Columbia River Project Water Use Plan

Columbia River White Sturgeon Management Plan

Mid-Columbia River Juvenile Sturgeon Detection and Habitat Use Study

Reference: CLBMON-21

Implementation Year: 12

Study Period: 2007 to 2018 Synthesis Report

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CLBMON-21: Middle Columbia River Juvenile White Sturgeon Detection and Habitat Use Program - 2007 to 2018 Synthesis Report

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Cover Photo: Juvenile White Sturgeon captured in the Middle Columbia River in August 2017. Photo Credit: Evan Smith

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Executive Summary

The population of White Sturgeon (*Acipenser transmontanus*) in the Columbia River in southeastern British Columbia was listed as endangered under the federal Species at Risk Act (SARA) in 2006 due to recruitment failure. One segment of this population resides in the Middle Columbia River (MCR), a section between Hugh L. Keenleyside Dam (HLK; Castlegar, BC) and Revelstoke Dam (REV; Revelstoke, BC) that encompasses the Arrow Lakes Reservoir (ALR). An estimate of 52 adult White Sturgeon (37 - 92 individuals at 95% CI) are thought to remain within the MCR, and all individuals aged were found to be older than the construction date of HLK Dam (1968). The primary reason for recruitment failure in the MCR is unknown as it is uncertain the extent that the area was used historically for all life stages.

In 2005, BC Hydro's Water Use Planning Consultative Committee (WUP CC) recommended a 10-year work plan to better understand juvenile White Sturgeon habitat capabilities in the MCR, and to investigate the potential for either building a self-sustaining or failsafe population in the ALR. In December 2010, REV implemented minimum flow operations of 142 m^3/s which coincided with the commissioning of an additional generation unit at Revelstoke Dam (REV5). As a result, the maximum generation discharge capacity of the dam increased from 1,700 m^3/s to 2,124 m^3/s; this was reflected in a mean daily discharge increase of approximately 200 m^3/s. The combined effects of these changes in dam operations are treated as one operational change in this report.

The management questions developed for CLBMON-21 Mid-Columbia River Juvenile White Sturgeon Detection and Habitat Program are:

1. Where are the habitat locations utilized by juvenile Sturgeon in the mid-Columbia?
2. What are the physical and hydraulic properties of this habitat that define its suitability as juvenile Sturgeon habitat?
3. What is the quantity of available habitat meeting these conditions in the mid-Columbia?
4. How do hydraulic conditions resulting from dam and reservoir operations relate to habitat suitability for juvenile White Sturgeon in the mid-Columbia?
5. What are the survival rates of juvenile White Sturgeon in the mid-Columbia?
6. Can modifications be made to the operations of REV and/or ALR to protect or enhance juvenile White Sturgeon habitat?

The program developed using two approaches to evaluate the above objectives.

1. Growth and Survival (2007-2018) – evaluating growth and survival of four different release sizes of hatchery-origin sturgeon including larval, small body Age-1, large Body Age-1, and Age-2. Size at release has increased over the 12 years of the program. This study initially focused on the Revelstoke Reach section of the Columbia River (REV to Beaton Flats), however was expanded to include the upper ALR from 2013-2018.
2. Habitat Use (2007-2018) – collection of background data on habitat use by juvenile sturgeon and describing the attributes of those habitats. Acoustic telemetry was used to describe sturgeon movements using both large (2007-2010) and fine scale (2011-2012) receiver arrays. Additional habitat use through direct captures (2007-2018) was used to complement the telemetry data.

CLBMON-21 was initiated in 2007 and at that time focused on acoustic telemetry to locate juvenile and adult White Sturgeon to identify habitat use, and to capture juveniles released by the conservation aquaculture program (marked with passive integrative transponder [PIT] tags) to assess growth and survival. In 2007, a conservation aquaculture program for White Sturgeon was also initiated with the objective of determining whether a failsafe population could be established within the ALR and to evaluate growth and survival of juvenile White Sturgeon. To date, 61,964 juvenile White Sturgeon have been released at either Revelstoke (RKm 230) or Shelter Bay (RKm 177). To evaluate overwinter survival, fish were released in one of the three following size categories: small body Age-1 (50-80 g), large body Age-1 (170 g) or Age-2 (350-400 g).

A capture program was run from 2007-2018 using gillnets and setlines throughout the study area in an attempt to recapture released fish. To date, only 39 (0.0006%) fish have been captured since release. Twenty-two of those captures survived at least one year at large, 11 of which were multi-year survivors. No fish have been captured from the 2010 (released 2011) or 2016 (released 2017) year classes. Growth rates of fish captured after at least one year at large was 9.3 cm ± 3.8 in length and mean annual increase in weight was 0.23 kg ± 0.2. As a result of low recapture rates of juvenile White Sturgeon, survival estimates could not be determined.

