Columbia River Project Water Use Plan

Implementation Year 13

Reference: CLBMON-23A

Middle Columbia River White Sturgeon Spawn Monitoring Data Report

Study Period: 2019

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Middle Columbia River White Sturgeon Spawn Monitoring (CLBMON-23A): 2019 Data Report (Year 13)

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Executive Summary

The population of White Sturgeon in the Canadian portion of the Columbia River is listed as Endangered under the federal Species at Risk Act. A small portion of this population exists in Arrow Lakes Reservoir (ALR) and the Middle Columbia River (MCR), situated between Revelstoke Dam and Hugh L. Keenleyside Dam. The only known spawning location for this segment of the population is located approximately 6 km downstream of Revelstoke Dam. Spawning has been documented at this location intermittently but recruitment to the juvenile stage from these spawning events has not been detected.

The MCR White Sturgeon Spawn Monitoring Program (CLBMON-23A) has been conducted annually since 2008, with previous monitoring occurring between 1999 and 2007 as part of other monitoring programs. The main objectives of CLBMON-23A are to document the timing, duration and frequency of spawning, and to identify important early life stage habitat conditions. In addition, CLBMON-23A supports a conservation aquaculture program by transferring captured eggs and larvae to the Kootenay Sturgeon Hatchery for rearing and subsequent release back into the MCR. Additional objectives were added to the program in 2019 to address key uncertainties identified by the Mid-Columbia River White Sturgeon Technical Forum:

- Sample to improve understanding of the timing and spatial extent of larval dispersal.
- Conduct analyses to assess the risk of eggs or larvae becoming stranded due to hydroelectric operations.

Egg collection mats and drift nets were used to sample for eggs and larvae in the primary spawning area during the historical spawning season (late July to late August), as in previous years of the monitoring program. Additional drift net sampling was conducted from September 3 to 19 downstream of the spawning area in the suspected larval rearing area to attempt to capture dispersing larvae in the exogenous feeding phase. In total, seven live eggs, two dead eggs, and one dead larva were collected using egg mats and drift nets in 2019. Based on the timing and developmental stages of the catch, all the eggs and the larva were estimated to be from one spawning event. The estimated timing of this spawning event was July 31, 2019. Larvae were not captured during drift net sampling for dispersing larvae in September.

The risk of egg stranding due to hydroelectric operations was assessed qualitatively for all years from 2008 to 2019 based on the potential for substrate dewatering due to discharge variability during the risk period when eggs or larvae were present. The risk classifications were based on the discharge from Revelstoke Dam, the difference between the current hourly discharge and the previous maximum, and the presence or absence of backwatering from Arrow Lakes Reservoir. The relative stranding risk varied between years and was lowest in years or periods when ALR was backwatering the incubation area, and greatest when discharge was less than the minimum flow of 142 m^3/s (pre-2011).

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1.0 INTRODUCTION

In 2006, the population of White Sturgeon (*Acipenser transmontanus*) in the Columbia River in Canada was listed as Endangered under the federal Species at Risk Act. A small part of this population exists between Hugh L. Keenleyside Dam (HLK) near Castlegar, BC and Revelstoke Dam (REV) near Revelstoke, BC. This portion of the Columbia River includes Arrow Lakes Reservoir (ALR) and an approximately 48 km section of the middle Columbia River (MCR) between ALR and REV. The adult population in this section is estimated at approximately 50 individuals (Golder 2006). The only known spawning area for this population is located adjacent to the Revelstoke golf course, approximately 6 km downstream of REV. Spawning has been documented at this location using egg collection mats and drift nets in many but not all years between 1999 and 2019 (Wood 2019). However, wild juvenile White Sturgeon from these spawning events have never been captured, which suggests failure to recruit to the juvenile life stage for this population (Hildebrand and Parsley 2013).

Initiated in 2007, BC Hydro's CLBMON-23 Mid-Columbia River White Sturgeon Egg Mat Monitoring and Feasibility Study was developed to monitor the annual spawning of White Sturgeon at the only known spawning site between REV and HLK. CLBMON-23 includes two components. The MCR White Sturgeon Spawn Monitoring Program (CLBMON-23A) uses egg collection mats and drift nets whereas the MCR White Sturgeon Underwater Videography Feasibility Study (CLBMON-23B) evaluated the feasibility of monitoring sturgeon using sonar (Johnson et al. 2010). Twelve years of previous monitoring have been completed in the CLBMON-23A program to date (2007 to 2018). This report describes the methods and results of egg mat and drift net monitoring for CLBMON-23A in 2019 (Year 13).

CLBMON-23A meets the requirement of the Columbia River Project Water License Order to document spawn timing, duration, and frequency, and to identify important early life stage habitat conditions (BC Hydro 2019). In addition, CLBMON-23A supports a conservation aquaculture program through the on-site incubation of eggs and transfer of larvae to the Kootenay Sturgeon Hatchery for rearing and subsequent release back into the MCR.

Specific management questions associated with CLBMON-23 as per the Terms of Reference (BC Hydro 2007) are as follows:

1. Where are the primary White Sturgeon incubation sites below Revelstoke Dam?
2. How do dam and reservoir operations affect egg and larvae survival in this area? Specifically, do significant numbers of eggs become dewatered as a result of operations?
3. Can underwater videography or other remote sensing methods be used to effectively monitor staging and spawning of White Sturgeon?
4. What is the most effective method for monitoring spawning of White Sturgeon?
5. Can modifications be made to operation of Revelstoke Dam and Arrow Lakes Reservoir to protect or enhance White Sturgeon incubation habitat?

Management question #3 has been addressed by a different monitoring program (CLBMON-23B; Johnson et al. 2010). Management questions #1, 2, 4, and 5 are relevant to the CLBMON-23A monitoring program.

A review of CLBMON-23A in 2018 identified the following key uncertainties (BC Hydro 2019):

- The number of adults contributing to spawning events
- Survival of early life stages
- The risk of eggs or larvae becoming stranded due to operations

An additional objective of the monitoring program in 2019 was to provide information to address the key uncertainties listed above, where possible. Genetic analyses to address uncertainty #1 are not part of this program but egg and larvae that were dead after capture were preserved, provided to BC Hydro, and will be used for genetic analyses in the future. Survival of early life stages (key uncertainty #2) cannot be directly measured or estimated using the data provided by this monitoring program. Stranding risk (key uncertainty #3) was assessed by examining river discharge data and ALR surface elevation data for large flow reductions during periods when there were known to be White Sturgeon eggs or larvae present in the spawning and incubation area (Section 2.9).

In addition to the main objective of annual spawn monitoring and addressing these uncertainties, two additional objectives were identified at the Mid-Columbia River White Sturgeon Technical Forum in December 2018 (BC Hydro 2018):

- Increasing the number of progeny (eggs or larvae) collected and transferred to the Kootenay Sturgeon Hatchery to increase the genetic diversity of the conservation aquaculture program
- Sampling to improve understanding of the timing and spatial extent of larval dispersal

In light of these two objectives, the study design for sampling in 2019 was modified from previous years of the monitoring program. A modification to attempt to increase the number of progeny collected for conservation aquaculture was to use an adaptive study design, where the sample sites and duration would be adapted during the sampling season based on the timing and location of capture of eggs or larvae. This differed from previous years, where consistent index sample sites and a set sampling schedule were used. To improve understanding of larval dispersal, drift net sampling was conducted further downstream and later in the season than was done in previous years. Details of the overall methods, including additional information about these modifications, are provided in the following section.

As there were relatively few eggs and larvae captured in 2019, this report is a brief data report focusing on the methodology and results, rather than a full interpretive report in the format of Water Use Plan (WUP) reports. For more detailed background information, interpretation of previous years' results, and discussion of the status of management questions, readers are referred to reports from previous years of the monitoring program[1].

2.0 METHODS

2.1 Study Area

The study area in the MCR extended from the upstream end of the primary spawning area (river kilometer [rkm] 230.3, as measured from the Canada-US border) downstream to the Centennial Park boat launch (rkm 225.5) in Revelstoke, BC. The spawn monitoring component of the program was conducted between rkm 230.3, the upstream end of the primary spawning area, and rkm 227.8, which is located approximately 400 m downstream of Big Eddy. This section includes the area where all White Sturgeon eggs and larvae were captured between 1999 and 2018 (Wood 2019). Sampling for larval dispersal was conducted between rkm 228.5 (between the Jordan River confluence and Big Eddy) and the Centennial Park boat launch. Maps and details of specific sample sites for monitoring spawning and larval dispersal are provided in sections 2.3 and 2.4.

2.2 Sampling Equipment

Egg collection mats ('egg mats') and D-ring drift nets ('drift nets') were used to capture drifting eggs and larvae of White Sturgeon. Egg mats consisted of a 0.77 x 0.92 m steel frame filled with latex-coated animal hair filter material. When deployed in the river, egg mats rest on the substrate and eggs or larvae can adhere to or become lodged in the filter material. Egg mats were deployed either as 'shore-sets' or 'mid-sets'. For shore-sets, egg mats were connected to shore by a section of rope tied to a natural anchor on shore (e.g., boulder or tree).
The shore-line was connected to the egg mat via a rope or cable bridle (i.e., approximately 0.5 m rope attached in a V-formation to one end of the egg mat). Shore-sets were retrieved by the shore-line but also had a float line consisting of 10 to 20 m of rope and a LD2 buoy attached to the egg mat as a secondary retrieval method in case the shore-line was severed.

To sample locations further away from shore, egg mats were deployed as mid-sets that were held in place by an anchor system. The anchor system for mid-sets consisted of two 30 kg claw anchors connected by steel chain. Mid-sets had a float line and LD2 buoy connected to the front anchor, and a second float line connected to the egg mat or drift net. The egg mat was connected to the downstream anchor by approximately 10 m of rope. In high velocity areas where rope could be abraded by the substrate, 10 m of steel cable was used instead of rope.

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[1] Reports from previous years of the monitoring program are available online at:
https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/columbia-sturgeon.html

Drift nets consisted of a D-shaped metal frame (0.8 m wide at the base and 0.6 m high) to which a drift net was attached (3.6 m long, 0.16 cm knotless mesh, tapered to an 11.4 cm diameter collection bottle). The D-ring frame was weighted at the front corners or base of the frame and a flow meter was affixed to the D-ring frame (over the opening) to measure the volume of water sampled. All drift nets were deployed using mid-set anchor systems as described above.

Egg mats and drift nets were deployed and retrieved from a jet-drive river boat by a three-person crew. Shore-sets were retrieved by the shoreline and mid-sets were retrieved by the float line attached to the egg mat or drift net. The boat was equipped with a bow winch and a side-mounted winch on a davit. Egg mats and drift nets were pulled from the bow or side winch, depending on the site. Generally, the side winch was used when possible, because it allows for better ergonomics for crew members. Use of the bow winch was limited to sites situated in very high water velocities or if rope, anchors or equipment were stuck and required greater force to retrieve.

2.3 Spawn Monitoring

Spawn monitoring used both egg mats and drift nets, as in all previous years of the monitoring program (Wood 2019). Spawn monitoring was conducted from July 24 to August 29, 2019. This timing was selected to cover the historical peak of the spawning period when most eggs and larvae have been captured in past years of the monitoring program (pers. comm., J. Crossman, BC Hydro). During each week of the monitoring period, a two-day site visit was conducted. During each site visit, egg mats were retrieved, checked for eggs/embryos, and redeployed. When possible, egg mats were replaced with drift nets that were fished for a short duration (1–3 hours) while the crew was on site sampling or overnight between the two days of weekly sampling. Drift nets create more drag in the water current than egg mats and therefore lower water velocities are required to deploy drift nets safely and without having the nets damaged or lost. Therefore, drift nets were only deployed at locations and during discharge conditions where it was feasible and safe to do so. After retrieving the drift nets, they were replaced by egg mats that were left to sample until the following week.

Sample sites were located between rkm 230.3 and 227.8 between mid-channel and the left bank as viewed facing downstream, where all collected eggs and larvae were captured between 2012 and 2018 (Wood 2019). The same twelve sites sampled in 2017 were sampled in 2019 (227.8M, 227.9L, 228.1M, 228.5M, 228.6M, 228.8L, 228.9M, 229.3L, 229.7L, 229.8L, 229.9M, 230.1L; Amec Foster Wheeler 2018). Exact locations were modified slightly depending on river conditions. Sampling near the right bank and further upstream was conducted in previous years of the program but was not conducted in 2019 because eggs and larvae were not captured in these locations between 2012 and 2019 (Wood 2019). This study design was intended to provide comparable monitoring to previous years, while not expending effort in areas unlikely to catch eggs and larvae.

Egg mat sample sites in 2019 are shown in Figure 1 and GPS coordinates are provided in Appendix A, Table A1. Due to high water velocities and fluctuating flows from REV, some of the mid-set anchor systems were dislodged and moved downstream while crews were not on site.

If displaced anchor systems were still located within the spawning area and situated where the equipment could effectively sample, the anchor systems were left at the new location. Anchor systems that were displaced into locations where catching eggs or larvae was unlikely were re-set at their original locations. Figure 1 shows the original sample sites and the sites that were sampled at new locations after anchor systems were displaced. The locations of drift nets that were fished at the egg mat sample sites are included in Figure 2 (Section 2.4).

The study plan was for an adaptive study design, where additional sample sites would be added depending on the location of egg captures. If eggs or larvae were captured, additional sites would be installed adjacent to (perpendicular to current) or downstream of the capture location. In addition, if significant numbers of eggs or larvae were captured, the two-day session would be extended by one day, to continue sampling with drift nets, which often catch more eggs/larvae than egg mats, and maximize catch during periods when spawning was occurring. However, due to limited catch of eggs and larvae, none of the two-day sessions were extended in 2019. Instead of extending weekly sessions by one day, an additional site visit was conducted on August 28 to 29, 2019, during a week when no sampling was initially planned.

