----------|------------------|-------|-----------|-------|-------|
| 2011 | | | | | |
| rkm 18.2 | 33 | 32 | [19, 58] | 28 | 18 |
| ALH | 104 | 16 | [9, 34] | 29 | 20 |
| Waneta | 232 | 46 | [31, 70] | 89 | 60 |
| 2012 | | | | | |
| Waneta | 112 | 79 | [56, 110] | 97 | 49 |

Table 12. Variation in inferred LCR adult White Sturgeon reproductive success between sampling years (2011 and 2012) and among sites (ALH and Waneta; see Table 11) including number of contributing inferred adults per estimated spawning date (ESD), number of breeding partners per inferred adult, and number of ESD per inferred adult.

| | Estimate or mean (\pm SD where provided) | | |
|-----------------------------------|---|-----------------|-----------------|
| | ALH 2011 | Waneta 2011 | Waneta 2012 |
| ESD | 5 | 19 | 18 |
| N_s | 29 | 89 | 97 |
| N_b | 16 | 46 | 79 |
| Number of contributing adults/ESD | 10.4 \pm 7.7 | 17.9 \pm 12.9 | 12.4 \pm 11.9 |
| Number of breeding partners/adult | 3.6 \pm 2.9 | 3.6 \pm 2.8 | 2.0 \pm 1.5 |
| ESD/adult | 2.1 \pm 1.1 | 2.4 \pm 1.2 | 1.4 \pm 0.6 |
| Number of offspring/adult | 7.2 \pm 6.9 | 5.1 \pm 5.6 | 2.2 \pm 1.8 |

Table 13. Comparison of pedigree analyses using reduced number of White Sturgeon tissue samples to determine the effects of subsampling on pedigree reconstruction. Estimates include N_b , N_s , and N_k (see Table 11) of collected progeny from the LCR in summer 2011 at the sites of Waneta (rkm 56.0) and ALH (rkm 0.1).

| | Total Collected | Total Analyzed | % of total collection | N_b | CI | N_s | N_k |
|-------------|-----------------|----------------|-----------------------|-------|--------|-------|-------|
| Waneta 2011 | | | | | | | |
| | 466 | 232 | 0.50 | 46 | 31, 70 | 89 | 61 |
| | 466 | 116 | 0.25 | 52 | 37, 77 | 87 | 46 |
| | 466 | 58 | 0.12 | 43 | 29, 70 | 48 | 28 |
| ALH 2011 | | | | | | | |
| | 417 | 104 | 0.25 | 16 | 9, 34 | 29 | 20 |
| | 417 | 52 | 0.12 | 17 | 10, 34 | 24 | 15 |
| | 417 | 26 | 0.06 | 24 | 14, 44 | 21 | 13 |

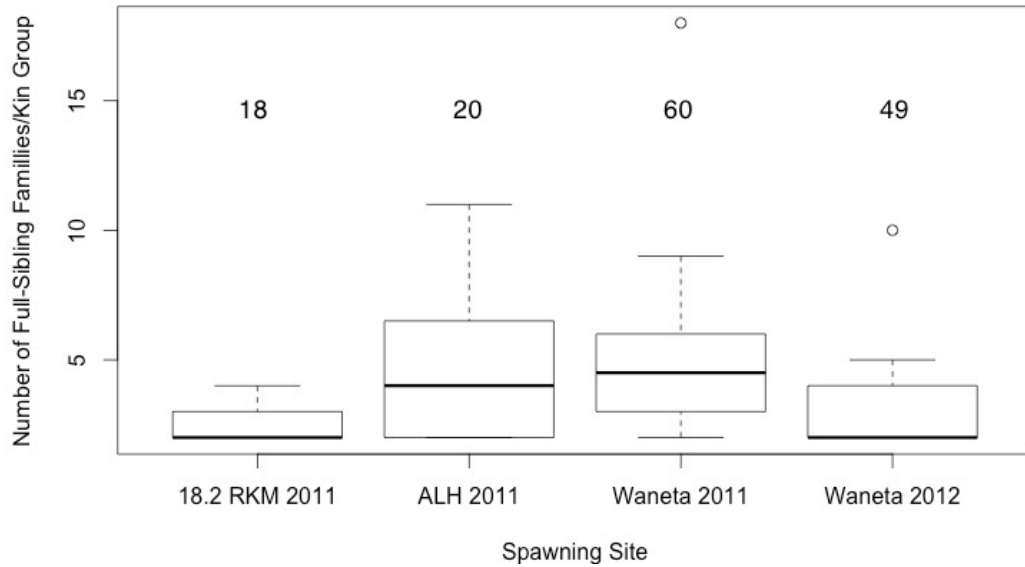


Figure 13. Whisker plots of the number of inferred full-sibling White Sturgeon families per kin group (N_k) for each year at the spawning sites of ALH, rkm 18.2, and Waneta. Numbers above the box plots represent N_k inferred at each site.

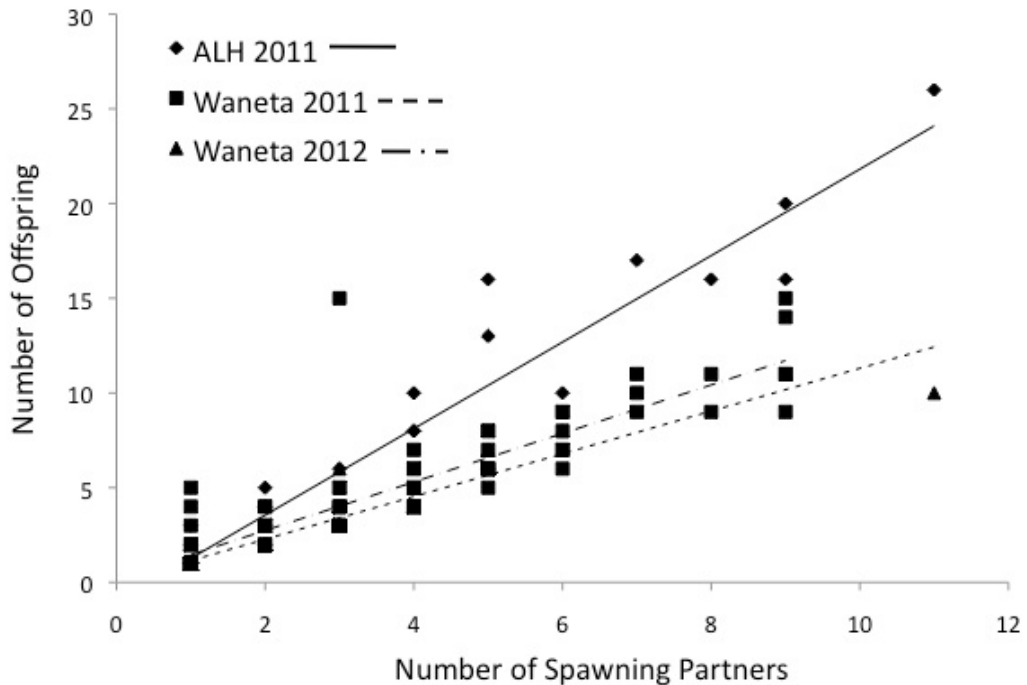


Figure 14. Relationship between number of spawning partners and number of offspring produced (as a measure of reproductive success) for inferred adult White Sturgeon at sites of ALH and Waneta in 2011 and 2012. Lines are of best fit.