A study design involving three phases of data collection was developed to assess juvenile White Sturgeon habitat use and movements. During the first phase (2007-2010), data on movements and macro-habitat use were obtained from acoustic-tagged juvenile White Sturgeon using both mobile tracking and anchored receivers. During this phase, 200 (50 in each year) acoustic-tagged juvenile Sturgeon were released in the upper section of the MCR and data was collected from receivers placed 5 km apart along the thalweg of the study area. Based on the movements of those fish post-release, the release sites were move downstream in 2009 and 2010, and sturgeon were released at five different locations spread throughout the upper 30 km of the study area. Many juveniles used the area between Greenslide Creek (RKm 212) and Beaton Flats (Rkm 180) during the summer months and tended to make downstream movements in the fall. The mean net movement of tagged fish was similar in all years, and fish remained within a 21 – 26 km length of the reservoir despite differences in release patterns, which suggests juvenile Sturgeon are selecting for specific habitats. This work also identified that juvenile White Sturgeon in the MCR prefer deep (>10 m), slow moving areas with fine substrates, and tend to be most active at night.

The second phase, implemented in 2011 (Year 5), was to determine the feasibility and best location of the Vemco Positioning System (VPS) array that would describe localized movements and habitat use which was used to inform the third phase, deployment of the fine-scale array in 2012. The data collected from the fine-scale array allowed analysis of movements related to daylight, habitat type, REV discharge, ALR elevation in 2012, and seasons. Tag locations clearly showed that juvenile White Sturgeon have a preference for thalweg areas in all seasons, however were also found in shallow and floodplain sites in summer and fall (when reservoir levels were high) but rarely in spring (when reservoir levels are low). Movement speeds were greatest in the summer, however, were similar between daytime and nighttime. This data also showed Sturgeon made the longest distance movements out of the shallows when the reservoir was emptying. Overall, results from the VPS telemetry array suggest juvenile White Sturgeon used a wider range of depths, and made more frequent, longer, and faster movements in the summer (reservoir is full) compared to spring (reservoir filling) or fall (reservoir emptying). Studies on juvenile White

Sturgeon in other areas of the upper Columbia River Basin have shown a preference for depths greater than 10 m, which may suggest depth is a factor in influencing seasonal habitat selection by juveniles in the MCR.

The third phase of data collection occurred through the whole program and focused on direct captures of individuals to inform habitat use. In 2018, sampling occurred from August 27 to September 30 resulting in the capture of two juvenile White Sturgeon. One of the 2018 recaptures was from the 2009-year class and had spent nearly 9.5 years at large prior to capture. These fish were captured between Blanket Creek – Greenslide Creek (RKm 205.6 – 209.7) and between Crawford Creek and Tree Island (RKm 192.1 - 197.5). During the 2018 field season, substrate samples were collected from sturgeon capture locations as well as non-capture locations for comparison. The average density of prey items was low in all substrate samples analysed. The most common bycatch species in 2018 were Mountain Whitefish (*Prosopium williamsoni*), Peamouth Chub (*Mylocheilus caurinus*), Bull Trout (*Salvelinus confluentus*) and Northern Pikeminnow (*Ptychocheilus oregonensis*).

The current state of knowledge for the juvenile White Sturgeon program in the Middle-Columbia River with respect to BC Hydro's Management Questions is provided in the table below.

Management Question	Status
1. Where are the habitat locations utilized by juvenile Sturgeon in the Middle-Columbia?	Based on data collected using both acoustic telemetry and direct capture efforts, juvenile White Sturgeon exhibit highest use of riverine habitats near Greenslide Cr. (RKm 212) downstream to Shelter Bay (RKm 177) and, to a lesser extent, further south into the Arrow Lakes Reservoir. Juveniles have not been directly captured below the Beaton Flats area in large numbers but telemetry and capture data has identified a few individuals further downstream towards Nakusp.
2. What are the physical and hydraulic properties of this habitat that define its suitability as juvenile Sturgeon habitat?	Juvenile White Sturgeon use deep (>10 m), low velocity (<0.5 m/s) habitats with fine substrates (sand/silt/clay). This is based primarily on movements of acoustically tagged juveniles (n=250) and general locations of capture. When releases occurred at the City of Revelstoke (RKm 229, 2007-2012), juveniles were found to move quickly downstream to Mulvehill and Greenslide Creeks, and Akolkolex River areas and further downstream into the reservoir where conditions are more favorable. Accordingly, the release site was moved to Shelter Bay (RKm 177) in 2013 to target release in closer proximity to suitable habitats.