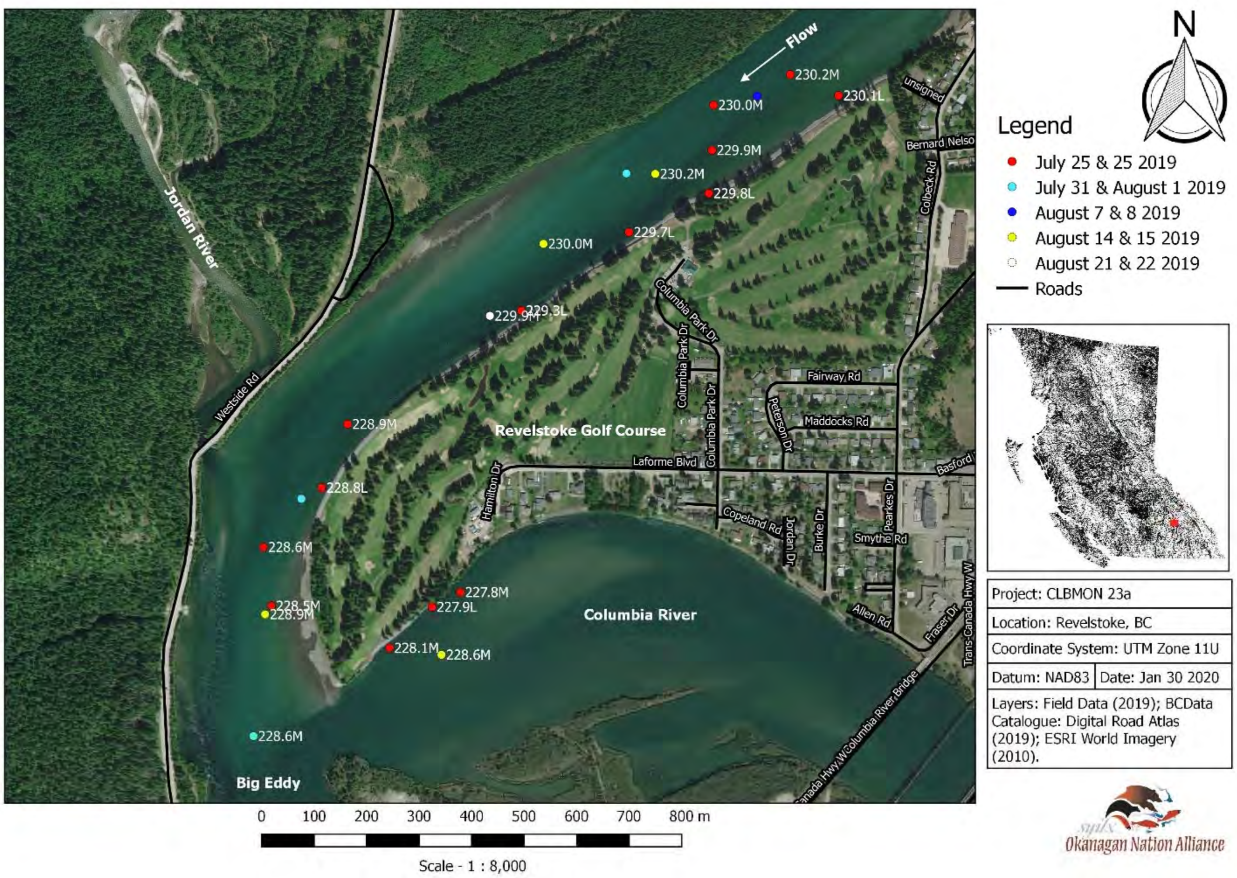

Figure 1. Egg mat sampling locations in the Middle Columbia River in 2019.

2.4 Larval Dispersal Sampling

After egg hatch, the first stage of larval development is referred to as the yolk-sac larva phase, when larvae hide in the substrate (Hildebrand et al. 2016). When the yolk-sac has been consumed, larvae emerge from the substrate, disperse, and begin feeding exogenously. Monitoring during previous years of CLBMON-23A has focused on the time of year when recently spawned eggs, developing eggs, and yolk-sac larvae are present in the study area. In 2019, sampling was also conducted later in the year to attempt to capture dispersing larvae in the exogenous feeding phase.

Sampling in the downstream portion of the study area was intended to improve understanding of larval dispersal and, if successful in catching dispersing larvae, contribute wild progeny for conservation aquaculture. Larvae in the dispersal and exogenous feeding phase have not previously been captured by CLBMON-23A, and therefore the timing and spatial extent of larval dispersal are not precisely known. Developmental rates, based on typical mean water temperatures in the MCR (approximately 9–11°C), suggest that egg hatching likely occurs approximately 14–20 days after spawning (Beer 1981; Wang et al. 1985; 1987; Parsley et al. 2011), and dispersal in the study area occurs approximately 30 to 40 days after spawning. The location of larval dispersal and early rearing in the MCR is unknown but is hypothesized to be between the downstream end of Big Eddy (rkm 228) and the Illecillewaet River confluence (Hildebrand et al. 2014). Model simulations of larval dispersal at various REV discharges and ALR water elevations have been conducted and were used to inform sampling locations for larval dispersal (Hildebrand et al. 2014). In the model, simulated larvae drifting from egg capture sites reached locations at the bend upstream of Big Eddy (rkm 228.5), in Big Eddy, in the upper portion of the putative rearing area (near rkm 228.1, just downstream or adjacent to Big Eddy), or downstream of the modeled area (which finished near the rock groyne at rkm 226.3), depending on river discharge and ALR elevation.

Sampling for larval dispersal was conducted from September 3 to 19, 2019. Based on the timing of sampling, and temperature-dependent developmental rates, larval dispersal sampling was intended to capture larvae in the yolk sac/hiding phase (involuntarily displaced or moving volitionally to seek hiding habitat), or larvae dispersing after consuming their yolk sac. Egg mats are not effective at capturing larvae in the yolk sac or feeding stages; therefore, larval sampling was conducted using drift nets only. This limited the potential collection of larvae to the weekly two-day site visits. Drift nets were deployed at sample sites while crews were on site during each two-day sample period (approximately 1–3 hours per day) and, when possible, overnight between sampling days (approximately 15 hours). Drift nets were only deployed overnight at sites and during conditions when water velocities were low enough that nets could be safely deployed and where overnight deployment was not likely to result in nets being lost or damaged. Due to high water velocities at most sites in 2019, only one or two drift nets per sample session were fished overnight and during some weeks, no nets were deployed overnight.

In total, 12 sites were sampled during larval dispersal monitoring. The number of sites sampled per week ranged from 5 to 12, depending on the discharge conditions at the time of sampling. Drift net sites for larval dispersal sampling are shown in Figure 2 and GPS coordinates are provided in Appendix A, Table A2.

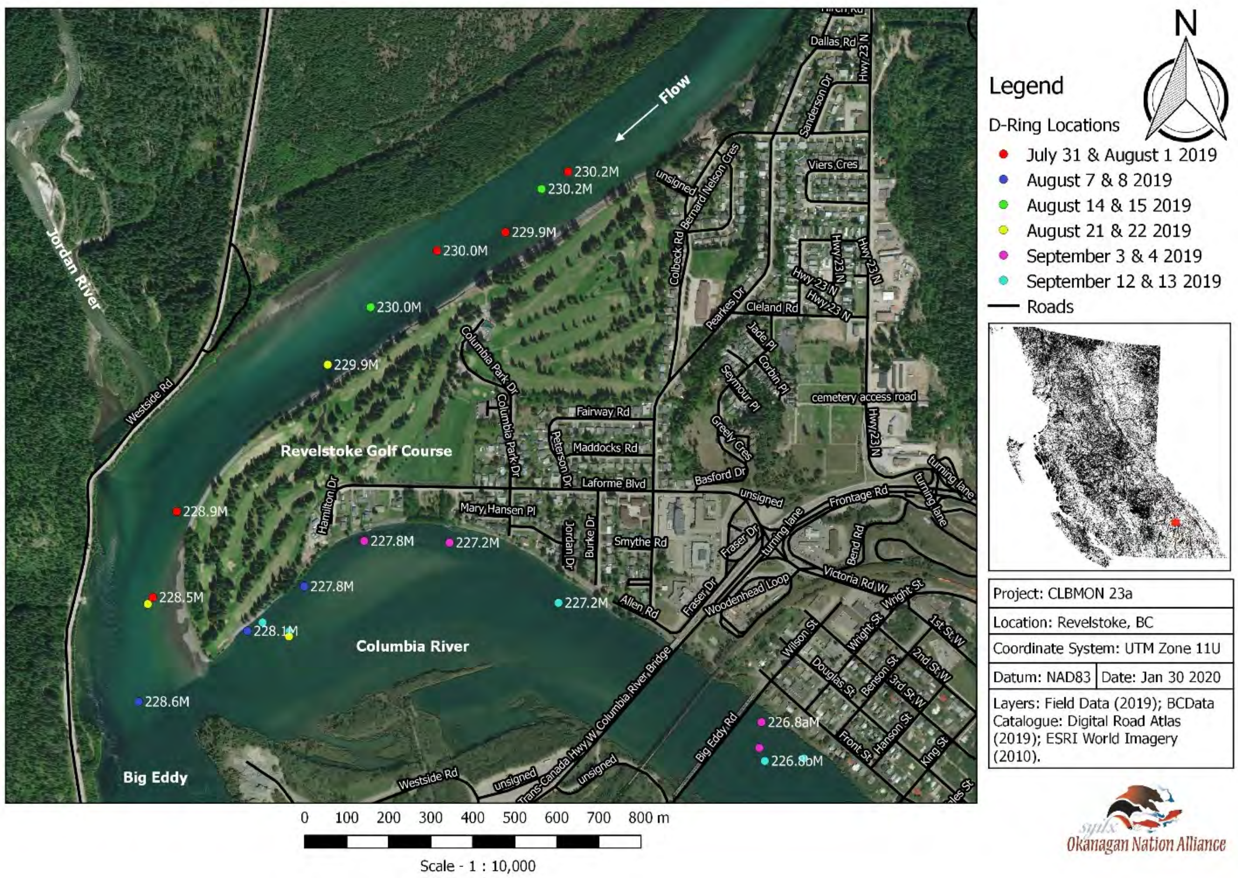

Figure 2. Drift net sampling locations in the Middle Columbia River in 2019. Drift nets sites used during spawn monitoring (July 24 to August 29) and larval dispersal sampling (September 3 to 19) are shown.

2.5 Study Period

Sampling activities and the timing of site visits relative to the suspected time periods for spawning and early life history phases of White Sturgeon are summarized in Table 1.

Table 1. Summary of sampling activities in 2019 relative to the suspected timing of White Sturgeon spawning and developmental stages.

Date	**White Sturgeon Early Life History (suspected)[1]**			**CLBMON-23A Sampling in 2019**		
	Spawning	**Yolk sac/hiding phase**	**Larval dispersal**	**Spawn Monitoring**	**Larval Dispersal**	**Activities**
July 24–25						Deployed egg mats and anchor stations
July 31–August 1						Egg mat and drift net sampling
August 7-8						Egg mat and drift net sampling
August 14-15						Egg mat and drift net sampling
August 21-22						Egg mat and drift net sampling
August 28-29						Retrieved and removed egg mats; drift net sampling; moved anchor systems downstream to larval dispersal area
September 3–4						Drift net sampling
September 12–13						Drift net sampling
September 18-19						Drift net sampling; retrieved anchor systems
September 25-26						No sampling conducted
October 2						No sampling conducted
October 9						No sampling conducted
October 16						No sampling conducted
October 23						No sampling conducted
October 30						No sampling conducted
November 6						No sampling conducted
November 13						No sampling conducted

Notes:

1. These are approximate timings based on typical MCR water temperature of approximately 9–11°C and the developmental rates reported in the literature (Beer 1981; Wang et al. 1985, 1987; Parsley et al. 2011). These authors reported 13 days to hatch and 30 days to completion of yolk absorption at 11°C. With the slightly cooler temperatures in the MCR, this table assumes 14–20 days post fertilization for hatch and 30-40 days post fertilization for completion of yolk sac absorption.

2.6 Egg and Larval Samples

All collected White Sturgeon eggs were developmentally staged in the field. Captured eggs were removed from egg mats or drift nets and transferred to small containers filled with river water using forceps or spoons. Eggs were examined using a hand lens or dissecting microscope and developmental stage was assigned using the stages (1 to 35) identified by Dettlaff et al. (1993) and described by Jay et al. (2016). All live eggs and larvae were held in insulated coolers of river water and transferred to staff of the Kootenay Sturgeon Hatchery for use in the conservation aquaculture program. Any eggs or larvae that were dead at capture were preserved in 90% ethanol and provided to BC Hydro.

2.7 Data Collection

Hourly discharge from REV and reservoir water surface elevation in ALR at Nakusp, BC were obtained from BC Hydro's Columbia Basin Hydrological Database. Water temperature, measured at 30-minute intervals, was obtained from a temperature logger (Levelogger Junior, Solinst, Georgetown, Ontario) deployed in a standpipe on the left downstream bank at Station 2 of the MCR Physical Habitat Monitoring Program (CLBMON-15A). Station 2 is located 3.7 km downstream of REV and 1 km upstream of the upstream end of the CLBMON-23A spawn monitoring study area.

Data recorded at each sample site during egg mat and drift net sampling included the following:

- Site name
- GPS location of site
- Time and date of deployment
- Time and date of retrieval
- Water temperature (°C) at deployment and retrieval
- Water depth (m) at deployment
- Start / end readings of flow meter (for drift nets only)
- Number of live eggs / larvae collected and number preserved (dead)
- Developmental stage of eggs / larvae
- Other species observed
- Comments (e.g., station drift, quantity of debris)

Data were recorded in the field on standard data sheets for the monitoring program and later entered into Microsoft Excel spreadsheet software.

2.8 Data Analysis

Spawn timing (spawning dates) was estimated by back-calculating from the date of egg/larvae collection using the egg/larvae developmental stage, the mean daily water temperature, and temperature-dependent rates of development reported in the literature (Beer 1981; Wang et al. 1985; Parsley et al. 2004, 2011). Based on the number of spawning dates and their spatial distribution, the number of discrete spawning events was estimated.

Sampling effort (hours) was calculated from deployment and retrieval date and times. For drift nets, sampling effort in volume of water sampled (m^3) was also calculated from the flow meters. Catch-per-unit-effort (CPUE) was calculated by dividing the total number of eggs/larvae by the total sampling effort for both egg mats and drift nets. GIS software was used to plot the location of sample sites and egg and larva capture locations.

2.9 Stranding Risk Assessment

The risk of egg stranding due to hydroelectric operations was identified as a key uncertainty (BC Hydro 2019) and was qualitatively assessed for all years of the monitoring program (2007 to 2019). The incidence, timing, and developmental stage of captured eggs or embryos were used to identify time periods when early life stages were present in the study area and would be vulnerable to stranding during discharge reductions. The periods when early life stages were present were calculated using the developmental stage of eggs/larvae captured and temperature-dependent developmental rates to cover the entire developmental period from fertilization to yolk sac absorption and dispersal. For these calculations, spawn timing was obtained from the present report for 2019 and from annual reports of the monitoring program for previous years (2007–2018)[2].