3.4.3 Comparisons of Genetic and Empirical Estimates of Mature Adult Population

Based on empirical data collected between 2009 and 2012, the mean annual number of captured and sexed individuals was 221.12 ± 25.61 (Table 14). The annual number of males and females in spawning condition was 137.80 ± 15.33 and 83.32 ± 21.25 representing 0.24 ± 0.03 and 0.14 ± 0.04 of the total population, respectively. In 2011, a total of 213 individuals were empirically estimated to be in spawning condition. The number of males and females was empirically estimated to be 141 and 72 representing 0.24 and 0.13 of the total population, respectively. Based on genetic data collected in 2011, the number of spawning adults was 146 representing a proportion of 0.13 of the total population. The ratio of $N_c:N_s$ (number of available spawners empirically estimated to inferred number of adults contributing offspring through pedigree analysis) was 0.683.

Table 14. Empirical (N_c) and genetic (N_s ; see Table 11) estimates of the proportion of the total White Sturgeon population in the Canadian portion of the LCR (1,157 [95% CI: 414-1,889]; Irvine et al. 2007) in spawning condition. Empirical estimates of number of individuals in spawning condition were calculated based on sex ratios (1:1) and maturation stages of adults captured via set line during the 2009-2012 broodstock programs.

| | Year | Sexed | Mature individuals | Proportion in spawning condition ^a | Individuals in spawning condition ^a |
|--------|------|-------|--------------------|---|--|
| N_c | | | | | |
| Female | 2009 | 51 | 10 | 0.20 | 113.33 |
| | 2010 | 63 | 9 | 0.14 | 82.57 |
| | 2011 | 64 | 8 | 0.13 | 72.25 |
| | 2012 | 71 | 8 | 0.11 | 65.13 |
| | Mean | 62 | 8 | 0.14 | 83.32 |
| Male | 2009 | 38 | 9 | 0.24 | 136.89 |
| | 2010 | 41 | 11 | 0.27 | 155.07 |
| | 2011 | 45 | 11 | 0.24 | 141.29 |
| | 2012 | 49 | 10 | 0.20 | 117.96 |
| | Mean | 43 | 10 | 0.24 | 137.80 |
| N_s | | | | 0.13 | 146 |

^aProportion of Canadian population (1,157)

3.5 Population Monitoring, Abundance, and Characteristics

3.5.1 Fish Capture and Handling

The biannual stock assessment program was initiated in Spring 2013. Sampling will continue twice a year (spring and fall), in both the Canadian and USA portions of the LCR, until Fall 2017. Results are only presented for data collected

in Canada as results from USA captures were unavailable at the time this report was finalized.

Within Canada, spring and fall stock assessments were conducted between the dates of April 14 through May 2 (15 days) and September 16 through September 26 (11 days) with mean (\pm SD) water temperatures of $6.1 \pm 0.8^\circ\text{C}$ and $15.9 \pm 0.6^\circ\text{C}$, respectively. During the spring, 1,788 hooks were set using 149 lines. In the fall, 1,368 hooks were set using 114 lines. A total of 3,156 hooks were deployed on 263 lines in 2013. Cumulative sampling effort was 5,368.2 hours (223.7 days) with sampling efforts of 3,020.6 hours (125.9 days) and 2,347.6 hours (97.8 days) during the spring and fall assessments, respectively. Mean (\pm SD) set line deployment during the spring and fall assessments was 20.3 ± 2.5 hours (0.8 ± 0.1 days) and 20.6 ± 2.2 hours (0.9 ± 0.1 days), respectively.

Total White Sturgeon captures during the spring and fall assessments was 116 and 250 (Table 15) for a CPUE of 0.038 and 0.110 captures/hour (Table 16), respectively.

Table 15. Total White Sturgeon captures during the spring and fall stock assessments of 2013 in the LCR, Canada. Unmarked fish were considered new captures (i.e., not previously handled by researchers; does not include hatchery released juveniles). Recaptured fish were handled more than once during the sampling period.

| | Total | Adult | Juvenile | New Capture | Recaptured |
|------------|-------|-------|----------|-------------|------------|
| Spring | 116 | 82 | 34 | 24 | 1 |
| Fall | 250 | 96 | 154 | 28 | 0 |
| Cumulative | 366 | 178 | 188 | 52 | 1 |

Table 16. Catch per unit effort (CPUE) for White Sturgeon caught on setlines during the spring and fall stock assessments of 2013 in the LCR, Canada.

| | Hours | Days | Hooks | Set Lines |
|--------|-------|------|-------|-----------|
| Spring | 0.038 | 0.92 | 0.065 | 0.79 |
| Fall | 0.110 | 2.56 | 0.080 | 1.02 |

3.5.2 Population Abundance

Abundance and survival estimates will be calculated as additional recapture data become available in future years of the stock assessment program.

3.5.3 Fork Length Frequency and Weight

Mean (\pm SD) fork length (FL; cm) of all fish collected in both stock assessments of 2013 ($n=366$) was 137.1 ± 47.3 cm (Table 17; Figure 15). The mean FL of juveniles captured during the spring and fall was 103.4 ± 15.7 cm and 92.6 ± 15.2 cm, respectively. The mean FL for adults captured in the spring and fall was 184.3 ± 19.0 cm and 181.1 ± 18.7 cm, respectively. The mean weight (kg) of all captures was 27.5 ± 25.2 kg (Table 17). The mean weight of juveniles

captured during the spring and fall was 8.5 ± 6.3 kg and 5.87 ± 5.04 kg, respectively. Mean adult weight was 53.6 ± 16.2 kg and 47.0 ± 17.7 kg for spring and fall captures, respectively. Relative weight (W_r) for adults captured in the spring and fall was 91.3 ± 9.6 and 84.1 ± 8.8 (mean \pm SD), respectively (Table 18). Mean juvenile W_r was 85.3 ± 15.6 and 81.3 ± 8.5 during the spring and fall stock assessments, respectively (Table 18).