3. What is the quantity of available habitat meeting these conditions in the Middle-Columbia?	The amount of available deeper, slower, habitat for juvenile White Sturgeon varies depending on discharge from REV and backwatering from the ALR. Thalweg habitats are available during all water elevations however the depth of the thalweg varies accordingly. During high water levels, shallows and floodplain habitats become available, though fine scale movement work found that those habitats are used less than the deeper thalweg when both are available. Most juvenile Sturgeon captures have occurred within a 35 km section of river from approximately Shelter Bay (RKm 177) to Greenslide Creek (RKm 212).
4. How do hydraulic conditions resulting from dam and reservoir operations relate to habitat suitability for juvenile White Sturgeon in the Middle-Columbia?	Both REV discharges and ALR operations influence habitat quality and quantity in the MCR. Discharge from REV influences the quantity and type of habitat available in riverine sections; however, the effects diminish with downstream distance. High reservoir elevations backwatering the river section results in greater availability of deeper, low velocity habitats further upstream. ALR levels can influence sturgeon movements in the river section and attenuate the effects of varying dam discharges on Sturgeon habitat.
5. What are the survival rates of juvenile White Sturgeon in the Middle-Columbia River?	Survival cannot be estimated at this time due to low recapture rates, attributed to a large study area and low capture efficiency. On average for all recaptured fish, total annual growth was 11.9 cm/year in length and 230 g/year in weight. This is comparable to the juveniles released and recaptured in the Lower Columbia River juvenile sturgeon program. While half of the fish in the MCR have been captured in the same year they were released, two of the captured juveniles have survived over 9 years. At this time additional captures are required to adequately estimate survival.
6. Can modifications be made to the operations of Revelstoke Dam and/or Arrow Lakes Reservoir to protect or enhance juvenile White Sturgeon habitat?	The main areas of habitat use by juvenile Sturgeon are situated >25 km downstream from REV, where it is unlikely that operational improvements or modifications at REV can be made. At this distance from the dam, large changes in flows are ameliorated and backwatering from the reservoir likely changes the flow dynamics. The landforms around the preferred area of the Walter Hardman Generation Station and Akolkolex River (RKm 200) constrict the Columbia River, which

	may be creating conditions that are more suitable to juvenile rearing for at least part of the year. In the reservoir, maintaining ALR water elevations at levels that ensure a deep thalweg (425-430 MASL) around Greenslide Creek (RKm 212) will maximize the amount of preferred habitat that is currently being used by juveniles in this area.

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Table of Contents

List of Figures

List of Tables

1.0 Introduction

White Sturgeon (*Acipenser transmontanus*) are the largest and longest lived freshwater fish species in North America, and are native to the Columbia River drainage in British Columbia, Canada. The population of White Sturgeon in the upper Columbia River was listed as Endangered under the Canadian Species at Risk Act (SARA) in 2006 due to recruitment failure (Fisheries and Oceans 2014). A small segment of the population from the pre-dam era occurs within the Arrow Lakes, a section of the Middle Columbia River (MCR) spanning from the Revelstoke Dam (REV) to the Hugh L. Keenleyside Dam (HLK). Population abundance is estimated at approximately 52 adult White Sturgeon for the Arrow Lakes (37 - 92 individuals at 95% confidence level; Golder 2006b), all of which are assumed to have been present prior to the building of HLK Dam in 1968. Using the estimated annual adult survival rate of 97%, the estimated adult White Sturgeon abundance in 2018 would near 35 fish (DFO 2014).

In 2007, BC Hydro's Water Use Plan Consultative Committee implemented minimum flow release requirements at REV to 142 m^3/s that coincided with the commissioning of an additional fifth generating unit (REV5) at REV on December 20, 2010. The addition of REV5 increased the maximum generation discharge capacity of the REV from 1,700 m^3/s to 2,124 m^3/s. The combined effects of the minimum flow release and the increased maximum discharge capacity from REV are collectively referred to as the 'flow regime change'.

As part of the Water License Requirements Program, BC Hydro implemented the MCR Juvenile White Sturgeon Management Plan under the Columbia River Water Use Plan. The purpose was to determine the suitability of the MCR as a second recovery area for White Sturgeon in the Upper Columbia River Basin and to evaluate the potential for a self-sustaining or failsafe population (i.e., a second population supported by artificial supplementation of juvenile White Sturgeon to provide future broodstock or genetic biodiversity in the event of a catastrophic failure of the primary population).

An experimental conservation aquaculture program was initiated in 2007 with releases of hatchery-origin juveniles occurring annually. A monitoring program was developed to investigate juvenile survival, growth, movement, habitat use, and habitat availability to support building a self-sustaining population in this section of the Columbia River. The program has been implemented adaptively, and as the monitoring progressed questions around Sturgeon movements to preferred habitats and optimal body size at release were incorporated into the study design.

1.1 Management Questions

The management questions defined by the Consultative Committee and associated with CLBMON-21 as per the Terms of Reference and Scope of Services (BC Hydro 2007) are:

1. Where are the habitat locations utilized by juvenile Sturgeon in the MCR?
2. What are the physical and hydraulic properties of this habitat that define its suitability as juvenile Sturgeon habitat?
3. What is the quantity of available habitat meeting these conditions in the MCR?
4. How do hydraulic conditions resulting from dam and reservoir operations relate to habitat suitability for juvenile White Sturgeon in the MCR?
5. What are the survival rates of juvenile White Sturgeon in the Middle Columbia River?

6. Can modifications be made to the operations of REV and/or Arrow Lakes Reservoir to protect or enhance juvenile White Sturgeon habitat?

1.2 Management Hypotheses

Hypotheses for the above management questions have been developed to guide the juvenile Sturgeon study, and are as follows:

H1: The recruitment of White Sturgeon in Arrow Lakes Reservoir is limited by the quality and quantity of juvenile habitat below Revelstoke Dam.