There is some uncertainty in developmental rates of White Sturgeon in the cool water temperatures of the MCR (Parsley et al. 2011). Beer (1981) found that egg hatch occurred 11 days after fertilization at 10°C, which is similar to typical water temperature in the MCR during the spawning period. However, a study mimicking the temperature regime of the MCR found that hatch occurred 13 to 16 days post-fertilization at water temperatures of approximately 10–11°C (Parsley et al. 2011). During the yolk-sac larva phase, development took 14 days post-hatch to reach the exogenous feeding and larval dispersal phase at 12.5°C (Jay 2014 as cited in Jay et al. 2016). As water temperature in some years in the MCR can be cooler (9-11°C) than these laboratory studies, it was assumed that it takes 13 to 20 days post-fertilization for hatch, and 30 to 40 days post-fertilization for complete absorption of the yolk sac, swim-up, and beginning of dispersal. Therefore, for the stranding assessment it was assumed that there were early life stages (eggs or yolk-sac larvae) present in the spawning and incubation area from the first detected spawning event until 40 days after the last detected spawning event in each year.

For the time period when early life stages were present (hereafter, the “risk period”), hourly discharge data from REV and ALR surface elevation data were used to identify periods when there were reductions in river stage that could have stranded eggs or larvae of White Sturgeon. Hourly discharge values were compared to the maximum of previous hourly discharges that year to infer whether the river stage was lower than it had been previously during the spawning

[2] Reports from previous years of the monitoring program are available online at: https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/columbia-sturgeon.html

and incubation period. Based on the magnitude of the difference in river discharge, the river stage, and the assumed backwatering effect of ALR, stranding risk was categorized as "No Risk", "Low", "Medium", "High", or "Very High" for each hour of the risk period.

When developing rules to assign stranding risk, it was assumed that relatively larger differences between current and previous maximum discharge resulted in relatively larger amounts of substrate being dewatered, which in turn resulted in relatively higher stranding risk. In addition, it was assumed that stranding risk was generally higher when the river stage was lower, especially during discharges lower than the current minimum flow of 142 m^3/s, which was implemented in 2010. This second assumption was based on locations of egg capture and egg stranding surveys from earlier years of the monitoring program, which suggested that a greater proportion of eggs are deposited at lower elevations of the river bed close to the thalweg than in upper elevations. A third assumption was that the magnitude of reduction that increased risk depended on river stage, where smaller reductions resulted in more risk at low river stage than at high river stage. The rules used to assign stranding risk are presented below and summarized in Table 2:

- If ALR surface elevation was greater than or equal to 437 masl (metres above sea level), the spawning and incubation areas were backwatered, which moderated the effect of discharge reductions (Wood 2019), resulting in a classification of "No Risk".
- If discharge was high (≥1000 m^3/s), it was assumed that the spawning and incubation areas were not dewatered, and stranding risk was classified as "Low", regardless of how much higher discharge had been previously.
- If discharge was medium (500–999 m^3/s), stranding risk was "Low" if the difference between the current and previous maximum discharge was less than 200 m^3/s and "Medium" if the difference was greater than 200 m^3/s.
- If discharge was low (142–499 m^3/s), stranding risk was "Low" if the difference between the current and previous maximum discharge was less than 99 m^3/s, "Medium" if the difference was between 100 and 199 m^3/s, and "High" if the difference was greater than 200 m^3/s.
- If discharge was very low (<142 m^3/s), stranding risk was "Very High" if the difference between the current and previous maximum discharge was greater than 100 m^3/s, "High" if the difference was between 50 and 99 m^3/s, and "Medium" if the difference was less than 50 m^3/s.

Stranding risk was assigned to each hour of the risk period using these rules. For each day, stranding risk was assigned based on the highest risk category assigned to hourly observations that day. The values used in these rules assigning stranding risk were based on best judgement but were somewhat arbitrary because informative data (hydraulic modelling, densities of eggs stranded at different river stages, etc.) were not available. Therefore, risk rankings should not be interpreted in an absolute sense, such as "High Risk" meaning that a large number of eggs or larvae were stranded. These rankings provide an initial effort to categorize the potential for stranding in historical years and should be used for comparisons of the relative risk within and between years. If informative data, such as substrate dewatering by discharge level and egg densities, are gathered in the future, then the values used in the stranding risk classification could be adjusted accordingly. Alternative cutoff values for the classification rules could also be trialed to assess sensitivity to these assumptions and how they affect predictions of stranding risk.

This relatively simple risk ranking made numerous simplifying assumptions that were untested. Some of these assumptions include the following:

- Eggs and yolk-sac larvae were present at all elevations of the riverbed on all subsequent days of the risk period after the river stage had reached that level once. This is a large and potentially influential assumption but was required because the extent of egg deposition, and how operations may affect this distribution in the study area are not known. In addition, the discharges at which various incubation substrates were dewatered would require a hydraulic model (which was not available for this analysis). Classification rules reflect that it is less likely that eggs and larvae were distributed into higher elevation substrates during daily maximum discharges, and that eggs and larvae were more likely to be found in lower elevation substrates. These rules were intended to minimize the influence of this assumption on the stranding risk assessment.
- Eggs and yolk-sac larvae were equally vulnerable.
- The duration or frequency of substrate dewatering did not influence the risk. As such, the risk rankings should be considered the relative risk of being dewatered at least once, for at least one hour in duration.
- High reservoir surface elevations (i.e., greater than 437 masl) eliminated substrate dewatering and stranding risk in the incubation area.

The degree to which violations of these assumptions affect relative risk is not known. Therefore, the risk classification should be interpreted as the potential for egg or larvae stranding in relative sense only.

Table 2. Definitions of relative stranding risk based on discharge and the difference between current discharge and previous maximum hourly discharge during the risk period for White Sturgeon eggs and larvae.

River Stage	Discharge (m^3/s)	Difference between current hourly discharge and previous maximum of hourly discharge that year (m^3/s)			
		<50	50-99	100-199	>200
Very Low	<142	Medium	High	Very High	Very High
Low	142 - 499	Low	Low	Medium	High
Medium	500 - 999	Low	Low	Low	Medium
High	>1000	Low	Low	Low	Low

2.10 Substrate Dewatering

A simple method to estimate the approximate amount of area dewatered in the egg incubation area was used in 2019. The study area for this task was limited to the cobble/gravel bar on the left bank (as viewed facing downstream) between Jordan River and Big Eddy, which is a suspected incubation area (Hildebrand et al. 2014). A GPS track was recorded along the water line and up to the permanently vegetated high water mark near the incubation area using a hand-held GPS. GPS tracks were recorded during two exemplary discharge rates in 2019. GIS software was used to calculate the difference in area of the bar exposed between the discharge levels as an example of the surface area dewatered for a given discharge reduction. As the route taken along the permanently vegetated high water mark differed slightly between GPS tracks (not related to dewatering or water level), the track for the left edge of the polygon (i.e., the left downstream bank) from the first measurement was used for both tracks, by snapping the second measurements points to the left edge of the polygon from the first measurement in GIS software. This was done to ensure that differences in area were related to dewatering, and not to differences in interpretation of the high water mark on the left downstream bank. Additional measurements of area at lower and higher discharge levels in the future could be compared to the data collected in 2019. This method was intended as an approximate and initial effort to quantify amounts of potential incubation substrate that were dewatered during exemplary discharge reductions.

3.0 RESULTS

3.1 Discharge, Water Temperature, and Reservoir Elevation

During sampling in 2019, discharge in the MCR exhibited large daily fluctuations that are typical for the hydropeaking operations at REV (Figure 3). Peak daily discharges during the sampling period were typically between 1500 and 2000 m^3/s and daily minimum discharge ranged from 256 to 549 m^3/s.

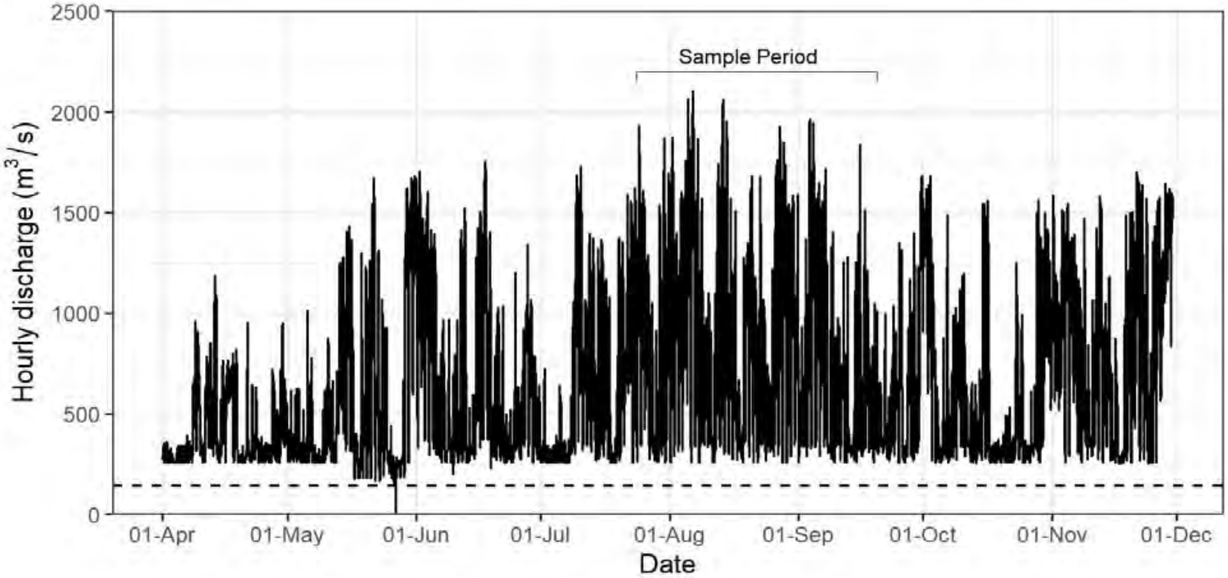

Figure 3. Hourly discharge in the Middle Columbia River downstream of Revelstoke Dam in 2019. The minimum flow of 142 m³s (dashed line) and the CLBMON-23A sample period are shown.

In 2019, surface elevation in ALR was 437.5 masl at the start of the sample period on July 24 and declined to 434.5 masl at the end of the sample period on September 19 (Figure 4). The surface elevation of ALR was less than 437 masl, the level above which the spawning area is backwatered, for the majority of the sample period (July 29 to September 19). Reservoir elevation varied between years, with the spawning area backwatered for the entire spawning season in some years, or not backwatered at all in other years (Appendix A, Figure A1).

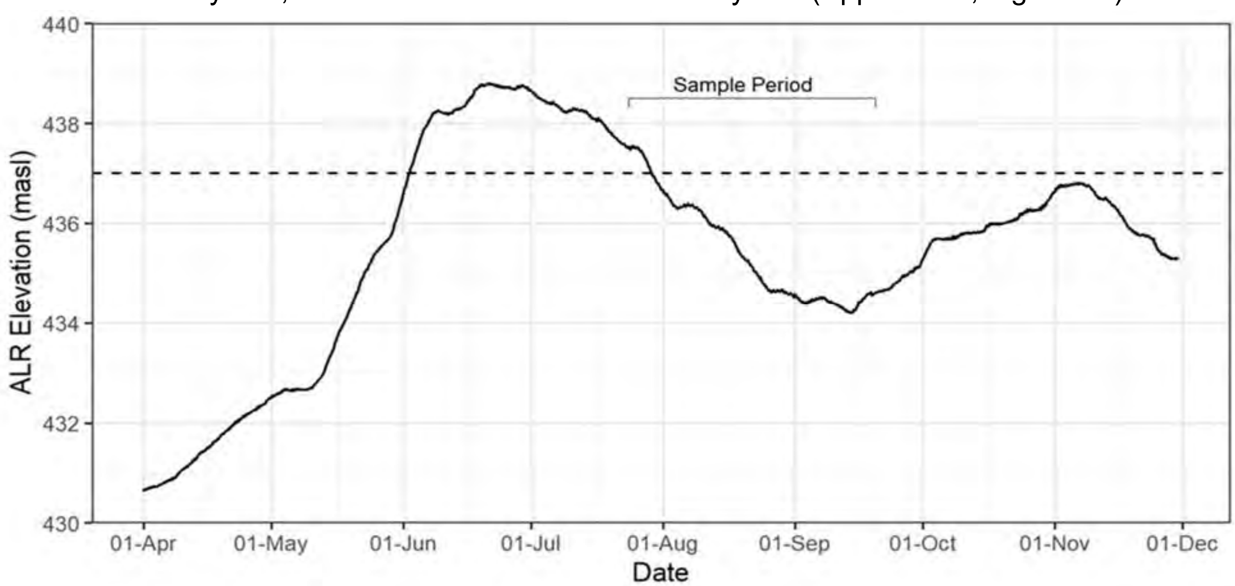

Figure 4. Reservoir surface elevation in metres above sea level (masl) in Arrow Lakes Reservoir (ALR) at Nakusp, BC in 2019. The dashed line represents an elevation of 437 masl, above which the reservoir is thought to backwater the spawning and incubation area (Golder 2009; Golder 2011).

Water temperature measured in the MCR 1 km upstream of the spawning area ranged from a minimum of 8°C to a maximum of 12°C (Figure 5). Typically, water temperatures during the late July to late August spawning season are between 9°C and 11°C.