Table 17. Fork length (FL; cm; mean \pm SD) and weight (kg; mean \pm SD) for adult and juvenile captures during the spring and fall stock assessments in the Canadian portion of the LCR in 2013.

| | Fork Length (cm) | | |
|------------|------------------|------------------|------------------|
| | Adult | Juvenile | All Captures |
| Spring | 184.3 ± 19.0 | 103.4 ± 15.7 | 160.2 ± 41.3 |
| Fall | 181.1 ± 18.7 | 93.0 ± 15.2 | 126.6 ± 46.2 |
| Cumulative | 182.5 ± 18.9 | 94.5 ± 15.8 | 137.1 ± 47.3 |
| | Weight (kg) | | |
| Spring | 53.6 ± 16.2 | 8.5 ± 6.3 | 40.1 ± 25.0 |
| Fall | 47.0 ± 17.7 | 5.9 ± 5.0 | 47.0 ± 17.7 |
| Cumulative | 50.0 ± 17.3 | 6.4 ± 5.4 | 27.5 ± 25.2 |

Table 18. Relative weight (W_r ; mean \pm SD) for White Sturgeon collected during stock assessment efforts on the Canadian portion of the LCR during spring and fall 2013. W_r is provided for specific juvenile age-classes stocked through the conservation aquaculture program.

| Age | Spring | Fall |
|----------|-----------------|----------------|
| Juvenile | 85.3 ± 15.6 | 81.3 ± 8.5 |
| 4 yrs | - | 86.6 |
| 5 yrs | - | 80.1 ± 5.2 |
| 6 yrs | - | 76.4 ± 7.4 |
| 7 yrs | - | 84.1 ± 8.2 |
| 8 yrs | - | 84.1 ± 7.4 |
| 9 yrs | 81.4 ± 8.6 | 75.5 ± 7.6 |
| 10 yrs | 77.5 ± 3.9 | 79.6 ± 7.6 |
| 11 yrs | 82.4 ± 8.1 | 78.4 ± 5.7 |
| 12 yrs | 83.7 ± 8.5 | 85.9 ± 9.4 |
| Adult | 91.3 ± 9.6 | 84.1 ± 8.8 |

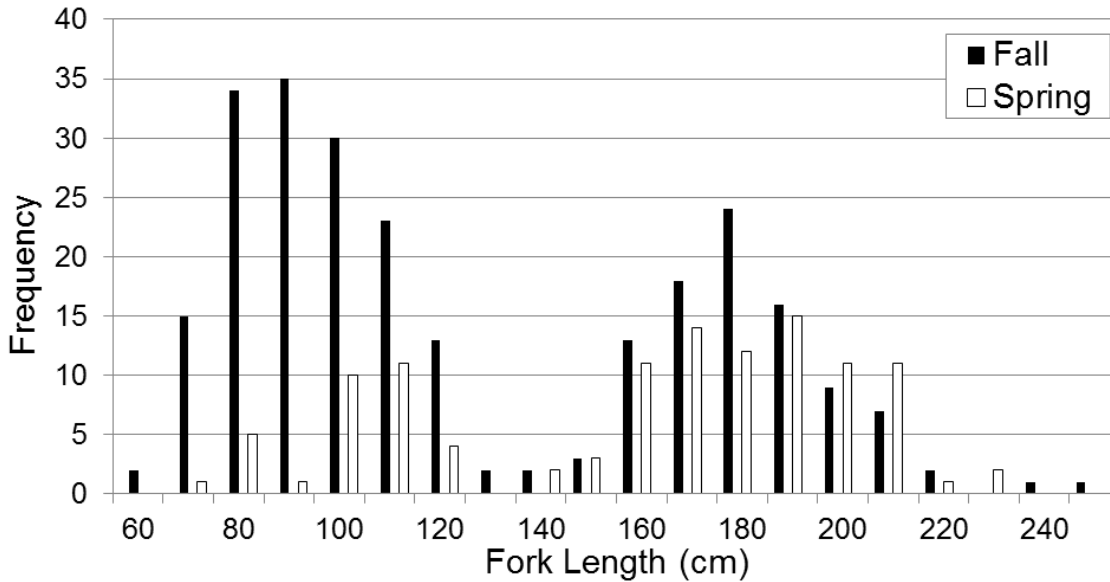


Figure 15. Fork length (cm) frequency of White Sturgeon captured during the 2013 spring and fall stock assessments in the LCR, Canada.

3.6 Acoustic Tagging and Telemetry

The movements of 98 adults (50 females and 48 males) tagged with acoustic transmitters were examined during 2008 through 2013. A total of 50,058 detections were recorded with a mean (\pm SD) of 572.9 ± 81.0 and 445.3 ± 64.3 detections for females and males, respectively. Habitat use was highest in the upper section of the river (e.g., Robson reach, rkm 0.1, 2.5, and 6.5) with marginal differences between females and males (Figure 16).

In 2012 and 2013, 16 (8 males, 7 females; Figure 17) and 20 (9 males, 11 females; Figure 18) adults were identified for suspected spawn related movements, respectively. In 2012, the highest proportion of adults identified at a suspected spawning location was detected at rkm 56.0 (0.31) followed by rkm 16.9 (0.25). The majority of males were detected at rkm 56.0 (0.63) and rkm 16.9 (0.25). The highest proportion of females was detected at rkm 26.0 (0.29) while the other detected females were evenly distributed between rkm 0.1, 9.0, 10.5, 16.9, and 53.8 (0.14). In 2013, the majority of adults identified at a suspected spawning location were detected at rkm 13.4 (0.45) and rkm 56.0 (0.20). Most males were detected at rkm 13.4 (0.56) and rkm 26.0 (0.22). The majority of females were evenly distributed between rkm 13.4 and 56.0 (0.36).

A high proportion of fish residing in the Upper section (0.71; HLK (rkm 0.1) to Kootenay River Confluence (rkm 10.5)) and Middle section (0.65; downstream Kootenay River Confluence to Birchbank (rkm 29)) migrated to adjoining downstream river sections during suspected spawn related movements (Table 19). Individuals detected in the Lower section (downstream Birchbank to Waneta (rkm 56.0)) tended to remain within the Lower section for spawn related movements (proportion of 0.67; Table 19). Individuals suspected to have

spawned in the Lower section travelled further (25.8 ± 13.3 km; mean \pm SD) from the suspected residency location compared to those suspected to spawn in the Upper (10.9 ± 4.4 km) and Middle (8.1 ± 8.6 km) sections (Table 20). Time spent on the suspected spawning grounds was greater within the Middle section (43.0 ± 40.1 days) than the Upper (7.9 ± 4.3 days) and Lower (29.2 ± 25.6 days) sections (Table 20).