> **$H1_A$:** Quality and quantity of White Sturgeon juvenile habitat in the MCR is directly related to discharge from the dam.
>
> **$H1_B$:** Quality and quantity of White Sturgeon juvenile habitat in the MCR is directly related to water elevation in Arrow Lakes Reservoir.
>
> **$H1_C$:** Quality and quantity of White Sturgeon juvenile habitat in the MCR is directly related to the interaction between discharge from the dam and water elevation in Arrow Lakes Reservoir.

H2: Quality and quantity of White Sturgeon juvenile habitat in the MCR can be significantly improved through changes in dam and reservoir operations.

$H3_A$: Juvenile White Sturgeon do not survive in the MCR in significant numbers from release as post-hatch larvae to year 1.

$H3_B$: Juvenile White Sturgeon do not survive in the MCR in significant numbers from release as late sub-yearling stage to year 2+ or older.

This report summarizes the key findings of the CLBMON 21 Program since its inception in 2007 to 2018. Additional details are provided in annual reports (Golder 2008, 2009, 2010, 2011, 2012, Golder and ONA 2013, ONA 2016, 2017, 2018), that are referenced collectively as the CLBMON-21 annual report series[1].

1.3 Key Water Use Decision

The key operating decision affected by the results of this monitoring program is the implementation of seasonal flow treatments from Revelstoke Dam. A seasonal flow treatment was to be implemented if age 0+ and 1+ juvenile Sturgeon releases show relatively strong survival during the first 4 years of study (BC Hydro 2007). Results are being used to inform BC Hydro on the value of the 142 m^3/s minimum flow at the end of the review period for the Columbia WUP. The juvenile White Sturgeon monitoring program will provide evidence towards determining if natural recruitment and rearing can be re-established for the Middle Columbia Sturgeon population.

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[1] https://www.bchydro.com/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/columbia-sturgeon.html

2.0 Methods

The following provides a brief discussion of the methods used over the course of the study program and highlights any changes in methodology that took place. Additional details are provided in the CLBMON-21 annual report series.

2.1 Study Location and Period

The MCR is a portion of the Columbia River spanning 230 km from REV downstream to HLK near Castlegar, BC. The MCR includes the Arrow Lakes Reservoir (ALR; both the Upper and Lower Arrow Lakes) and Revelstoke Reach, defined as the section of the Columbia River from REV downstream to Beaton Flats (Figure 1). Revelstoke Reach is approximately 50 km in length and varies in width from approximately 150 m at points below Revelstoke Dam (RKm 234.5) to over 2 km at Arrowhead (RKm 184). This section of river is influenced by discharge from REV, experiencing water level changes of over 3.0-5.0 m and large daily velocity changes. An additional effect in this area is the filling and draining of the ALR, which dictates the location of the river-reservoir interface throughout the year due to backwatering. Immediately downstream of Revelstoke Reach is the Beaton Flats area (RKm 184 to 180) which is a transitional zone between the river and the deeper ALR and includes the adjacent Beaton Arm which extends to the east. The ALR extends approximately 73 km from Beaton Flats (RKm 180) to the downstream end of the Arrow Lake Narrows (RKm 107). The entire study area of CLBMON-21 is approximately 127 km in length. The juvenile White Sturgeon study location and study periods have varied for different components of the study over the years of the program.