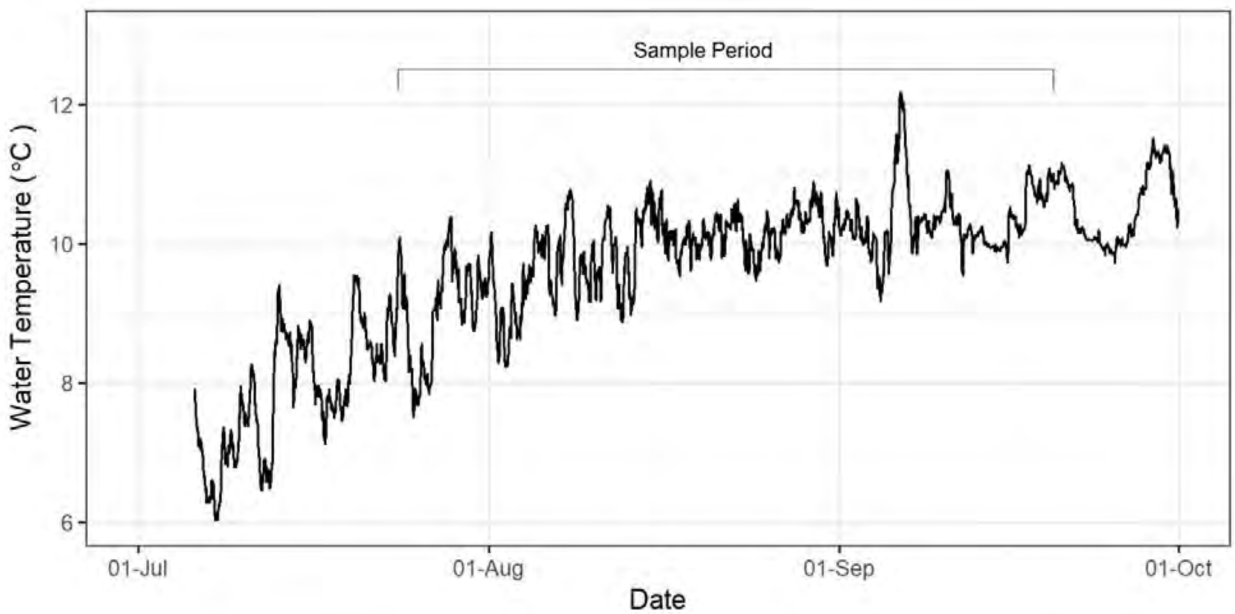

Figure 5. Water temperature in the Middle Columbia River measured 1 km upstream of the White Sturgeon spawning area in 2019.

3.2 Catch and Effort

Between July 24 and August 22, 2019, 11,569 mat-hours were expended while sampling 14 sites in the study area (Table 3). In total, two White Sturgeon eggs were captured using egg mats in 2019; both of these eggs were dead at capture. These two eggs were captured at site 228.9M, which was located near the left downstream bank across from the mouth of the Jordan River (Appendix A, Figure A2). Total CPUE in 2019 was 0.004 eggs/mat/24 h. Catch and effort by site and date are provided in Appendix A, Tables A3 and A4.

Table 3. Egg mat sampling effort, catch of White Sturgeon eggs and larvae, and catch-per-unit-effort in the Middle Columbia River in 2019.

Date	Effort (mat-hours)	Effort (mat-days)	# Sites	# Live Eggs	# Dead Eggs	# Live Larvae	# Dead Larvae	CPUE[a] (#/mat/24 h)
July 24-25	2,334	97.3	14	0	0	0	0	0.000
31 July - August 1	2,319	96.6	14	0	2	0	0	0.021
August 7-8	2,264	94.3	14	0	0	0	0	0.000
August 14-15	2,681	111.7	14	0	0	0	0	0.000
August 21-22	1,970	82.1	12	0	0	0	0	0.000
Total	**11,569**	**482.0**	**14**	**0**	**2**	**0**	**0**	**0.004**

a. CPUE was measured in number of all eggs and larvae combined per egg mat per 24 h.

In 2019, 148.5 hours of sampling were expended using drift nets (Table 4). In total, 48 sets were deployed during the day (1–3 hours each), and 4 sets were deployed overnight (15–18 hours each). In total, seven live eggs, two dead eggs, and one dead larva were captured. The total CPUE was 0.07 eggs and larvae/net/hour. The seven live eggs were captured on August 1 at Site 228.9M (n = 5) and 228.5M (n = 2), as shown in Appendix A, Figure A3. All seven live eggs were provided to the Kootenay Sturgeon Hatchery. The two dead eggs were captured at Site 227.8M (one White Sturgeon egg casing) and 229.9M (one fungus-encased White Sturgeon egg) on August 15. A single dead larva was captured at Site 229.9M on August 21 (Appendix A, Figure A4).

Sampling effort using drift nets was lower than previous years of this program from 2013 to 2018 but greater than during 2007 to 2012. In particular, few (n = 4) over-night sets were deployed in 2019 due to higher than expected water velocities, which hindered safe deployment or made sampling ineffective. Issues encountered while drift net sampling that reduce sampling effectiveness included the following:

- Collection bottles that were full or overflowing with sediment and therefore less effective at sampling for eggs for the remainder of deployment. Collection bottles also often had the filtering mesh damaged.
- Drift nets that were partially or completely torn off of the D-ring frame, resulting in damage or loss of the net.
- Anchor systems that dislodged during high flows while the field crew was not on site.
- Float lines and buoys that submerged due to high water velocities or discharge increases, regardless of rope scope (i.e., length of float line relative to water depth).

Over-night sets were not deployed if conditions were unsafe or if nightly discharge forecasts were expected to result in damaged or lost equipment. During most sampling weeks, the afternoon of the first sampling day, when over-night sets could potentially be deployed, coincided with high REV discharge (i.e., discharge greater than 1500 m^3/s). In addition to these high discharges, the low reservoir level in 2019 reduced backwatering in the study area, further increasing water velocities.

Table 4. Drift net sampling effort, catch of White Sturgeon eggs and larvae, and catch-per-unit-effort in the Middle Columbia River in 2019.

Dates	Effort (net-hours)	Effort[a] (m^3)	# of Day Sets	# of Over-night Sets	# Live Eggs	# Dead Eggs	# Live Larvae	# Dead Larvae	CPUE[b] (#/net/h)
July 31 - August 1	12.9	2,414	5	0	7	0	0	0	0.540
August 7-8	14.7	2,728	8	0	0	0	0	0	0.000
August 14-15	27.9	1,956	6	1	0	2	0	0	0.071
August 21-22	26.9	2,171	5	1	0	0	0	1	0.040
August 28-29	1.4	141	1	0	0	0	0	0	0.000
September 3-4	15.9	3,295	11	0	0	0	0	0	0.000
September 12-13	15.3	2,344	9	0	0	0	0	0	0.000
September 18-19	33.7	594	3	2	0	0	0	0	0.000
Total	**148.5**	**15,641**	**48**	**4**	**7**	**2**	**0**	**1**	**0.070**

a. Effort in volume (m^3) of water sampled was calculated from flow meters but does not include overnight sets because the counters had re-set (exceed maximum value) an unknown number of times.

b. CPUE was measured in number of all eggs and larvae combined per drift net per 24 h.

3.3 Developmental Staging and Estimated Spawn Timing

Based on the catch and staging of eggs, only one spawning event was detected in 2019. The eggs captured on August 1 included five eggs captured at 10:13 that were assigned stages of 8 or 9, and two eggs captured at 11:08 that were assigned stages of 9 and 10. The back-calculated times of spawning for these eggs were 13:08 and 19:13 on July 31, 2019 (Table 5), which were considered a single spawning event. All of the other eggs captured (n = 4) were dead and too damaged or encased in fungus to assign a developmental stage. The single dead larva collected on August 21 was suspected to be in the yolk-sac phase (stage 36–44) but was too damaged to assign a more precise stage. As the larva was captured 21 days after the July 31 spawning event, and yolk-sac larvae were expected approximately 13 to 30 days after spawning (Section 2.9), this larva could have been from the previously documented July 31 spawning event. Therefore, the larva was not considered evidence of a separate spawning event.

Table 5. Estimated date and time of spawning that was back-calculated from capture date, developmental stage, and water temperature.

Date and Time of Capture	Water Temp. (°C)	Egg Stage at Capture (Dettlaff 1993)	Egg Stage at Capture (Beer 1981)	Estimated Date & Time of Spawning Event	Estimated Date and Time of Hatch
01-Aug-2019 10:13	9.4*	8,9	16	31-Jul-2019 19:13	14-Aug-2019 16:13
01-Aug-2019 11:08	9.4*	9,10	17	31-Jul-2019 13:08	14-Aug-2019 10:08

* A water temperature of 10°C was used to estimate spawn timing because 10°C is the lowest temperature included in published developmental rates (Beer 1981).

3.4 Stranding Risk Assessment

For years when spawning events were detected during CLBMON-23A (i.e., all years except 2007, 2010, and 2015), relative stranding risk was assessed based on ALR surface elevation, REV discharge, and the difference between current and previous maximum hourly discharge (Figure 6). Some years (2008 and 2017) were classified as “No Risk” for the entire risk period when eggs and larvae were present. “No Risk” was assigned when ALR elevation was greater than 437 masl because it was assumed that the incubation area was backwatered enough to prevent dewatering of eggs and larvae. In years when ALR backwatered the incubation area for only part of the risk period (2011, 2012, and 2018), relative risk was classified as “No Risk” during the early part of the risk period while backwatering occurred, whereas relative risk was typically classified as “High” during the period when backwatering did not occur. In years when backwatering did not occur at all during the risk period (2013, 2014, 2016, 2019), relative risk was classified as “High” for most days with a small number of days classified as “Medium” risk. In 2009, relative stranding risk was “Very High” for most of the risk period, due to the lack of a minimum flow release during that study year (minimum flows were implemented in 2010).
In 2009, discharge was frequently reduced from between 500 to 1200 m³/s to less than 0 m³/s (Golder 2010).

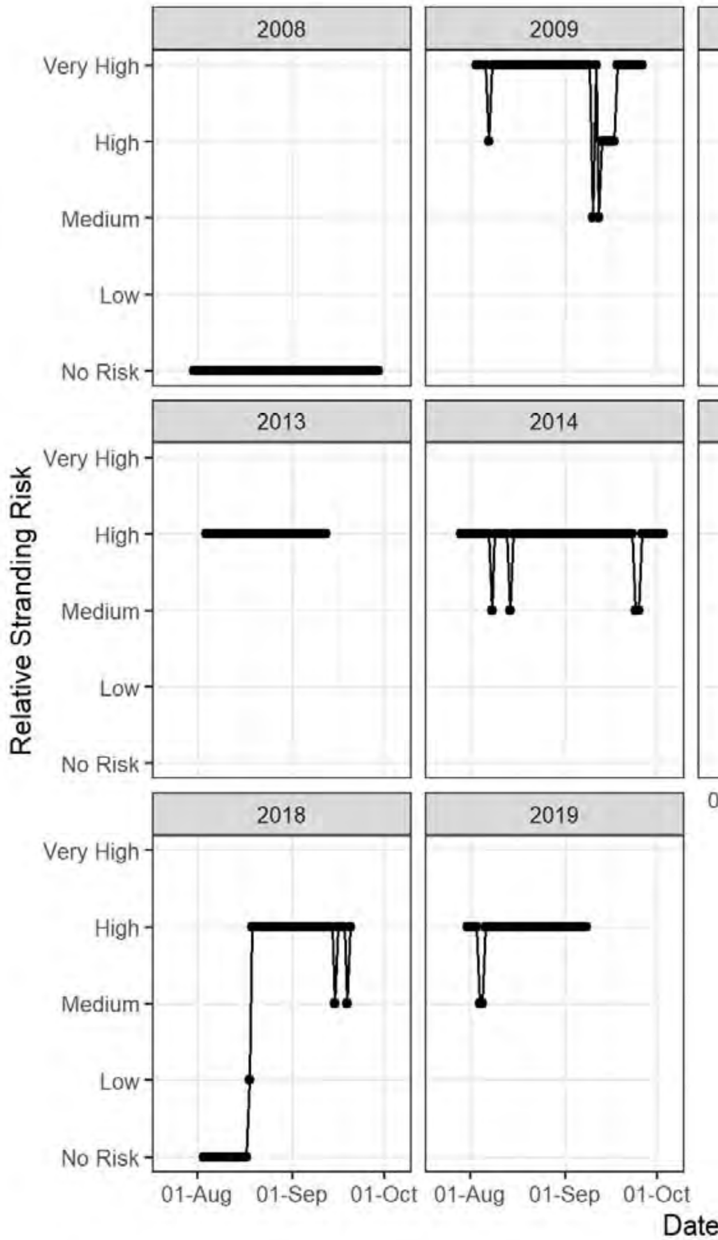

Figure 6. Relative stranding risk of early life stages of White Sturgeon in the Middle Columbia River by year. Years between 2007 and 2019 when spawning was not detected are not shown.

The percentage of days during the risk period assigned to each risk category was summarized (Table 6). The “High” risk category comprised the greatest percentage of days in years when ALR was not backwatering the incubation area (63% to 100% of days). The “Low” and “Medium” risk categories were assigned to a small percentage of days (≤5%) in all years except 2016, when 30% of the risk period was assigned “Medium” risk. In years before the implementation of a minimum flow release (2008 and 2009), daily risk was classified as “No Risk” for 100% of the days in 2008, when ALR elevation was high (>437 masl), and was classified as “Very High” for most (85.5%) days in 2009, when ALR elevation was low and backwatering of the incubation area was limited.

When summarizing hourly risk categories (Table 7), a greater percentage of time was classified as “Low” or “Medium” risk when compared to the daily risk values (Table 6). This was because daily risk was assigned based on the highest hourly risk classification each day. For instance, in 2013 and 2014, risk was classified as “High” on 100.0% and 94.0% of days, respectively, but only 36.1% and 30.5% of hours during those years. Hourly risk was often lower than daily risk because relatively higher stranding risk was assigned during daily low flows than during higher flows (Table 2), and low flows were typically only observed during part of the day during hydropeaking operations at REV. Overall, hourly classifications of relative stranding risk were lower than daily classifications in all years.

Table 6. Percentage of days during risk period that were assigned different stranding risk categories. Percentages were calculated from the daily risk values presented in Figure 6.

Year*	Percentage of Days During Risk Period for Each Relative Stranding Risk Category (%)				
	No Risk	Low	Medium	High	Very High
2008	100.0	0.0	0.0	0.0	0.0
2009	0.0	0.0	3.6	10.9	85.5
2011	69.6	0.0	0.0	30.4	0.0
2012	68.0	0.0	4.0	28.0	0.0
2013	0.0	0.0	0.0	100.0	0.0
2014	0.0	0.0	6.0	94.0	0.0
2016	0.0	0.0	30.0	70.0	0.0
2017	100.0	0.0	0.0	0.0	0.0
2018	30.6	2.0	4.1	63.3	0.0
2019	0.0	0.0	5.0	95.0	0.0

* Years between 2007 and 2019 when spawning was not detected are not included.

Table 7. Percentage of hours during risk period that were assigned different stranding risk categories by year.