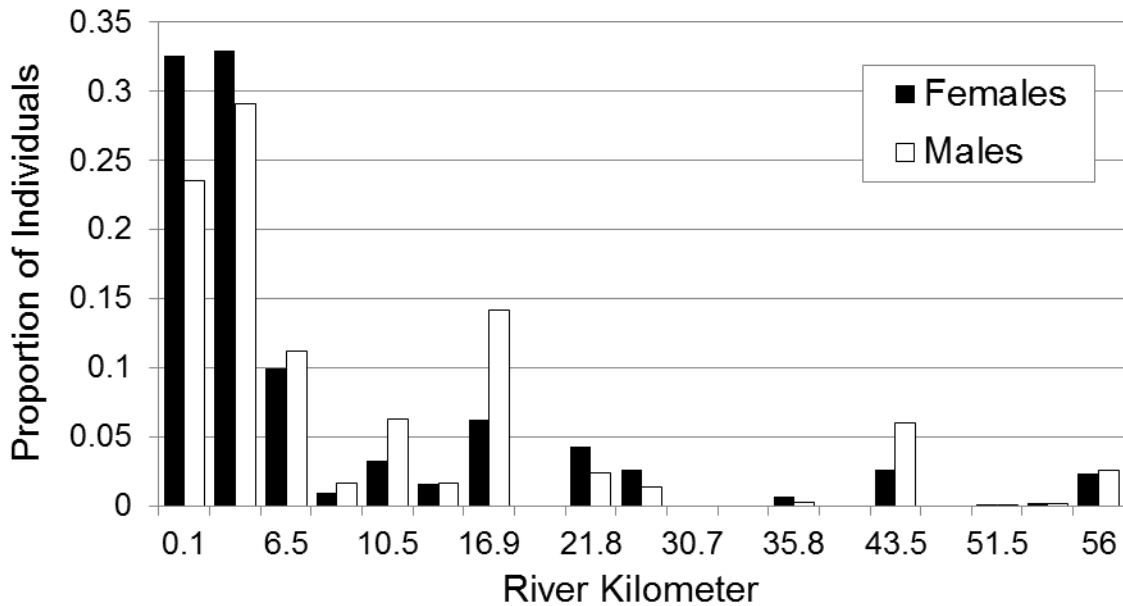


Figure 16. The proportion of detections by river kilometer of female (n = 50) and male (n = 48) adult White Sturgeon implanted with acoustic transmitters in the LCR, 2008-2013.

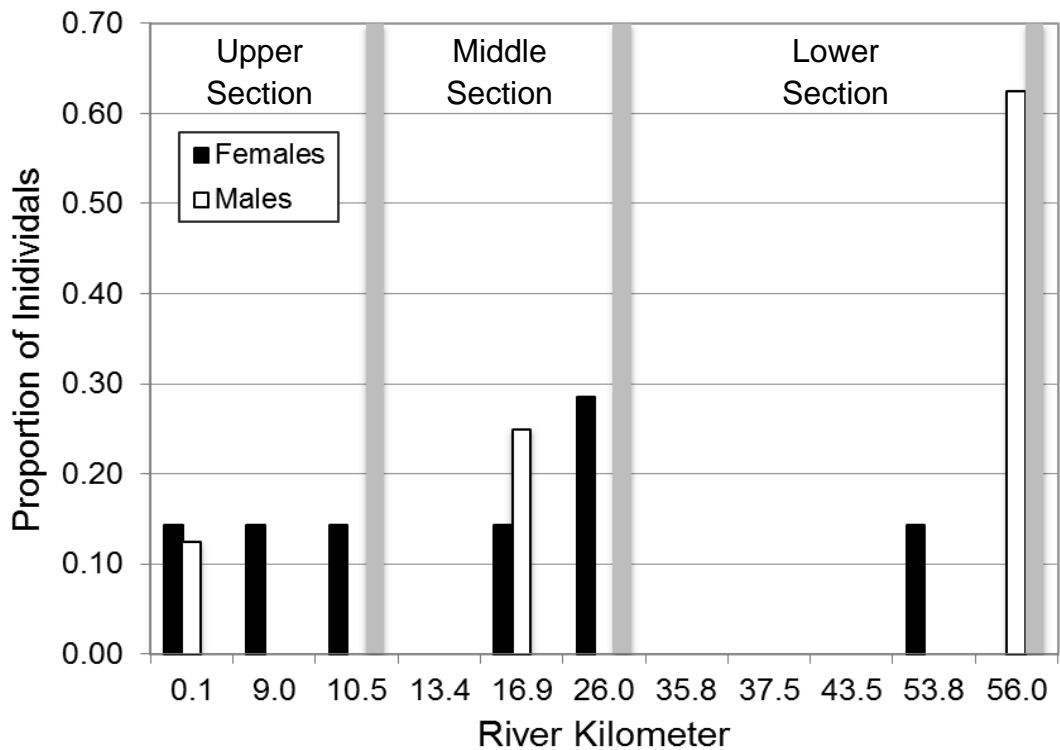


Figure 17. Proportion of detections by river kilometer of acoustically tagged female and male adult White Sturgeon identified for suspected spawn related movements in the LCR in 2012. LCR was divided into three sections including: Upper (HLK (rkm 0.1) to Kootenay River Confluence (rkm 10.5)), Middle (downstream Kootenay River Confluence to Birchbank (rkm 29)), and Lower (downstream Birchbank to Waneta (rkm 56.0)).