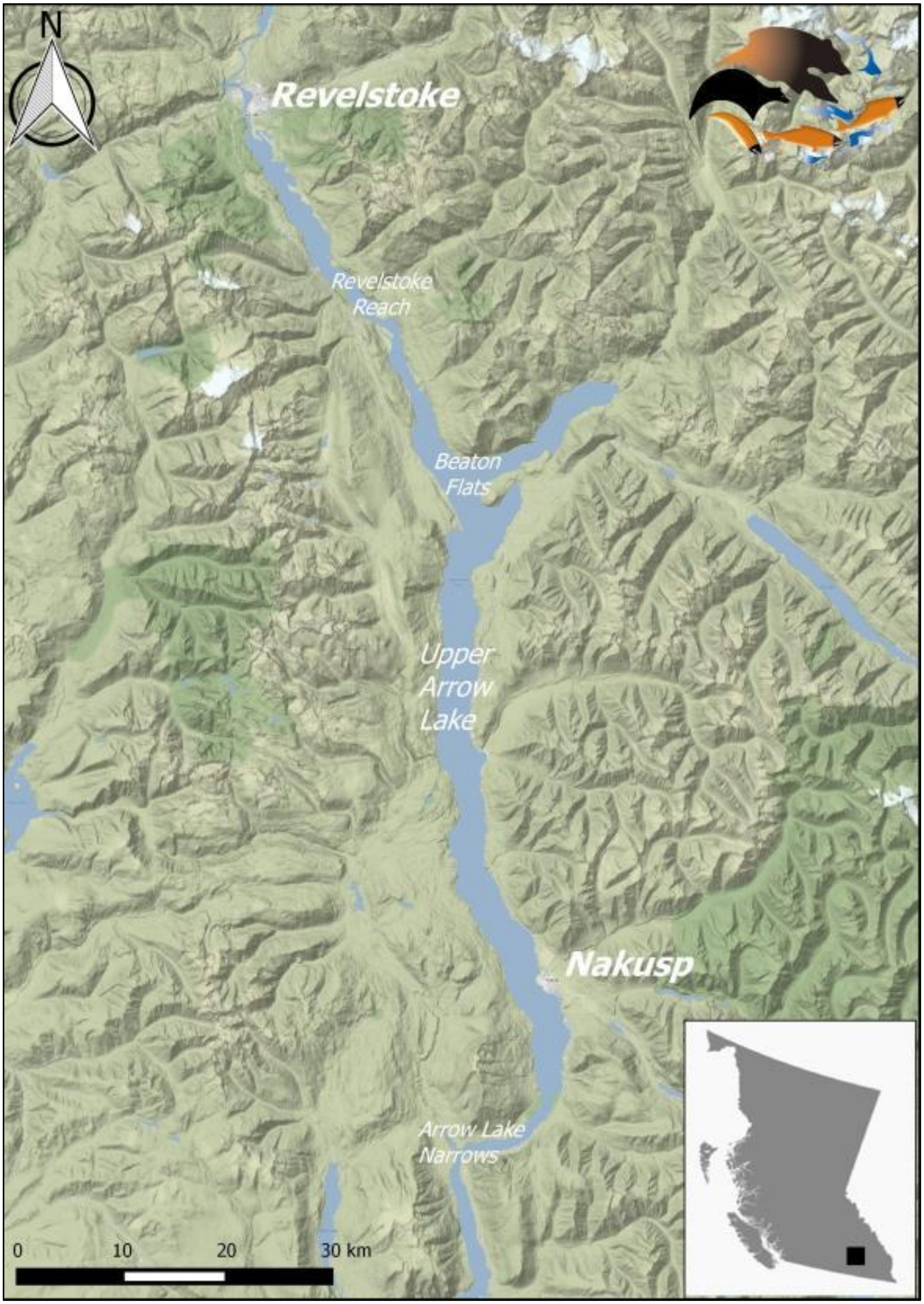

Figure 1: Map of the Middle Columbia River study area from 2007 to 2018.

2.2 Physical Habitat Parameters

2.2.1 Discharge, Water Temp and Reservoir Elevations

Hourly discharge data for the Columbia River at Revelstoke Dam and water elevation data for ALR were obtained from BC Hydro Power recording stations. Water temperature data were obtained from various sources. Thermistors were deployed in selected locations within the study area to collect water temperatures representative of the different areas being studied each year (Table 1).

Table 1: Description of temperature stations and logger types used throughout CLBMON-21.

Year	Station	Logger Type
2007, 2009-2014	CLBMON15A Station 6 (RKm 216)	Solinst data loggers
2011-2012	VR2W Receiver Stations	Onset StowAway Tidbits™
2013	CLBMON15A Station 5 (RKm 219.9)	Solinst data loggers
2015	CLBMON15A Station 3 (RKm 227.9)	
2016	CLBMON-21 Temp Stations (Nakusp, Greenslide Ck, Shelter Bay)	Hobo™ Tidbits
2017	CLBMON-21 Temp Stations (Nakusp, Greenslide Ck, Shelter Bay, ALR Narrows)	
2018	CLBMON-21 Temp Stations (Greenslide Ck, Shelter Bay)	

2.2.2 Meso-Habitat Measurements

Over the 12 years of the program, a range of meso-habitat parameters were recorded in the immediate vicinity of where acoustic-tagged juvenile White Sturgeon were detected and at gill net and set line sites (Table 2). Data collected were:

- depth (determined by boat sounder to the nearest 0.1 m);
- current velocity (determined using a Marsh-McBirney electromagnetic flowmeter accurate to ± 2% of reading);
- surface water temperature (determined by a calibrated alcohol thermometer accurate to ± 0.1°C);
- turbidity (mid-column water samples taken using a Van Dorn sampler; turbidity determined using an OrbecoHellige Model 966 portable turbidity meter accurate to 0.01 NTU in the lowest range);
- Secchi depth (to nearest cm, deployed on shaded side of the boat);
- substrate and cover (percent composition; determined by visual assessment using underwater video or a Ponar Grab sampler; and

• UTM coordinates (determined using a Trimble differential GPS unit and/or a handheld Garmin unit).

Table 2: Summary of meso-habitat measurements taken near juvenile White Sturgeon detection and capture sites in the MCR from 2007 to 2018.

Study Year	Depth (m)	Water Temperature		Turbidity	Secchi depth (m)	Current Velocity		Substrate Type	UTM
		Surface	Bottom			No. of Locations	Seasonal Data [a]		
2007	√	√		√	√	12 sites		√	√
2008	√	√							√
2009	√	√				√			√
2010	√	√		√	√	32 sites		√	√
2011	√	√		√		2 sites	√		√
2012	√	√	√	√	√	32 sites			√
2013	√	√							√
2014	√	√						√	√
2015	√	√						√	√
2016	√	√	√		√			√	√
2017	√	√	√		√			√	√
2018	√	√	√		√			√	√

[a] Seasonal sampling consisted of sampling once during each session selected to represent the spring summer and fall seasons.