Year	Percentage of Hours During Risk Period for Each Relative Stranding Risk Category (%)				
	No Risk	Low	Medium	High	Very High
2008	100.0	0.0	0.0	0.0	0.0
2009	0.0	26.7	32.3	19.8	21.3
2011	70.5	12.9	6.6	10.0	0.0
2012	69.7	17.4	6.2	6.8	0.0
2013	0.0	48.0	15.8	36.1	0.0
2014	0.0	42.2	27.2	30.5	0.0
2016	0.0	46.5	30	23.5	0.0
2017	100.0	0.0	0.0	0.0	0.0
2018	32.3	23.6	24.3	19.7	0.0
2019	0.0	41.4	23.6	35.0	0.0

* Years between 2007 and 2019 when spawning was not detected are not included.

3.5 Substrate Dewatering

The area of exposed substrate on the exposed gravel/cobble bar between the Jordan River and Big Eddy was measured using GPS tracks on two dates in 2019 and analyzed using GIS software (Table 8; Appendix A, Figures A5 and A6). ALR surface elevation was similar on the two dates when measurements were taken (436.3–436.8 masl). The data indicate that the area of exposed bar was 11,260 m² when discharge was 882 m³/s and 10,409 m² when discharge was 869 m³/s, a difference of 851 m². A greater area of exposed bar at higher discharge (on August 8 vs. November 4) was the opposite of the expected trend of more exposed substrate at lower discharge. This discrepancy may be due to the lower reservoir level on August 8.

Table 8. Substrate dewatering measurements from an exposed gravel bar downstream of the spawning area in 2019.

Date	Time	Area of Exposed Bar (m²)	REV Discharge* (m³/s)	ALR surface elevation (masl)
August 8, 2019	9:55 – 10:07	11,260	882 m³/s at 9:00 951 m³/s at 10:00	436.3
November 4, 2019	23:07 – 23:26	10,409	869 m³/s at 23:00	436.8

* Hourly discharge at REV. Two values are given for August 8 because a change in discharge occurred at 10:00 while GPS transect was occurring. These hourly discharge values do not account for the time lag between changes in discharge at REV at the resulting change in discharge downstream in the study area.

4.0 DISCUSSION

One White Sturgeon spawning event was documented in the MCR on July 31, 2019, which is near the start of the range of spawn timing documented in previous years (Figure 8 in Wood 2019). This is the 10th year spawning has been detected since the monitoring program began in 2007. Since the inception of monitoring spawning activity for White Sturgeon in the MCR, spawning has been detected in 13 of 18 years assessed. While spawning was detected in 2019, only a few live eggs (n = 7) were captured and transferred to the Kootenay Sturgeon Hatchery. Despite limited captures, the results still demonstrate that both egg mats and drift nets are effective for monitoring spawning and collecting eggs and larvae, and a combination of the two methods is likely the best approach to achieve the objectives of the monitoring program (Wood 2019).

An objective of the program in 2019 was to increase sampling effort using drift nets compared to previous years to increase the number of larvae available for conservation aquaculture. Unfortunately, sampling effort in 2019 was 50% less than recent years of the program from 2013 to 2018. The reduction in sampling effort is attributed to high discharge during sampling sessions combined with low reservoir levels resulting in high water velocities that limited drift net sampling effort. To increase drift net sampling effort, future years of the program could consider alternative strategies, particularly in years when reservoir levels are low enough to reduce backwatering effects in the study area. Positioning drift nets in slower water that is closer to shore or near back-eddies would be desirable but very little of this type of habitat is available near the spawning area, especially during high discharge periods. Another possible strategy would be to deploy drift nets at night, when REV discharge is typically lower (i.e., after approximately 10:00 PM), and retrieve them early in the morning before discharge increases. Sampling during low flows would likely allow more drift nets to be fished over-night without nets being damaged or lost. However, the effectiveness of sampling during low flow periods (e.g., often 300 to 500 m^3/s during night-time hours in August) for catching eggs is unknown.

The stranding assessment presented here was intended to address uncertainty regarding stranding risk of White Sturgeon eggs and larvae due to hydroelectric operations. The criteria used to classify stranding risk were based on several untested assumptions and therefore the rankings should only be considered as the potential for stranding due to discharge variability, and only in a relative sense within and between years. These relative risk rankings are likely sensitive to the threshold values of discharge and discharge difference that were selected (Table 2), and data were not available to inform the discharge levels and magnitude of discharge differences where stranding was more likely. In light of these limitations, conclusions drawn from this assessment should be considered uncertain, and a quantitative approach using a hydraulic model would be required to reduce uncertainty in stranding risk.

Two strong assumptions of the stranding risk assessment were as follows: 1) stranding risk was highest when discharge was less than the minimum flow (142 m^3/s); and, 2) there was no stranding risk, regardless of the magnitude of discharge variability, when ALR elevation was greater than 437 masl. The first assumption remains uncertain but is supported by the location of the small number of eggs found during egg stranding surveys before and after the implementation of minimum flows (Golder 2010; Golder 2012; Wood 2019). Additional sampling or modelling is recommended to test the validity of the second assumption regarding backwatering by ALR. A simple method to test this assumption would be to repeat the substrate dewatering survey (sections 2.9 and 3.5) at high and low discharges, when ALR elevation is greater than 437 masl.

This data report is intended to detail the methods and results of monitoring in 2019. For discussion of the status of management questions and comparisons between previous study years, readers are referred to the interpretive reports from previous years of this monitoring program (Wood 2019).

5.0 REFERENCES

Amec Foster Wheeler. 2018. Middle Columbia River White Sturgeon Spawning Monitoring (CLBMON-23A). Year 11 Data Report. Report Prepared for: BC Hydro, Castlegar. 27 pp + 3 App.

Beer, K.E. 1981. Embryonic and larval development of White Sturgeon (*Acipenser transmontanus*). MS Thesis, UC Davis. 93 p.

BC Hydro. 2007. Columbia River Project Water Use Plan Monitoring Program Terms of Reference – Columbia River White Sturgeon Management Plan. CLBMON-23 Mid Columbia River Sturgeon Egg Mat Monitoring and Feasibility Study. 14 pp.

BC Hydro 2018. Mid Columbia River White Sturgeon Technical Forum – Summary and Action Items. Memo produced by BC Hydro, 4pp.

BC Hydro. 2019. CLBMON-23A Scope of Services. 6 pp.

Dettlaff, T.A., A.S. Ginsburg and O.I. Schmalhausen. 1993. Sturgeon fishes. Developmental biology and aquaculture. Springer-Verlag, Berlin, Germany, 300 pp.

Golder Associates Ltd. 2006. A synthesis of White Sturgeon investigations in Arrow Lakes Reservoir, B.C. 1995 – 2003. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 041480016F: 61 p. + plates + 11 app.

Golder Associates Ltd. 2009. Middle Columbia River white sturgeon spawn monitoring study: 2008 investigations. Report prepared for BC Hydro, Revelstoke, B.C. Golder Report No. 08-1480-0029F: 24 p. + 2 app.

Golder Associates Ltd. 2010. Middle Columbia River white sturgeon spawn monitoring: 2009 investigations data report. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 09-1480-0044F: 20 p. + 2 app.

Golder Associates Ltd. 2011. Middle Columbia River White Sturgeon spawn monitoring: 2010 investigations. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 10-1492-0061F: 17 p. + 1 app.

Golder Associates Ltd. 2012. Middle Columbia River White Sturgeon spawn monitoring: 2011 investigations. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 11-1492-0071F: 21 p. + 1 app.

Hildebrand, L. R. and M. Parsley. 2013. Upper Columbia White Sturgeon Recovery Plan – 2012 Revision. Prepared for the Upper Columbia White Sturgeon Recovery Initiative. 129 pp. + 1 app. Available at: www.uppercolumbiasturgeon.org

Hildebrand, L. R., A. Lin, M. C. Hildebrand, and D. Fissel. 2014. Effects of Flow Changes on White Sturgeon Spawning, Incubation, and Early Rearing Habitats in the Middle Columbia River (CLBMON-20 and CLBMON-54). Prepared for BC Hydro, Castlegar, BC by Golder Associates Ltd, Castlegar, BC and ASL Environmental Sciences Inc., Victoria, BC. 64 pp. + 3 app and 1 Attachment.

Hildebrand, L.R., A. Drauch Schreier, K. Lepla, S.O. McAdam, J. McLellan, M.J. Parsley, V.L. Paragamian, and S.P. Young. 2016. Status of White Sturgeon (*Acipenser transmontanus* Richardson, 1863) throughout the species range, threats to survival, and prognosis for the future. Journal of Applied Ichthyology 32: 261-312.

Jay, K.J. 2014. Estimating effective number of breeding adults, reproductive success, and spawning duration for White Sturgeon in the Upper Columbia River, Canada. M.Sc. Thesis. Michigan State University, USA.

Jay, K., J. Crossman, and M. Webb. 2016. Developmental Staging for Sturgeon Embryos and Yolk-Sac Larvae. Prepared for the 2016 NASPS Annual Meeting Workshop, Hood River, OR. 21 p.

Johnson, P.N., S. LeBourdais, and M. Tiley. 2010. Monitoring Study No. CLBMON#23b. Mid Columbia River White Sturgeon Underwater Videography Feasibility Study 2009. Final Report.

Parsley, M.J., D.M. Gadomski, and P. Kofoot. 2004. White sturgeon mitigation and restoration in the Columbia and Snake rivers upstream from Bonneville Dam: Annual Progress Report. U.S. Geological Survey, Western Fisheries Research Center. Report C: 10pp.

Parsley, M. J., E. Kotfoot, T. J. Blubaugh. 2011. Mid Columbia sturgeon incubation and rearing study (year 2). Report prepared for BC Hydro, Castlegar, BC. 23 p. + 1 app.

Wang, Y.L., F.P. Binkowski, and S.I. Doroshov. 1985. Effect of temperature on early development of white and lake sturgeon, *Acipenser transmontanus* and *A. fulvescens*. Environmental Biology of Fishes 14:43-50.

Wang, Y.L., R.K. Buddington, and S.I. Doroshov. 1987. Influence of temperature on yolk utilization by the white sturgeon, *Acipenser transmontanus*. Journal of Fish Biology 30: 263-271

Wood. 2019. Middle Columbia River White Sturgeon Spawning Monitoring (CLBMON-23A). Year 12 Data Report. Report Prepared for: BC Hydro, Castlegar. 32 pp + 3 App.

APPENDIX A

SUPPLEMENTARY INFORMATION AND MAPS

APPENDIX A SUPPLEMENTARY INFORMATION AND MAPS

Table 1. Locations of egg mat sample sites in the Middle Columbia River in 2019.

Site Name	UTM Coordinates			Set Dates*
	Zone	Easting	Northing	
227.8M	11	413577	5651469	July 25 to August 22, 2019
227.9L	11	413523	5651441	July 25 to August 21, 2019
228.1M	11	413442	5651363	July 25 to August 22, 2019
228.5M	11	413217	5651443	July 25 to August 22, 2019
228.6M	11	413202	5651555	July 25, 2019
228.6M	11	413183	5651195	August 1 and 7, 2019
228.6M	11	413541	5651350	August 15 and 21, 2019
228.8L	11	413313	5651668	July 25 to August 21, 2019
228.9M	11	413362	5651790	July 25, 2019
228.9M	11	413274	5651647	August 1 and 8, 2019
228.9M	11	413205	5651427	August 14 and 22, 2019
229.3L	11	413693	5652006	July 24 to August 21, 2019
229.7L	11	413898	5652155	July 24 to August 21, 2019
229.8L	11	414050	5652229	July 24 to August 21, 2019
229.9M	11	414056	5652311	July 24; August 1, 7, and 15, 2019
229.9M	11	413633	5651996	August 21, 2019
230.0M	11	414059	5652397	July 24, 2019
230.0M	11	413893	5652267	August 1 and 7, 2019
230.0M	11	413735	5652133	August 14, 2019
230.1L	11	414297	5652415	July 24 to August 21, 2019
230.2M	11	414205	5652455	July 24 and August 1, 2019
230.2M	11	414142	5652414	August 7, 2019
230.2M	11	413948	5652266	August 14, 2019

* Some sites have more than one row because they were displaced from their original set locations but were fished at the new locations on the dates shown in the “Set Dates” column.

APPENDIX A SUPPLEMENTARY INFORMATION AND MAPS

Table 2. Locations of drift sample sites in the Middle Columbia River in 2019.

Site Name	UTM Coordinates			Set Dates*
	Zone	Easting	Northing	
226.8aM	11	414665	5651146	September 3 and 4, 2019
226.8aM	11	414766	5651060	September 13 and 18, 2019
226.8bM	11	414660	5651085	September 3, 2019
226.8bM	11	414673	5651054	September 12, 13, and 18, 2019
227.0M	11	414766	5651060	September 12, 2019
227.2M	11	413923	5651573	September 3 and 4, 2019
227.2M	11	414182	5651430	September 12, 13, and 18, 2019
227.8M	11	413577	5651469	August 8 and 15, 2019; September 3, 2019
227.8M	11	413720	5651577	September 4, 2019
228.1M	11	413442	5651363	August 8 to September 4, 2019
228.1M	11	413478	5651383	September 12 and 13, 2019
228.5M	11	413217	5651443	August 1 to September 4, 2019
228.6M	11	413183	5651195	August 7, 2019
228.6M	11	413541	5651350	August 21, 2019
228.6M	11	413542	5651362	September 13, 2019
228.9M	11	413274	5651647	August 1, 8, and 14, 2019
228.9M	11	413205	5651427	August 21 and September 3, 2019
229.9M	11	414056	5652311	August 1, 7, and 14, 2019
229.9M	11	413633	5651996	August 21, 2019
230.0M	11	413893	5652267	July 31 and August 7, 2019
230.0M	11	413735	5652133	August 14, 2019
230.2M	11	414205	5652455	August 1 and 7, 2019
230.2M	11	414142	5652414	August 14, 2019

* Some sites have more than one row because they were displaced from their original set locations but were fished at the new locations on the dates shown in the “Set Dates” column.

APPENDIX A SUPPLEMENTARY INFORMATION AND MAPS

Table A3. Sampling data from egg mat sampling in the Middle Columbia River in 2019.