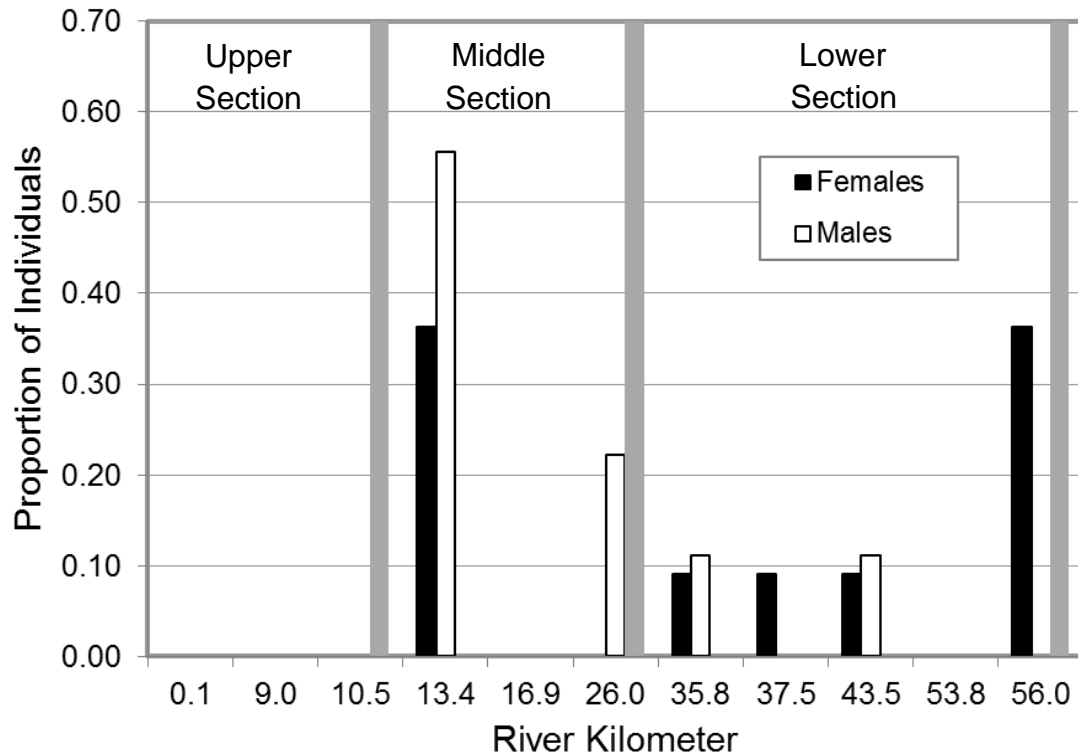


Figure 18. Proportion of detections by river kilometer of acoustically tagged female and male adult White Sturgeon identified for suspected spawn related movements in the LCR in 2013. LCR was divided into three sections including: Upper (HLK (rkm 0.1) to Kootenay River Confluence (rkm 10.5)), Middle (downstream Kootenay River Confluence to Birchbank (rkm 29)), and Lower (downstream Birchbank to Waneta (rkm 56.0)).

Table 19. The proportion, by river section, of adult White Sturgeon (n=36) implanted with acoustic transmitters identified for suspected spawn related movements in the LCR in 2012 and 2013. LCR was divided into three sections including: Upper (HLK (rkm 0.1) to Kootenay River Confluence (rkm 10.5)), Middle (downstream Kootenay River Confluence to Birchbank (rkm 29)), and Lower (downstream Birchbank to Waneta (rkm 56.0)).

| Suspected Residency | Suspected Spawning Area | | |
|---------------------|-------------------------|-------------|-------------|
| | Upper | Middle | Lower |
| Upper | 0.14 | 0.71 | 0.14 |
| Middle | 0.10 | 0.25 | 0.65 |
| Lower | 0.00 | 0.33 | 0.67 |

Table 20. Mean (\pm SD) distance travelled (km), travel time (days), and total time on site (days) for suspected spawn related movements for adult White Sturgeon implanted with acoustic tags in the LCR in 2012 and 2013. LCR was divided into three sections including: Upper (HLK (rkm 0.1) to Kootenay River Confluence (rkm 10.5)), Middle (downstream Kootenay River Confluence to Birchbank (rkm 29)), and Lower (downstream Birchbank to Waneta (rkm 56.0)).

| River Section | Distance Travelled (km) | Travel Time (Days) | Time Spent on Site (Days) |
|---------------|-------------------------|--------------------|---------------------------|
| Upper | 10.9 \pm 24.2 | 24.2 \pm 43.1 | 7.9 \pm 4.3 |
| Middle | 8.1 \pm 8.6 | 12.4 \pm 17.9 | 43.0 \pm 40.1 |
| Lower | 25.8 \pm 13.3 | 18.4 \pm 21.7 | 29.2 \pm 25.6 |
| Overall | 16.6 \pm 13.6 | 16.5 \pm 22.6 | 32.7 \pm 32.8 |

4.0 DISCUSSION

The primary objectives of this study were to describe adult White Sturgeon life history, biological, and population characteristics. Through the fifth and sixth years of this work, we have been successful in quantifying fish condition, estimating timing and duration of spawning, breeding population size, and reproductive success, identifying environmental spawning cues, and describing spawning-related movements and habitat use of adult White Sturgeon in the LCR. Further, this program was responsible for the collection of sexually mature White Sturgeon to use as broodstock for the conservation aquaculture program. Data collection will continue in the following years to provide an estimate of population abundance, growth rates, age class structure, and survival rates, all of which will be used in recovery planning going forward. Outstanding issues identified by the WUP Fisheries Technical Committee (FTC) are described in Table 21.

Table 21. Outstanding issues identified by the WUP Fisheries Technical Committee (FTC) in the Terms of Reference for this monitoring program.

| FTC Outstanding Issue | Current Status |
|---|--|
| As the annual average number of spawning days 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. | Spawning days are not viewed as a reliable indicator of the adult breeding population, given uncertainties in how efficient the methodology is when comparing among years. Genetic analyses has identified >100 adults spawning annually in the Canadian portion of the Columbia River, with additional adults spawning at two locations downstream. There are now 5 known spawning sites in the transboundary section of the Columbia River. |
| 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. | Additional spawning sites have been identified through analysis of adult movements (e.g., ALH spawning area in 2010). Currently, known spawning sites in Canada are being monitored annually and spawning related movements are evaluated in order to identify any further locations. |
| Baseline information acquired through this monitoring program may verify that the abundance of adult White Sturgeon in the LCR will not be adversely affected by management response measures. | Revised abundance estimates for wild adult White Sturgeon are being conducted through the entire transboundary reach, with a revised population estimate expected by 2017. This estimate will be used as a baseline for recovery planning moving forward. |
| Of equal importance to the maintenance of the remaining White Sturgeon population; are there sufficient adults to continue the conservation aquaculture program? | As of 2013, 157 individual adults (85 males and 72 females) have contributed to the conservation aquaculture program. Based on capture records and genetic studies completed to date, there are enough mature wild adults at large to maintain the conservation aquaculture program if needed. However, it is important to note that the success of the conservation aquaculture program has resulted in a strong presence of juvenile age classes, many of which are captured during assessments for broodstock. This has reduced efficiency of the broodstock program and as a result, significant sampling effort is required to meet broodstock goals (10 males and 10 females). |