In Year 1 (2007), meso-habitat data was collected near the locations of sonic-tagged Sturgeon. The boat was equipped with a sounding reel and arm connected to a 45.5 kg lead “fish”. An Aqua-Vu underwater camera and the flowmeter were attached to the “fish” and lowered into the water. Current velocities were obtained at 0.36 m above bottom and at 0.8 and 0.2 of the total depth at the site. In Year 3 (2009), a decision was made to maximize fish capture efforts, therefore habitat data collection was limited to surface water temperature, depth (as determined by the boat depth sounder) and a visual assessment of surface current velocity conducted by observing floating debris moving past a stationary float (from sample gear).

From 2007 to 2010, visual estimates of benthic substrate were obtained using an Aqua-Vu SV-120™ (Aqua-Vu) used to assess the substrate characteristics and cover type and availability at locations where habitat measurements were obtained. The camera was also used for an underwater video survey of Big Eddy on 27 September 2007 to check for the presence of juvenile White Sturgeon. The Aqua-Vu unit consisted of a compact camera in a plastic housing (equipped with multi-coloured lights), a 30 m cable, and a weather resistant 10 cm^2 monitor.

During most years of the program, the majority of habitat data was collected in the summer period (August to October). In Year 5 (2011), meso-habitat data was collected over three different sample sessions (May, August, and October). In 2012, physical habitat measurements were taken at four representative locations within the study area during VPS downloading sessions near the Walter Hardman Generating Station (August to October; Golder and ONA 2013). From 2013 onwards, habitat related data was collected at juvenile White Sturgeon capture sites.

Water quality parameters collected within the Revelstoke Reach were limited to surface water temperature and turbidity. A standard suite of basic water quality parameters (continuous daily water temperature regimes and routine water quality parameters) was obtained under a separate program (CLBMON-15a Mid-Columbia River Physical Habitat Monitoring).

Benthic substrates were collected at a subsample of Sturgeon capture sites from 2014 to 2018 using a Ponar Grab with a grab capacity of 2,376 cm^3. Grab samples were stored in glass containers with ethanol preservative until processing. Substrate sample volume was recorded prior to sorting. Samples were sorted using size 105 or 500 micron stainless steel screening depending on sample type. Samples were differentiated by dominant and secondary substrate types (fine-medium-coarse sand/clay/granule/pebbles) and recorded for contents.

2.3 Juvenile Sturgeon Releases

2.3.1 Conservation Aquaculture and Origin of Stock

In 2007, the WUP Consultative Committee identified knowledge gaps for recruitment of juvenile White Sturgeon in the MCR (BC Hydro 2007). Following this, a supplemental hatchery program was initiated to release juvenile White Sturgeon annually in the MCR. The Upper Columbia White Sturgeon Recovery Initiative Technical Working Group (UCWSRI-TWG), which is responsible for the White Sturgeon Recovery Plan for the Columbia River upstream of Grand Coulee Dam, was involved in the WLR process and contributed to designing the hatchery program.

Since 2007, juvenile Sturgeon have been produced from either direct gamete crosses (broodstock; 2007-2014) or from eggs and larvae collected in the wild. From 2007 to 2014, mature adult White Sturgeon (broodstock) captured in the lower Columbia River (HLK to the Canada-US Border) were transported to the Kootenay Trout and Sturgeon Hatchery (KTSH), spawned, and returned to the river (details in FFSBC 2014). More recently, research has identified that genetic diversity can be increased in supplemental progeny by collecting naturally produced eggs and larvae in the wild (Crossman et. al. 2011; Jay et al. 2014). This led to a change in the conservation aquaculture program and the broodstock program was ceased in 2014. Juvenile Sturgeon reared from eggs or larvae captured from natural spawning events are referred to as 'wild origin' juveniles. The first wild origin juveniles (approximately 10 months old) for release in the MCR originated from collections on the Columbia River south of the border in Washington with the objective of testing size at release effects on survival. These were surplus fish to the US juvenile release program and were transported across the border to the KTSH for an additional year of rearing and subsequent release (as 22 month-old fish) in the MCR in 2016-2018.

2.3.2 Marking and Tagging

In March of each year, juvenile Sturgeon were individually marked at the KTSH using a Passive Integrated Transponder (PIT) tag into the dorsal musculature at the midpoint between the dorsal and lateral scute line and inferior to the anterior margin of the dorsal fin (Figure 2). All juveniles also received a secondary mark by the removal of selected scutes. Scute removal marking has been conducted since the inception of the White Sturgeon Conservation Aquaculture program. For hatchery origin fish, scute removal patterns used from 2001 to 2014 involved scutes removed on the fishes left side below the dorsal fin: two scutes removed prior to 2011 and three scutes since 2011, or a combination thereof. Prior to 2011, it was always the first scute and then a second one, taken after counting the number of scutes that corresponded to the year class. For example, a fish born in 2002 would be missing the first and the fourth scutes on the left side. Sturgeon collected in the wild as fertilized embryos or larvae, and then reared in the hatchery before release had a strip of three scutes taken from the right side of the fish directly below the dorsal fin.