Site Name	Set Data			Pull Data			Depth (m)	Effort (hours)	Number of WSG Eggs	Number of WSG Larvae
	Date	Time	Water Temp. (°C)	Date	Time	Water Temp. (°C)				
230.2M	24-Jul-19	15:41	9.0	01-Aug-19	6:48	9.9	4.1	183.1	0	0
230.0M	24-Jul-19	16:27	9.0	31-Jul-19	15:30	9.3	4.7	167.1	0	0
229.9M	24-Jul-19	16:57	9.1	01-Aug-19	7:14	9.5	3.3	182.3	0	0
230.1L	24-Jul-19	17:10	9.1	31-Jul-19	15:50	9.3	3.1	166.7	0	0
229.8L	24-Jul-19	16:06	9.1	31-Jul-19	16:06	9.3	2.4	168.0	0	0
229.7L	24-Jul-19	17:29	8.7	31-Jul-19	16:21	9.3	3.1	166.9	0	0
229.3L	24-Jul-19	17:44	8.7	31-Jul-19	16:35	9.3	4.1	166.8	0	0
228.9M	25-Jul-19	9:04	7.1	01-Aug-19	7:31	9.5	3.6	166.5	2	0
228.6M	25-Jul-19	9:23	7.4	01-Aug-19	8:29	9.1	3.6	167.1	0	0
228.5M	25-Jul-19	9:50	7.5	01-Aug-19	8:10	9.4	2.0	166.3	0	0
228.1M	25-Jul-19	10:12	7.7	01-Aug-19	8:46	9.8	3.4	166.6	0	0
227.8M	25-Jul-19	10:30	7.9	01-Aug-19	9:05	9.4	3.6	166.6	0	0
228.8L	25-Jul-19	10:46	7.7	31-Jul-19	16:48	9.3	3.6	150.0	0	0
227.9L	25-Jul-19	10:55	8.0	31-Jul-19	17:04	9	3.7	150.1	0	0
230.1L	31-Jul-19	15:07	9.3	07-Aug-19	15:07	9.9	2.3	168.0	0	0
229.8L	31-Jul-19	16:18	9.3	07-Aug-19	15:20	9.7	2.5	167.0	0	0
229.7L	31-Jul-19	16:30	9.3	07-Aug-19	15:31	9.7	4.4	167.0	0	0
229.3L	31-Jul-19	16:41	9.3	08-Aug-19	9:01	10.6	2.6	184.3	0	0
228.8L	31-Jul-19	16:55	9.3	08-Aug-19	9:22	10.6	2.4	184.5	0	0
227.9L	31-Jul-19	17:13	9.0	08-Aug-19	9:39	10.6	2.5	184.4	0	0
228.6M	01-Aug-19	8:29	9.4	07-Aug-19	14:57	9.7	4.4	150.5	0	0
228.1M	01-Aug-19	8:46	9.8	08-Aug-19	8:33	10.6	3.4	167.8	0	0
227.8M	01-Aug-19	9:05	9.4	08-Aug-19	8:47	10.6	3.2	167.7	0	0
230.0M	01-Aug-19	9:24	9.4	07-Aug-19	14:41	9.9	3.4	149.3	0	0
230.2M	01-Aug-19	9:31	9.4	07-Aug-19	14:15	9.6	3.9	148.7	0	0
229.9M	01-Aug-19	9:50	9.4	07-Aug-19	14:29	9.9	4.0	148.7	0	0
228.9M	01-Aug-19	10:13	9.4	08-Aug-19	8:07	10.4	3.4	165.9	0	0
228.5M	01-Aug-19	11:08	9.3	08-Aug-19	8:16	10.6	2.0	165.1	0	0
230.1L	07-Aug-19	15:16	9.9	14-Aug-19	14:07	2.6	2.6	166.8	0	0
229.8L	07-Aug-19	15:27	9.7	14-Aug-19	14:20	10.2	1.5	166.9	0	0
229.7L	07-Aug-19	15:40	9.7	14-Aug-19	14:35	9.8	3.9	166.9	0	0
230.2M	07-Aug-19	15:47	10.1	14-Aug-19	13:17	10.2	4.0	165.5	0	0
229.9M	07-Aug-19	16:04	10.1	14-Aug-19	13:28	10.2	4.0	165.4	0	0
230.0M	07-Aug-19	16:18	10.1	14-Aug-19	13:42	10.2	3.2	165.4	0	0
228.6M	07-Aug-19	16:39	10.1	14-Aug-19	16:50	10.2	4.5	168.2	0	0
229.3L	08-Aug-19	9:16	10.6	14-Aug-19	16:00	10.2	1.5	150.7	0	0
228.8L	08-Aug-19	9:35	10.2	14-Aug-19	16:15	10.2	2.0	150.7	0	0

Continued…

APPENDIX A SUPPLEMENTARY INFORMATION AND MAPS

Table A3. Concluded.

Site Name	Set Data			Pull Data			Depth (m)	Effort (hours)	Number of WSG Eggs	Number of WSG Larvae
	Date	Time	Water Temp. (°C)	Date	Time	Water Temp. (°C)				
227.9L	08-Aug-19	9:50	10.5	14-Aug-19	16:29	10.5	2.2	150.7	0	0
228.9M	08-Aug-19	10:13	10.1	14-Aug-19	13:55	10.2	2.5	147.7	0	0
228.5M	08-Aug-19	10:29	10.1	15-Aug-19	8:10	10.4	1.3	165.7	0	0
228.1M	08-Aug-19	10:41	10.1	15-Aug-19	9:21	10.2	2.7	166.7	0	0
227.8M	08-Aug-19	10:53	10.3	15-Aug-19	9:40	10.1	2.5	166.8	0	0
230.1L	14-Aug-19	14:17	10.2	21-Aug-19	15:05	9.8	2.1	168.8	0	0
229.8L	14-Aug-19	14:31	9.8	21-Aug-19	15:17	9.8	2.4	168.8	0	0
229.7L	14-Aug-19	14:57	10.1	21-Aug-19	15:29	9.8	2.8	168.5	0	0
230.2M	14-Aug-19	15:03	10.1	29-Aug-19	10:30	10.4	3.8	355.5	0	0
229.9M	15-Aug-19	9:00	9.9	21-Aug-19	13:58	9.4	3.7	149.0	0	0
230.0M	14-Aug-19	15:23	10.5	29-Aug-19	9:58	10.4	3.8	354.6	0	0
228.9M	14-Aug-19	15:43	9.7	21-Aug-19	14:19	9.7	2.8	166.6	0	0
229.3L	14-Aug-19	16:09	9.8	21-Aug-19	15:42	9.8	2.7	167.5	0	0
228.8L	14-Aug-19	16:24	10.2	21-Aug-19	15:57	9.8	1.5	167.5	0	0
227.9L	14-Aug-19	16:47	10.2	21-Aug-19	16:12	9.8	3.2	167.4	0	0
228.6M	15-Aug-19	10:39	9.9	21-Aug-19	14:38	9.4	1.3	148.0	0	0
228.5M	15-Aug-19	10:44	10.3	22-Aug-19	9:11	10.2	1.3	166.5	0	0
228.1M	15-Aug-19	10:52	10.3	22-Aug-19	8:51	10.2	2.7	166.0	0	0
227.8M	15-Aug-19	11:04	10.3	22-Aug-19	9:40	9.8	2.5	166.6	0	0
229.9M	21-Aug-19	16:29	9.8	29-Aug-19	10:10	10.5	5.0	185.7	0	0
228.9M	22-Aug-19	8:14	10.2	28-Aug-19	15:20	10.1	1.0	151.1	0	0
228.6M	21-Aug-19	17:13	9.8	29-Aug-19	10:27	10.5	1.5	185.2	0	0
230.1L	21-Aug-19	15:13	9.8	28-Aug-19	14:02	10.1	2.0	166.8	0	0
229.8L	21-Aug-19	15:25	9.8	28-Aug-19	14:15	10.1	2.1	166.8	0	0
229.7L	21-Aug-19	15:38	9.8	28-Aug-19	14:27	10.1	3.5	166.8	0	0
229.3L	21-Aug-19	15:53	9.8	28-Aug-19	14:40	10.1	1.0	166.8	0	0
228.8L	21-Aug-19	16:08	9.8	28-Aug-19	14:55	10.1	2.4	166.8	0	0
227.9L	21-Aug-19	16:22	9.8	28-Aug-19	15:39	10.1	2.7	167.3	0	0
228.1M	22-Aug-19	10:55	10.2	28-Aug-19	15:48	10.1	2.5	148.9	0	0
228.5M	22-Aug-19	11:09	10.3	28-Aug-19	15:10	10.1	1.1	148.0	0	0
227.8M	22-Aug-19	10:02	9.9	28-Aug-19	16:06	10.1	2.0	150.1	0	0

Table A4. Sampling data from drift nets in the Middle Columbia River in 2019.

Site Name	Set				Pull				Depth (m)	Effort (m³)	Effort (hours)	Number of WSG Eggs	Number of WSG Larvae
	Date	Time	Flow Meter Reading	Water Temp (°C)	Date	Time	Flow Meter Reading	Water Temp (°C)					
230.0M	31-Jul-19	15:30:00	644457	9.3	31-Jul-19	17:23:00	935318	9	3.3	476	1.9	0	0
230.2M	01-Aug-19	06:48:00	935308	9.5	01-Aug-19	09:31:00	227719	9.4	2.3	478	2.7	0	0
229.9M	01-Aug-19	07:14:00	17	9.5	01-Aug-19	09:50:00	215240	9.4	3	352	2.6	0	0
228.9M	01-Aug-19	07:31:00	198590	9.5	01-Aug-19	10:13:00	558723	9.4	4	589	2.7	5	0
228.5M	01-Aug-19	08:10:00	999943	9.1	01-Aug-19	11:08:00	318172	9.3	1.7	520	3	2	0
230.2M	07-Aug-19	14:15:00	318165	9.6	07-Aug-19	15:46:00	451832	10.1	3.8	219	1.5	0	0
229.9M	07-Aug-19	14:30:00	227714	9.9	07-Aug-19	16:03:00	408993	10.1	4	296	1.5	0	0
230.0M	07-Aug-19	14:42:00	558720	9.9	07-Aug-19	16:17:00	813674	10.1	3.3	417	1.6	0	0
228.6M	07-Aug-19	14:58:00	215238	9.7	07-Aug-19	16:36:00	386794	10.1	4.4	280	1.6	0	0
228.9M	08-Aug-19	08:08:00	386784	10.4	08-Aug-19	10:12:00	624414	10.1	1.4	388	2.1	0	0
228.5M	08-Aug-19	08:18:00	408994	10.6	08-Aug-19	10:28:00	589550	10.1	0.8	295	2.2	0	0
228.1M	08-Aug-19	08:34:00	813687	10.6	08-Aug-19	10:40:00	95831	10.1	1.9	461	2.1	0	0
227.8M	08-Aug-19	08:48:00	451834	10.6	08-Aug-19	10:52:00	678484	10.3	1.7	371	2.1	0	0
230.2M	14-Aug-19	13:18:00	95843	10.2	14-Aug-19	15:02:00	350944	10.1	4.1	417	1.7	0	0
229.9M	14-Aug-19	13:29:00	589580	10.2	15-Aug-19	07:57:00	278877	10.5	4.2	n/a	18.5	1	0
230.0M	14-Aug-19	13:44:00	678485	10.2	14-Aug-19	15:22:00	938453	10.5	3.2	425	1.6	0	0
228.9M	14-Aug-19	13:57:00	624431	10.2	14-Aug-19	15:42:00	818774	10.1	3.5	318	1.7	0	0
228.5M	15-Aug-19	09:11:00	278881	10.2	15-Aug-19	10:43:00	410493	10.3	1	215	1.5	0	0
228.1M	15-Aug-19	09:22:00	938461	10.2	15-Aug-19	10:51:00	105917	10.3	2.6	274	1.5	0	0
227.8M	15-Aug-19	09:41:00	350952	10.1	15-Aug-19	11:02:00	538783	10.3	2.3	307	1.4	1	0
229.9M	21-Aug-19	13:59:00	105917	9.4	21-Aug-19	16:28:00	450456	9.8	4.5	563	2.5	0	1
228.9M	21-Aug-19	14:20:00	410490	9.7	21-Aug-19	16:55:00	709460	10.2	1.9	489	2.6	0	0
228.6M	21-Aug-19	14:39:00	538770	9.4	21-Aug-19	17:12:00	740415	10.2	1.4	330	2.5	0	0
228.9M	21-Aug-19	16:56:00	450452	10.2	22-Aug-19	08:12:00	190412	10.2	2	n/a	15.3	0	0
228.1M	22-Aug-19	08:52:00	190414	10.2	22-Aug-19	10:54:00	506791	10.3	2.2	517	2	0	0
228.1M	29-Aug-19	11:15:00	915900	10.5	29-Aug-19	12:38:00	1930	10.7	2.6	141	1.4	0	0

Table A4. Concluded.