4.1 Physical Parameters

The 2012, LCR total water supply volume was within the top 16% of highest unregulated water supply recorded since 1940 (measurement recorded at

Birchbank, rkm 29; BC Hydro unpublished data). The 2012 hydrograph exhibited a high, sustained freshet period peaking on June 28 and decreasing gradually over the months of July and August (Figure 4). Average mean daily discharge in 2012 was higher than previous years (Figure 19; BC Hydro 2013) as well as discharge levels recorded in 2013 (Table 2). In the absence of dams, the peak LCR flow was estimated to have been 359,000 cfs compared to the actual 175,000 cfs under dam regulation (BC Hydro unpublished data). This peak flow would have been within 5% of the highest ever-recorded peak flow in 1961 (BC Hydro unpublished data). The high flows in 2012 reached a 50-year flood level flooding many areas along the LCR shoreline. While these large flow years are important for long-term monitoring, they result in challenges when sampling. High flows had a negative impact on the spawn monitoring program in 2012, delaying gear deployment and possibly explaining the failure to capture any live eggs or larval samples (see Section 3.3.1). Additionally, sampling effort and duration was not adjusted for, despite the late initiation of sampling and increase in sampling area due to high water levels. However, the success in estimating spawning days at the downstream location (i.e., Waneta) in 2012, and both downstream and upstream locations (i.e., Kinnaird, rkm 14.5 and rkm 18.2) in 2013, further support the importance of environmental cues such as temperature and flow (spawn occurring on the descending limb) for predicting how sampling effort should be distributed (Figures 4 through 7).

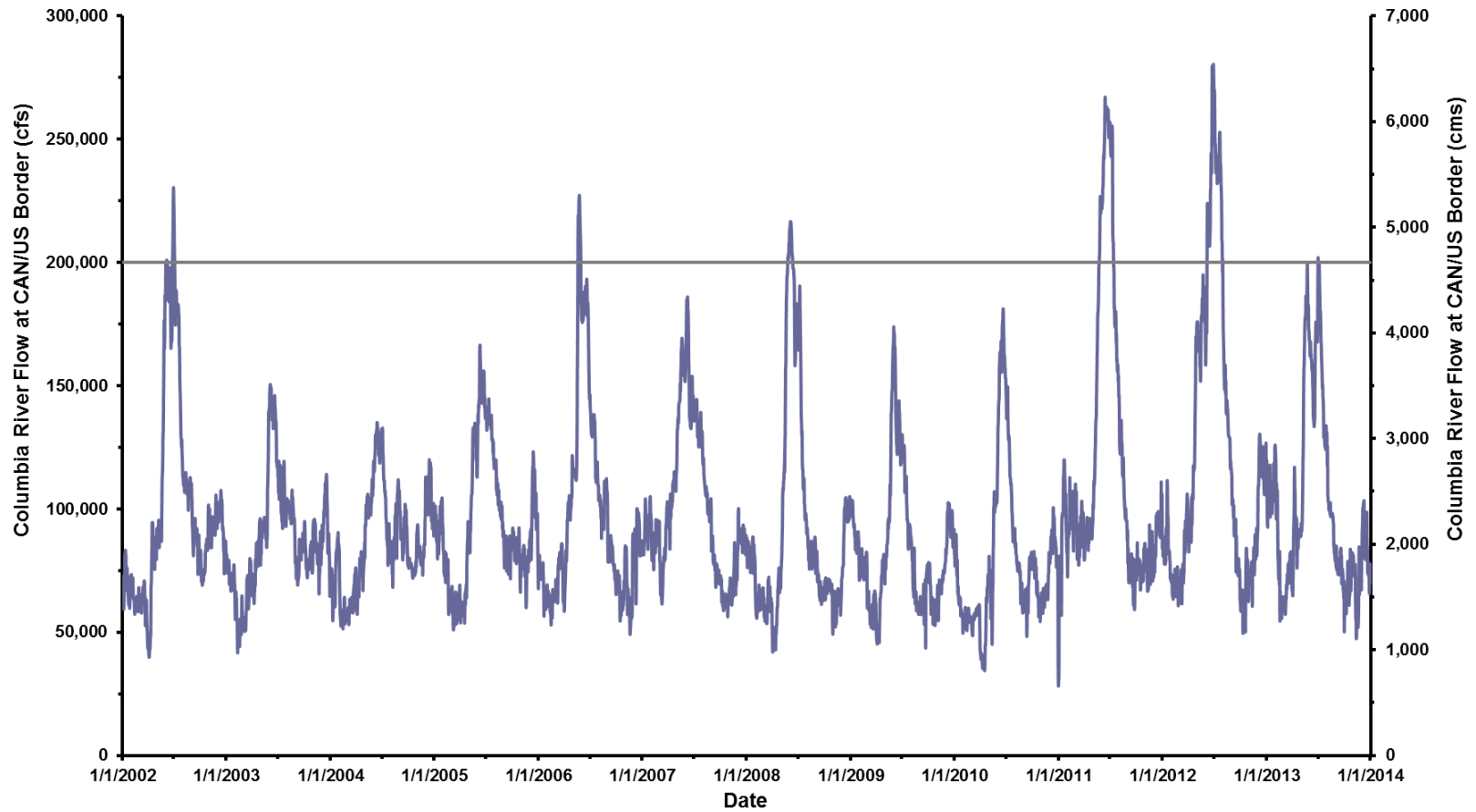


Figure 19. Columbia River discharge measured at the international border from 2002 through the end of 2013. The horizontal line indicates a flow of 200,000 cfs, which is considered a high flow year for the LCR when exceeded.

4.2 Broodstock Acquisition

The primary focus of the White Sturgeon broodstock program is to provide mature adults to contribute progeny for stocking through the conservation aquaculture program. The target of 10 mature females and 10 mature males was not reached in either 2012 or 2013, although has been met in previously years through the program (FFSBC 2011, 2012). In 2012, 18 White Sturgeon (8 females and 10 males) were transported to the KSH and successfully spawned; however progeny of 3 females did not survive past hatch. All individuals were implanted with acoustic transmitters prior to release into the LCR. In 2013, 16 White Sturgeon (8 females and 8 males) were transported to the hatchery where only 9 (6 females and 3 males) were successfully spawned due to under developed gametes/gonads in the remaining 7 adults. One immature female was tagged with an acoustic transmitter to monitor possible post release, spawning related movements. To date, adults have not been reused in the program other than a single female that contributed eggs for production in 2001 and reused strictly for experimental purposes in 2010. Given the high number of adults captured annually that have not been used in the conservation aquaculture program, 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 (e.g., Waneta 68%; Table 4) reinforcing the importance of spatially balanced sampling due to high site fidelity.