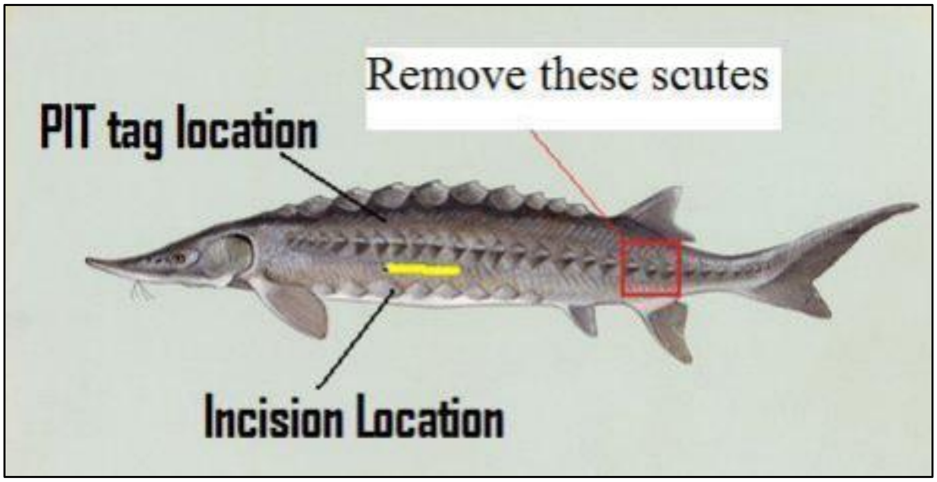

Figure 2: Juvenile White Sturgeon showing the PIT tag location, sonic tag incision location scute removal pattern. Figure from FFSBC (2017).

PIT tag number, scute pattern removal, fork length (cm), weight (g), and fin deformities were recorded for each individual fish at the hatchery in mid-April, as close as possible to their release. This was done to ensure no additional growth occurred in-hatchery that may be attributed to post-release growth. Each individual fish can subsequently be identified to its release location and date of release in addition to family record. Juveniles are transported in Freshwater Fisheries Society of British Columbia (FFSBC) fish transport vehicles according to UCWSRI-TWG transport protocols.

2.3.2 Size at Release Study

The size of fish being released through the conservation aquaculture program has increased over the years of the program to determine the most successful size-at-release for hatchery-raised juveniles. Four different size categories have been released within the Revelstoke Reach, resulting in three age classes of Sturgeon with Age-1 fish grown to two different weight categories (Table 3).

Size at release categories were determined through consultation with the UCWSRI-TWG. From 2007 to 2015, hatchery origin White Sturgeon juveniles were reared at the KTSH to 10 months of age before they were transported to the MCR for release. These 10 month old (~Age-1) fish can be further categorized into small bodied form (2007-2012) and large bodied form (2013-2015) fish. The juveniles released in 2016-2018 were reared in the hatchery for 22 months (~Age-2) to allow for additional growth before being released into the MCR. Mean annual FL and weight of these fish were at least double that of the Age-1 fish (Table 3).

Table 3: Size categories by age and average length and weight of larval and juvenile White Sturgeon released in the MCR from 2007 to 2018.

Size Category	Age at release	Study Year Released	Number Released	Average Length (cm)	Average Weight (g)
Larval	1 to 60 days	2008, 2009, 2010	1,370,749	n/a	n/a
Age-1 Small bodied	10 months	2007 to 2012	42,828	20.7	67
Age-1 Large bodied	10 months	2013 to 2015	15,245	27.5	169
Age-2	22 months	2016 to 2018	3,891	39.4	407.3

In 2008, the UCWSRI-TWG approved the release of fed and unfed larvae below REV (FFSBC 2010). A dedicated portable hatchery facility, located at the KTSH, housed 6 three-meter aluminum troughs with four MacDonald jars per trough that contained eggs from Sturgeon broodstock. Approximately 619,480 larvae (fed and unfed combined) from this facility were released at the confluence of the Columbia and Jordan Rivers in 2008 and 260,000 (fed and unfed) larvae were released in 2009. In 2010, 336,270 unfed day-old larvae were released in the upper Revelstoke Reach as part of an experiment to assess the effects of substrate modifications on larval retention and growth (Crossman and Hildebrand 2012). The monitoring described in this report is expected to detect any survival of these larvae to the juvenile life stage.

2.3.3 Release Locations

The location of juvenile Sturgeon release was also tested in conjunction with the acoustic-tagged fish movement study. Fifty acoustic-tagged juvenile Sturgeon were released at single locations in both 2007 and 2008 (Moses Creek and Big Eddy; Table 4) to observe initial dispersal movements. In both years, the fish release was also split into two times of day: 25 fish were released at noon, and 25 fish were released at midnight. In 2009 and 2010, 10 acoustic-tagged juvenile Sturgeon were released at one of five locations: Big Eddy, Begbie Creek, Mulvehill Creek, Tree Island, and Arrowhead during the day.

Table 4: Summary of the release location and time of day study for hatchery juvenile White Sturgeon released in the middle Columbia River below Revelstoke Dam, 2007 - 2010.