Site Name	Set				Pull				Depth (m^3)	Effort (m^3)	Effort (hours)	Number of WSG Eggs	Number of WSG Larvae
	Date	Time	Flow Meter Reading	Water Temp. (°C)	Date	Time	Flow Meter Reading	Water Temp. (°C)					
228.9M	03-Sep-19	14:12:00	0	9.8	03-Sep-19	15:08:00	172589[b]	9.7	2.7	282	0.9	0	0
228.5M	03-Sep-19	14:17:00	757555	9.8	03-Sep-19	15:17:00	936785	9.7	2.1	293	1	0	0
228.1M	03-Sep-19	14:23:00	60408	9.8	03-Sep-19	15:40:00	247001	10.1	3.6	305	1.3	0	0
227.8M	03-Sep-19	14:28:00	980	10.1	03-Sep-19	15:58:00	218293	9.4	3.4	355	1.5	0	0
227.2M	03-Sep-19	14:32:00	682829	10.1	03-Sep-19	16:18:00	915862	9.8	4	381	1.8	0	0
226.8aM	03-Sep-19	14:56:00	882828	9.7	03-Sep-19	16:41:00	893700	9.8	3	18	1.8	0	0
226.8bM	03-Sep-19	14:59:00	283328	10.1	03-Sep-19	16:45:00	373063	9.8	2.6	147	1.8	0	0
228.5M	04-Sep-19	08:40:00	915875	9.3	04-Sep-19	09:55:00	88092	9.1	1.9	282	1.3	0	0
228.1M	04-Sep-19	08:45:00	373102	9.5	04-Sep-19	10:08:00	591589	9.4	3.5	357	1.4	0	0
227.8M	04-Sep-19	08:49:00	218300	9.5	n/a	n/a	n/a	n/a	4.4	n/a	n/a	0	0
227.2M	04-Sep-19	08:56:00	246997	9.1	04-Sep-19	10:25:00	484441	9.4	3.5	388	1.5	0	0
226.8aM	04-Sep-19	09:00:00	936783	9.1	04-Sep-19	10:49:00	234435	9.4	2.3	487	1.8	0	0
226.8bM	12-Sep-19	14:17:00	172608	9.9	12-Sep-19	16:14:00	317576	9.9	0.6	237	2	0	0
226.8aM	12-Sep-19	14:25:00	208501	9.9	12-Sep-19	16:34:00	422853	9.9	0.5	350	2.2	0	0
227.2M	12-Sep-19	15:41:00	234431	9.9	12-Sep-19	17:05:00	352033	9.9	4	192	1.4	0	0
228.1M	12-Sep-19	15:52:00	591579	9.9	12-Sep-19	17:22:00	817410	9.9	1.6	369	1.5	0	0
226.8bM	13-Sep-19	08:17:00	352056	9.7	13-Sep-19	09:25:00	442848	9.9	2.9	148	1.1	0	0
226.8aM	13-Sep-19	08:22:00	422844	9.7	13-Sep-19	09:45:00	559176	9.9	0.7	223	1.4	0	0
227.2M	13-Sep-19	08:27:00	817446	9.9	13-Sep-19	10:08:00	953442	9.9	3.8	222	1.7	0	0
228.1M	13-Sep-19	08:34:00	317610	9.9	13-Sep-19	10:34:00	491370	9.8	1.8	284	2	0	0
228.6M	13-Sep-19	08:50:00	484425	9.9	13-Sep-19	10:53:00	678576	9.8	1	317	2.1	0	0
226.8aM	18-Sep-19	15:47:00	491374	11.3	18-Sep-19	17:09:00	618729	10.6	2.2	208	1.4	0	0
226.8bM	18-Sep-19	15:51:00	442856	10.6	18-Sep-19	17:17:00	577057	10.6	1.8	219	1.4	0	0
227.2M	18-Sep-19	15:55:00	678563	10.6	18-Sep-19	16:54:00	780136	10.6	5.5	166	1	0	0
226.8aM	18-Sep-19	17:32:00	577085	10.4	19-Sep-19	08:16:00	99754	10.1	1.4	n/a	14.7	0	0
226.8bM	18-Sep-19	17:35:00	780125	10.4	19-Sep-19	08:44:00	53299	10.1	1.2	n/a	15.1	0	0

APPENDIX A SUPPLEMENTARY INFORMATION AND MAPS

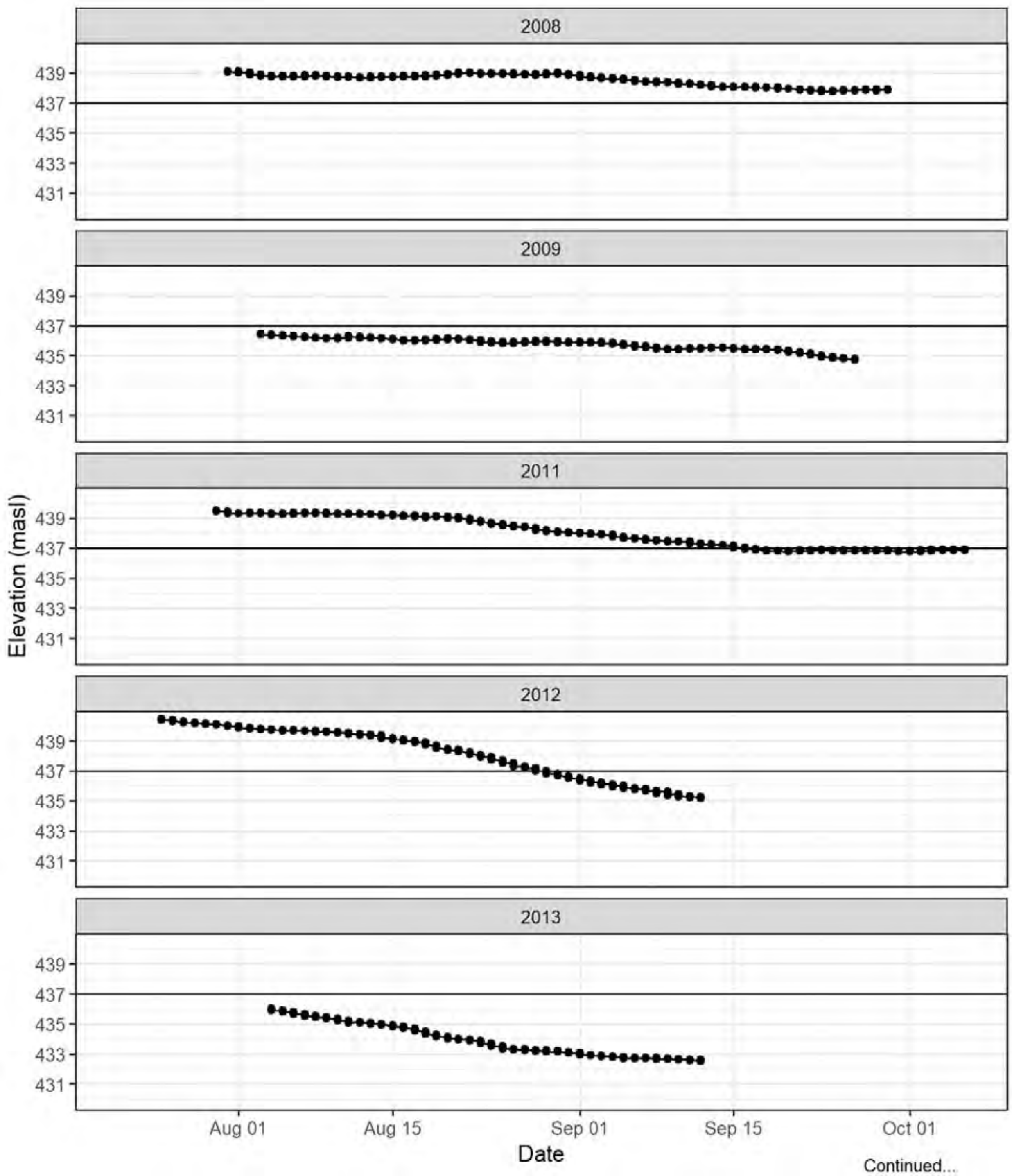

Figure A1. Surface elevation in metres above sea level (masl) of Arrow Lakes Reservoir in years when White Sturgeon spawning was detected in the Middle Columbia River. Values are only shown during the estimated period when White Sturgeon eggs and larvae were present. Horizontal line at 437 masl represents the level above which the reservoir is thought to backwater the spawning and incubation area.

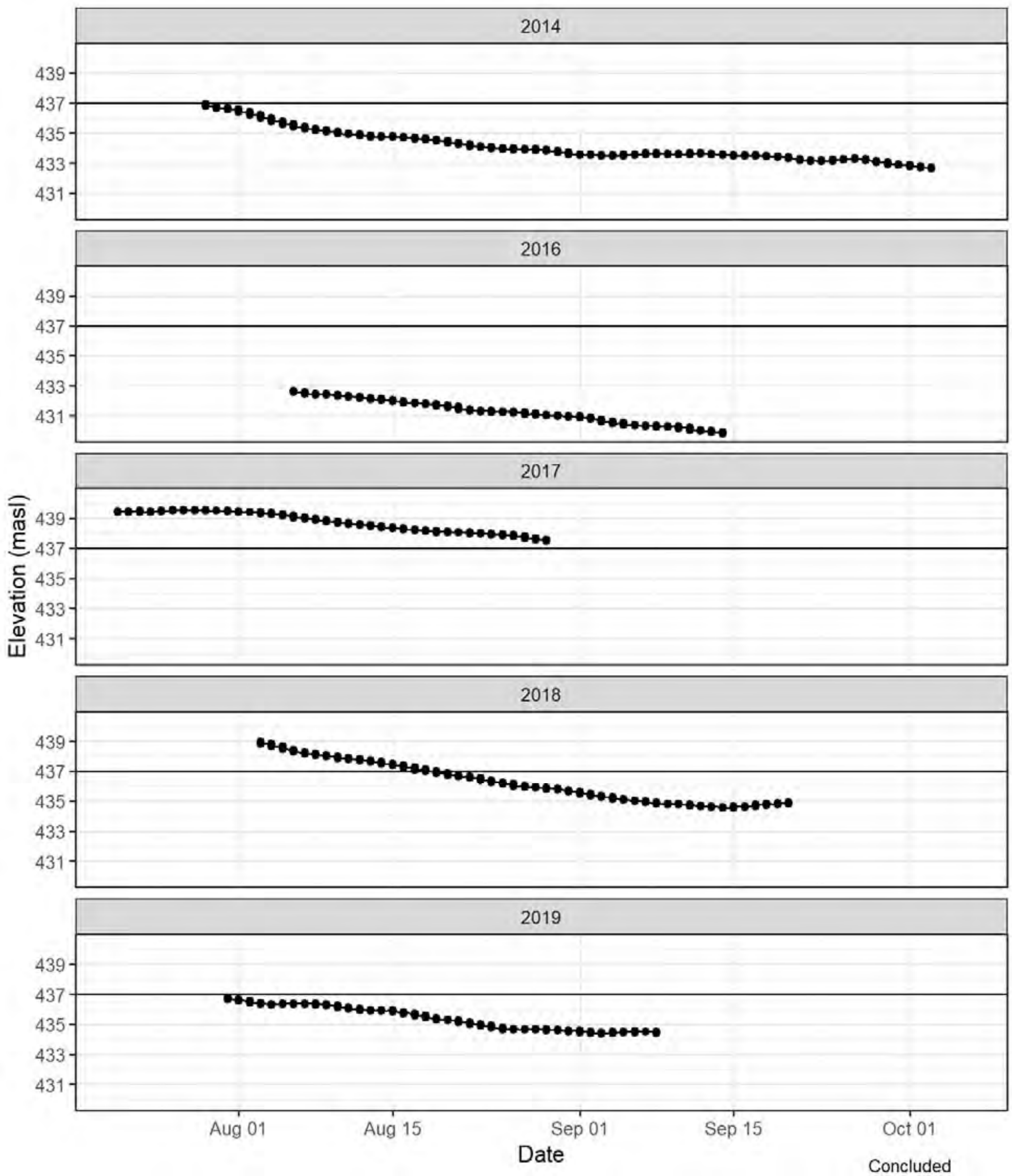

Figure A1. Concluded.

APPENDIX A SUPPLEMENTARY INFORMATION AND MAPS

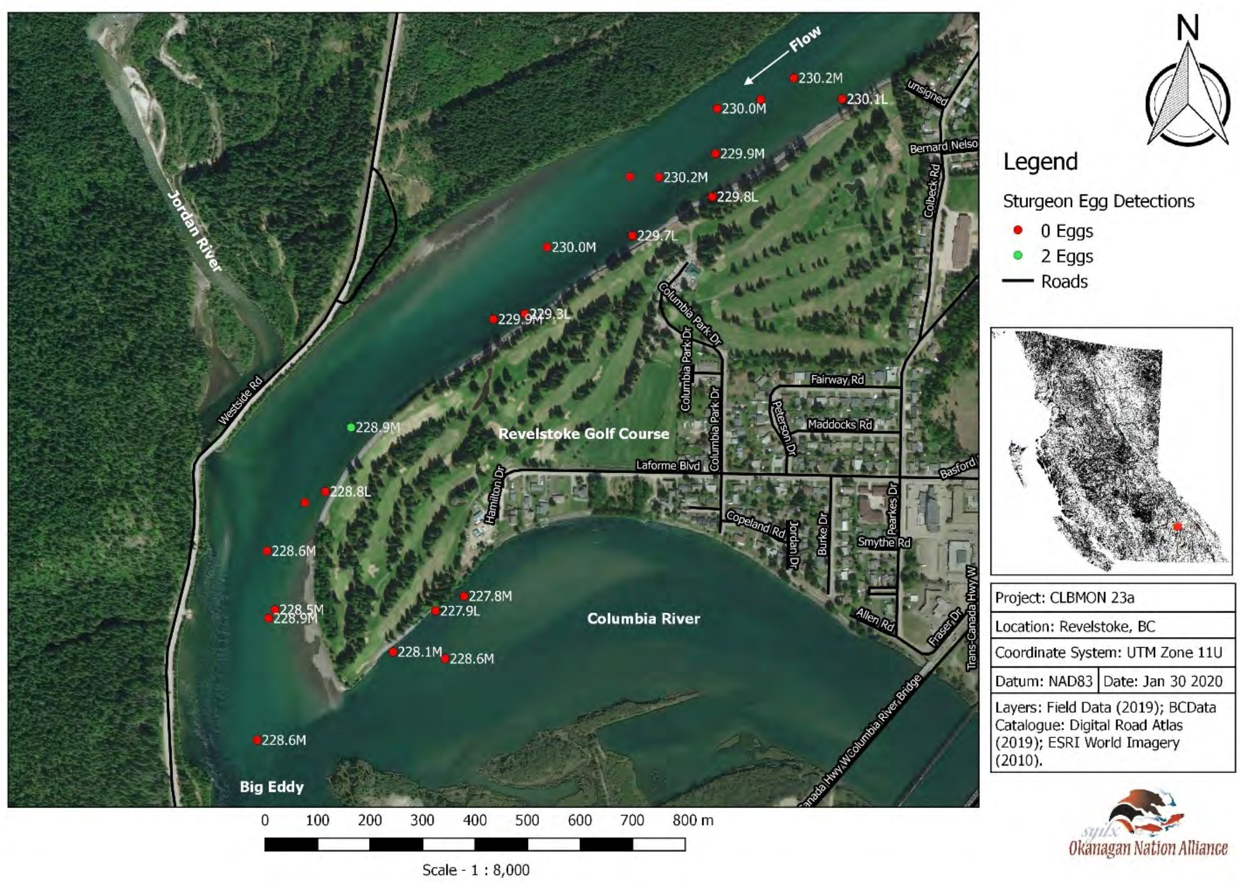

Figure A2. Location of White Sturgeon eggs captured by egg collection mats in 2019.