4.3 Spawn Monitoring

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 2012, spawning was estimated to have occurred from late June into late July at the downstream site of Waneta (Figure 11). Despite sampling effort consistent with previous years, no live eggs or larvae were collected upstream therefore spawning duration could not be estimated. In 2013, spawning was estimated to have occurred between mid June and mid July at the Waneta site and in late July at the upstream location of Kinnaird (rkm 14.5 and rkm 18.2; Figure 12). Dispersing larvae were collected within the vicinity of Kinnaird; however, exact location of the spawning area remains unknown. The timing and duration of spawning activity for both years is similar to past years, with the majority of estimated spawning days occurring on the descending limb of the hydrograph and at water temperatures above 14°C (Golder 2012).

Determining capture efficiency of both egg and larval samples between gear types is important when identifying exact spawning locations of unknown areas. Egg mats have been consistently used at Waneta for the collection of White Sturgeon eggs since the spawning location was first described in 1993 (Hildebrand and Parsley 2013). At the upstream locations (ALH, rkm 14.5, and rkm 18.2), the use of drift nets has been more effective in collecting eggs or larvae (Table 8). 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 use of egg mats be restricted to Waneta, and that drift nets are the primary technique used in areas where spawning locations are uncertain (e.g., Kinnaird).

4.4 Larval Genetics

We used pedigree analyses to quantify the effective number of breeding adults (N_b), number of adults contributing progeny (N_s), and individual reproductive success of White Sturgeon in the LCR. Developmentally staging collected eggs and larvae allowed for estimation of spawning period, and thereby spawning group composition and duration of spawning by an individual adult. Reductions in N_b relative to N_s were observed and varied among sites and between years, suggesting variation in number of adults contributing offspring, sex ratios, and reproductive success. Estimation of fertilization date of collected eggs and larvae provided a measure of spawning activity. However, the observed variation in number of mates, number of adults contributing offspring within a single spawning day, and spawning duration of individual adults implies that the estimated number of spawning days was a poor indication of number of adults contributing to larval production. This study didn't incorporate downstream spawning areas south of the Canada/USA border where adults from the LCR are known to migrate to spawn. Future studies incorporating samples from other accessible spawning grounds would improve estimates of the total spawning population of this transboundary population and would further increase knowledge of reproductive ecology.

Results of these pedigree analyses revealed that the Waneta is the main spawning site within the LCR, representing 61% of the total LCR spawning population during the two years of study. A smaller group of adults was estimated to have spawned over a shorter time period at the ALH site; a site that has only been identified in recent years and likely represents an important contributing spawning site. Despite the few samples collected at rkm 18.2, the number of inferred adults contributing to the collected offspring represented 19% of the total spawning population. Importantly, the exact geographical extent of this spawning area is still being described, and sampling proximity to the egg depositional area is unknown. Samples collected at all sites were young, developed only to the yolk-sac larval stage, justifying our sampling sites and larvae are not originating from further upstream. In the wild, hatched yolk-sac larvae burrow into the substrate where they remain until yolk-sac reserves are depleted (McAdam 2011). Yolk-sac larvae captured here were estimated to be zero to three days post-hatch, suggesting either larvae were hatching immediately upstream from the sampling equipment or larval rearing habitat at spawning sites is poor and results in non-volitional dispersal prior to the larvae utilizing endogenous yolk-sac reserves.

Variance in reproductive success, based on number of offspring produced by individual adults, was inferred within spawning sites, among spawning sites and

between years. Reconstructed pedigrees revealed differences in: 1) the duration of spawning among individual fish, 2) the number of days over which spawning occurred among individual fish, and 3) the number of spawning partners, all of which were unknown for White Sturgeon populations prior to this study. Spawning was estimated to have occurred over shorter periods at the ALH site in 2011 compared to the Waneta site during 2011 and 2012. However, inferred adults spawning at ALH were estimated to have a similar mean number of spawning partners and contributed to a similar mean number of estimated spawning days. The number of contributing adults per estimated spawning day was greater at the Waneta site in 2011 compared to the ALH site in 2011 and the Waneta site in 2012. Within all sites, variation in number of spawning days and duration of spawning between inferred individual adults was observed. Although sex was unknown, both sexes were estimated to have spawned during multiple days. Analyses of genetic data also determined variation in number of spawning partners within and between sexes. This observed variation in number of adults spawning on a given day, and number of days a single inferred adult spawned, implied that the number of estimated spawning days is not a reliable estimate of annual spawner abundance. Estimating White Sturgeon spawning period within the LCR using staged eggs has been used as the primary measure of spawning activity for many years and has been the best available metric describing start and end dates of spawning activity. We included staged larvae in the spawning duration estimate to provide a better representation of all spawning days. Based on these results, managers would be advised to estimate the number of spawning days using both staged eggs and larvae as a management tool to determine duration of spawning but not to infer the number of spawning adults.

The ratio of N_s (genetically estimated) to N_c (number of available spawners based on stage of maturation) was 0.683. Although N_s was lower, an underestimation is expected due to restrictions in sampling methods and genotyping a subsample of the total capture. However, when pedigree analyses were conducted using reduced datasets from Waneta and ALH 2011 samples, estimates of N_s were similar (Table 13). Estimates of N_b were also similar while N_k decreased when pedigrees were reconstructed with reduced number of samples (Table 13). These results show that sample sizes of larvae used were representative of the population present. Not all family crosses were observed with reduced sample size and/or collection duration, suggesting sample size may affect estimates of individual reproductive success. An overestimation of N_c within the Canadian portion of the LCR is expected as all sexually mature adults may not successfully reproduce and/or mature adults may spawn in areas south of the border. This data highlights the importance of using multiple methods to describe adult demographics for under-studied species when possible. Future studies that investigate spawning periodicity for adult males and females would add further information regarding the number of adults available to spawn in any given year. Finally, additional years of empirical and genetic data collection would be beneficial to further compare estimates made using both methods.

Estimates of N_b were found to be less than N_s at the ALH and Waneta sites, implying there is inter-individual variation in reproductive success. Variation could be due to unequal sex ratios (Moyer et al. 2012), variance in reproductive success (Duong et al. 2013), and/or variation in the number of spawning individuals over time, which was seen in our results of individual reproductive

success. Despite a stable N_s across years, Duong et al. (2013) found the polygamous mating system of Lake Sturgeon *Acipenser fulvescens* resulted in low standardized variance in reproductive success causing inter-annual variation in N_b/N_s ratios. We also observed relatively constant estimates of N_s at Waneta across both years despite the 8-fold difference in number of offspring collected. Results presented here, and by past studies (Duong et al. 2013; Moyer et al. 2012), indicate that environmental conditions and the nature of sturgeon reproductive ecology interact to affect demographic parameters, N_b/N_s estimates, and offspring survival.

The pedigree methods employed in this study are useful for populations where access to spawning adults is not possible, making more traditional parentage analysis difficult. Further, the White Sturgeon genome has complicated genetic analyses to date due to issues with polyploidy. A recent study by Wang and Scribner (2014) examined the effects of polyploidy levels, actual pedigree structures, and marker number and polymorphism on the accuracy of sibship assignments using simulated and empirical data of polyploid species based on full likelihood and pairwise likelihood methods. Their results showed that sibship could be accurately recovered for polyploid species based on a typical set of microsatellites (e.g., 10 markers each with 10 alleles) using the full likelihood methods developed for diploid species (Wang 2004; Wang and Santure 2009) when applying the marker data transformation described by Rodzen et al. (2004). Wang and Scribner (2014) also showed that including more marker information and allowing for a small mistyping error rate ($e = 0.04$) treats the low proportions of the probability of recessive phenotypes as a mistyping error within the analysis, thereby reducing sibship grouping split during reconstruction. Additionally, they found that 80 transformed loci were sufficient to achieve almost perfect sibship of uniformly large full sib families, while 125 transformed loci were able to correctly reconstruct sibships containing unrelated individuals (singletons) at a rate of 99%. The inference accuracy for all types of relationships increased rapidly with an increased number of alleles per untransformed locus. The findings of Wang and Scribner (2014) validated our methods of inferring sibship from 12 microsatellite loci (a total of 143 transformed loci; Rodzen et al. 2004) using the full likelihood method. The empirical estimates of mistyping error rate we used in analyses were low (0.008 and 0.003 for 2011 and 2012 data, respectively). However, pedigree reconstruction and estimates of N_b and N_s were similar when the ALH 2011 data was analyzed using error rates of 0.02 and 0.04 (data not shown). Additionally, we observed a high degree of consistency in pedigree assignment and estimated N_b and N_s across replicate runs within a site further confirming the reliability of the results.

The LCR White Sturgeon population has been experiencing recruitment failure over the past several decades and hatchery supplementation has been the primary means of mitigation while research into recruitment failure is ongoing (Hildebrand and Parsley 2013). For hatchery programs focused on species that do not use captive broodstock, factors such as number of spawning adults, limited access to spawning adults, and life history characteristics (i.e., intermittent spawning, delayed maturity, skewed sex ratios) can lead to management practices that reduce offspring levels of genetic diversity relative to levels represented in the adult spawning population (Allendorf and Phelps 1980; Ryman 1991; Crossman et al. 2011). Crossman et al. (2011) found that Lake Sturgeon

offspring of naturally produced eggs and larvae collected in drift nets and raised in a hatchery were less related (lower coancestry) and were produced by greater effective breeding numbers than offspring produced from direct gamete collections from adults. Current LCR White Sturgeon recovery measures include a hatchery supplemental program capturing broodstock of up to 20 adults (10 females and 10 males) annually for the production of offspring. Results from this study, and Crossman et al. (2011), suggest that representation of additional spawning adults could be achieved by incorporating wild caught eggs and larvae into the aquaculture program. This has been recommended for other sturgeon species (e.g., Lake Sturgeon; Crossman et al. 2011).

Using genetic data, we estimated the effective breeding number for polyploid species inhabiting large river systems where direct observation of mating is impossible or misleading, and spawning population census data are difficult to obtain. If genetic techniques are not available or affordable, concordance between empirical estimates of spawning census size and genetic estimates of number of adults contributing offspring supports the use of alternative means of estimating the number of adults that may be spawning in any given year. Conversely, census data support genetic findings and thus in situations where adult sampling is not feasible but eggs and larvae are sampled, genetic data can provide viable means of inferring the number of spawning adults, at least to the larval stage. These methods of determining spawning population size and effective population size are fundamental to our understanding of life history strategies and can be applied to recovery planning and aquaculture programs for species of conservational concern.

4.5 Population Monitoring, Abundance, and Characteristics

Prior to 2013, the broodstock program served as the sole method of providing information on the biology of the population (e.g., length frequency, growth rates, population estimates). The systematic stock assessment program was initiated to address uncertainties in abundance and survival rate estimates of the LCR White Sturgeon population. Using life history and biological data collected using capture-mark-recapture methods, we will also be able to estimate growth rates across females, males, and immature fish (<150 cm fork length), fish condition, age class structuring, and density dependent responses. This information is required to inform management of LCR White Sturgeon population dynamics and assess trends within the population.

4.6 Acoustic Tagging and Telemetry

White Sturgeon in the LCR tend to select deep, slow moving sections of the river. These habitats do not appear to be limited under the current operating regime. Similar to past years, movement data indicated that activity generally occurred during the summer months for assumed foraging or spawning. Suspected spawning related movements revealed that resident adults within the upper or middle river sections tend to migrate to adjacent downstream spawning areas (Table 19). These movements differed from previous years that identified adults undergoing shorter suspected spawning related migrations staying within their

resident river section (BC Hydro 2013). However, White Sturgeon residing in the lower section were observed migrating within this section for suspected spawning related movements and not further downstream past the Canada/US border (Table 19). A small portion of adults monitored in this study exhibited putative spawning migrations to adjoining river areas indicating mixing of adults throughout the river (Table 19).

Though current results from the telemetry monitoring program reveal patterns of habitat use and possible spawning related movements, caution is advised when interpreting results, as the long-term movement patterns of White Sturgeon are poorly understood. Additional data through the duration of this program are needed to address how the operation of the river may influence White Sturgeon 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.

5.0 RECCOMENDATIONS

1. Drift nets maximize catch per unit effort of eggs and larvae from locations upstream of the sampling equipment and should continue to 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. Consider deploying additional drift net stations downstream of Kinnaird to determine where larvae may be originating from.
2. Continue to collect tissue samples from offspring at the different spawning areas and from wild juveniles and adults for future genetic analyses.
3. Additional range testing should be conducted throughout the LCR to describe detection probabilities for each unique receiver station.
4. Continue coordinated stock assessment program with US agencies to improve our confidence in the abundance of White Sturgeon in the transboundary reach.
5. Development of a database that could store all life history data and telemetry data among researchers and industries.

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