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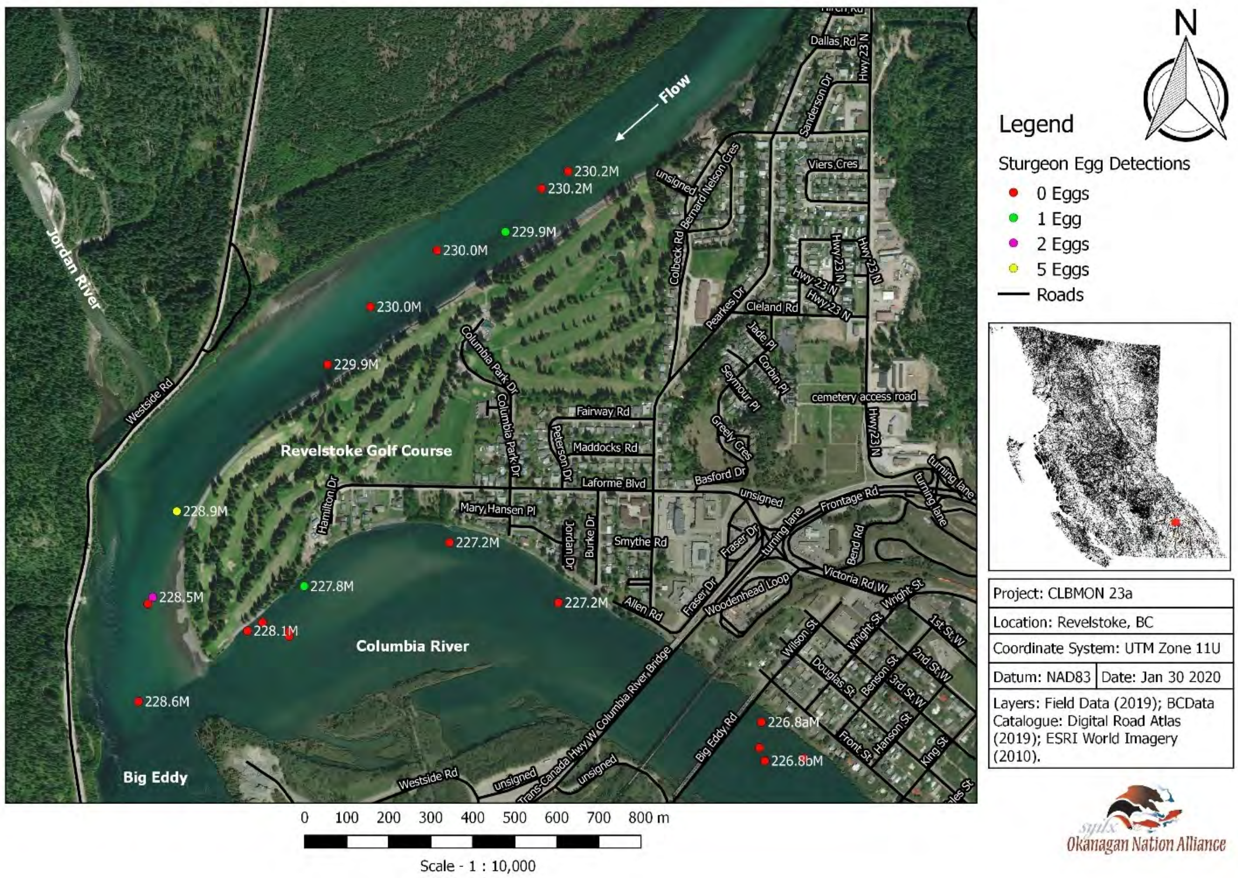

Figure A3. Location of White Sturgeon eggs captured by drift net sampling in 2019.

APPENDIX A SUPPLEMENTARY INFORMATION AND MAPS

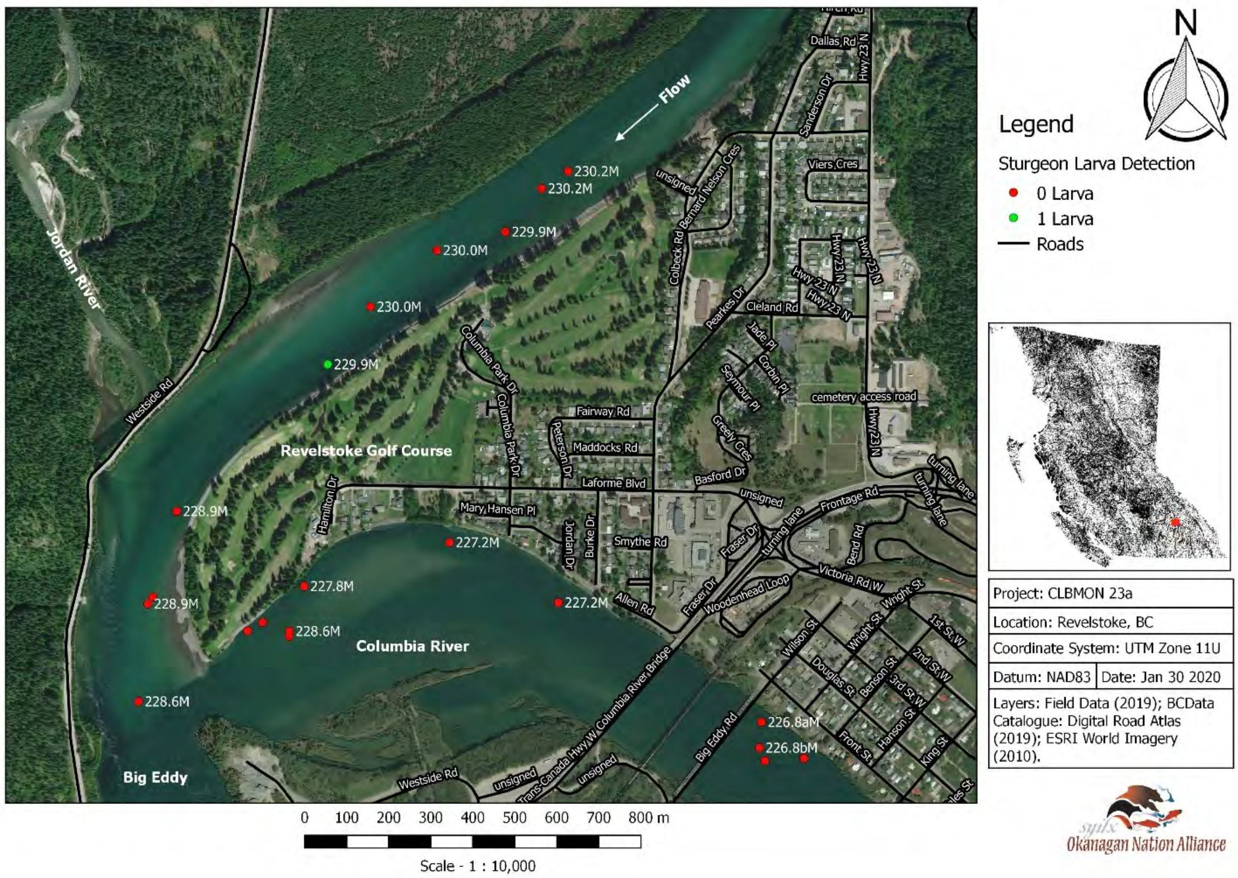

Figure A4. Location of White Sturgeon larvae captured by drift net sampling in 2019.

APPENDIX A SUPPLEMENTARY INFORMATION AND MAPS

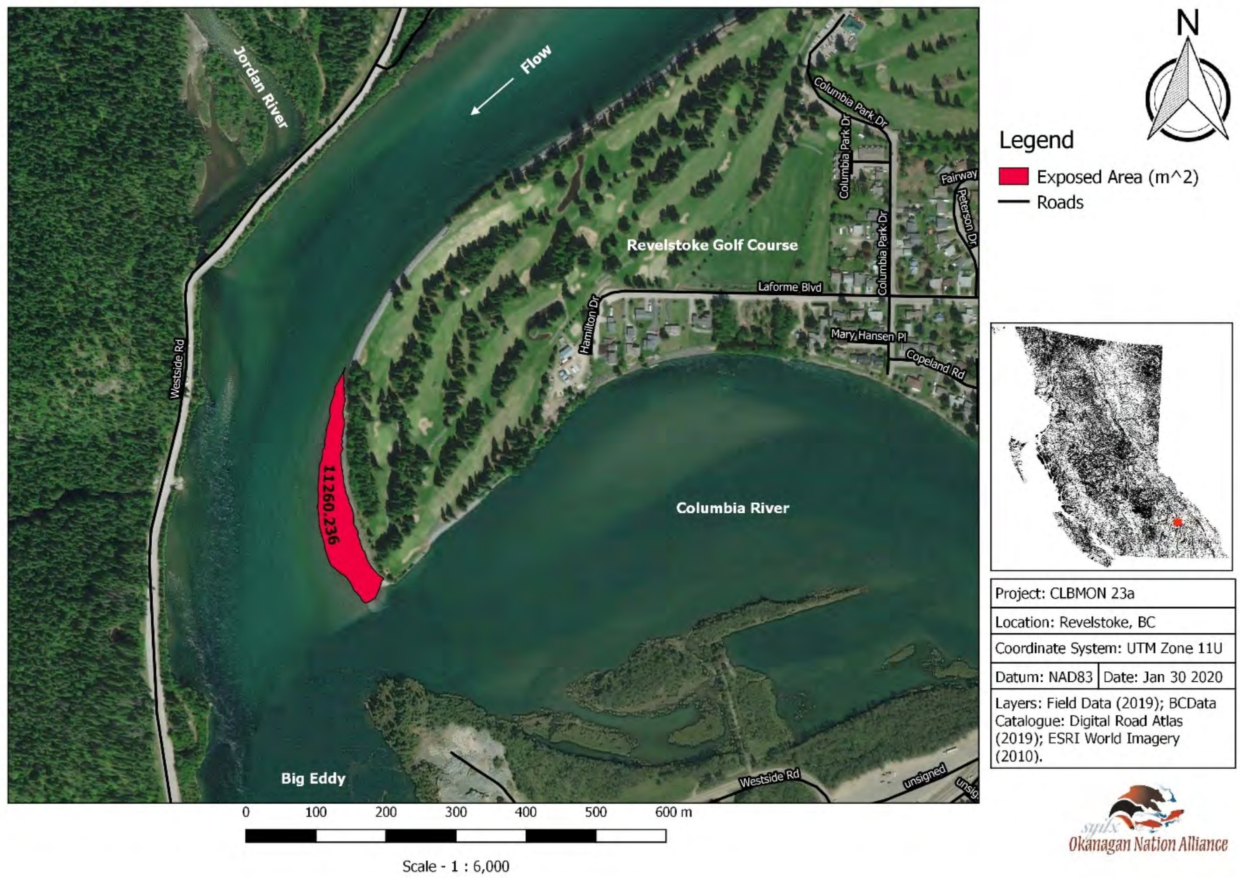

Figure A5. Area of exposed substrate (11,260 m²) on the gravel/cobble bar within the suspected White Sturgeon egg incubation area as measured on August 8, 2020.

APPENDIX A SUPPLEMENTARY INFORMATION AND MAPS

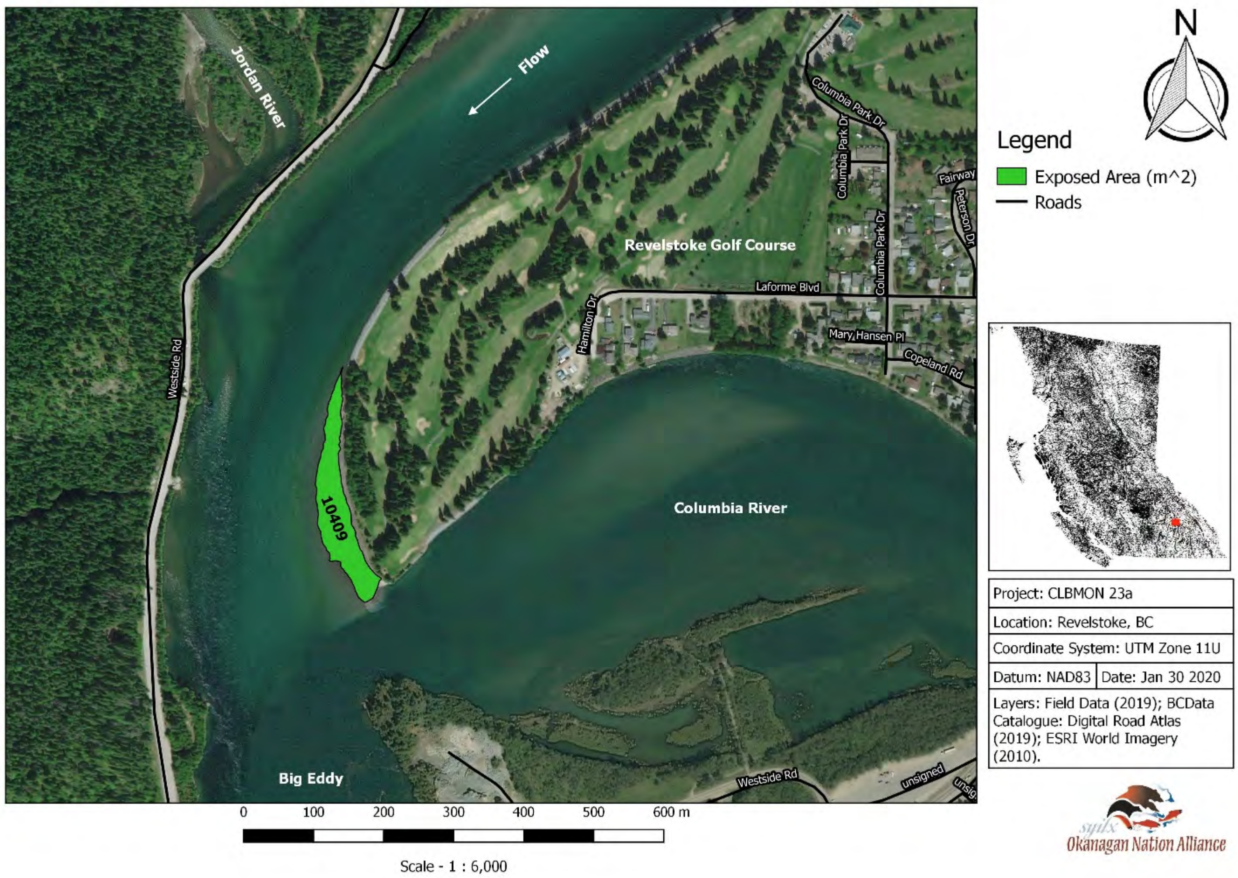

Figure A6. Area of exposed substrate (10,409 m²) on the gravel/cobble bar within the suspected White Sturgeon egg incubation area as measured on November 4, 2020.