Release Date	Brood Year	River Kilometre	Release Location[a]	Release Time	Sonic-Tagged?	Number of Fish
23-Apr-10	2009	225.8	Centennial Launch	Day	No	400
		228.3	Big Eddy	Night	No	9175
22-Apr-10		228.3	Big Eddy	Day	Yes	10
		216	Begbie Creek	Day	Yes	10
		206.1	Mulvehill Creek	Day	Yes	10
		203	Tree Island	Day	Yes	10
		194.1	Arrowhead	Day	Yes	10
2010 Release Total						**9625**
23-Apr-09	2008	225.8	Centennial Launch	Day	No	600
		228.3	Big Eddy	Night	No	7518
		228.3	Big Eddy	Day	Yes	10
		216	Begbie Creek	Day	Yes	10
		206.1	Mulvehill Creek	Day	Yes	10
		203	Tree Island	Day	Yes	10
		194.1	Arrowhead	Day	Yes	10
2009 Release Total						**8168**
29-Apr-08	2007	225.8	Centennial Launch	Day	No	600
		228.3	Big Eddy	Night	No	5884
		228.3	Big Eddy	Night	Yes	50
2008 Release Total						**6534**
3-May-07	2006	233	Moses Creek	Noon	No	1984
			Moses Creek	Midnight	No	2172
			Moses Creek	Noon	Yes	25
			Moses Creek	Midnight	Yes	25
2007 Release Total						**4206**

[a] See Figure 1 for locations.

2.4 Juvenile Sturgeon Movement and General Habitat Use

2.4.1 Study Design

The juvenile Sturgeon movement study consisted of two components; from 2007 to 2010 (Phase 1), the study focused on larger movements and in 2011-2012 (Phases 2 and 3) focused on fine-scale movements. During Phase 1, juvenile Sturgeon implanted with acoustic tags were tracked using receivers anchored in a linear array every 5 km along the thalweg within the Revelstoke Reach (RKms 229.7 to 179). Mobile acoustic tracking was also conducted in Years 1 to 4 in the Revelstoke Reach during September and October (Table 5). These early studies provided data on large scale movements (e.g., movements of several kilometres or greater) and identified the general areas and macro-habitats used by these fish, but did not identify fine scale movements or micro-habitats. The low number of captures during this study precluded statistical analysis of survival and life history parameters.

A better understanding of fine-scale movements was desired to contribute to the overall knowledge base, including habitat use during varying ALR water elevations. The objective of Phase 2, implemented in 2011 (Year 5), was to determine the feasibility and best location of the VPS 2D Grid Array that would be used to track fine-scale movements. Phase 3 was implemented in 2012 (Year 6) and involved concentrating all the acoustic receivers into a 3 km section of river near the Walter Hardman Generation Station and Akolkolex River confluence over the period of five months (May to October). The three different phases are described in the following sections.

Table 5: Timing of annual tracking activities for acoustic-tagged juvenile and adult Sturgeon in the MCR from 2007 to 2012. Grayed cells indicate activity during that year.

Year	VR2W Linear Array	Mobile Tracking	VPS 2D Grid Array	Adult Acoustic Tracking [a]
2007	Installed April 2007; RKm 228 to 179	28 Sept – 6 Oct; RKm 223 to 204		Using both VR2W Array and Mobile Tracking
2008	Continuous; RKm 228 to 179	7 Sept – Near Mulvehill Creek; RKm 210 to 205		Using both VR2W Array and Mobile Tracking
2009	Continuous; RKm 228 to 180	18-19 Sept; RKm 202 - 195		
2010	Continuous; RKm 228 to 112	Winter (Feb); RKm 184 to 153 [b]		
2011	Array remove 24 May 2011		Acoustic range testing, 2D array development	
2012			15 May to 30 Oct 2012; RKm 203 to 200	

[a] Due to remnant active acoustic-tagged adult Sturgeon in the study area, acoustic tags were tracked and reported in this program at the same time as juveniles. See Golder 2007.

[b] There was no summer mobile tracking program in 2010. CLBMON-31 submitted mobile tracking results for Sturgeon tags located in Arrow Lake Reservoir during the Burbot tracking program in February.

2.4.2 Passive Acoustic Array

The acoustic receivers used during Phase 1 (2007-2010) were Vemco Ltd. (VR2W) single channel receivers. VR2W receivers are submersible, single channel acoustic receivers that operate at a frequency of 69 kHz and are capable of identifying and decoding Vemco sonic transmitter signals. The receivers are housed in a corrosion resistant cylindrical plastic high pressure case and incorporate an integral hydrophone. For each tag detection, the date and time is recorded along with the transmitter code. Data are stored in flash memory until downloaded and reinitialized using a VR2W Communications Key, Bluetooth® wireless technology, and a laptop computer running Vemco User Environment (VUE) software. Each VR2W uses a Tadiran TL-5930/F lithium 3.6 volt "D" cell battery with an operating life of approximately 15 months. Time was synchronized among receivers during initialization, which matched the time on each receiver to that of the laptop computer.

In April 2007, prior to the first release of acoustic-tagged juvenile White Sturgeon below REV, 18 remote telemetry receivers were deployed in a linear array within the MCR (passive acoustic array; Golder 2008). This passive array, located from RKm 233 (Moses Creek) to RKm 180 (Beaton Flats) was in constant operation until spring 2011, although the configuration changed over time. By 2010, the passive acoustic array consisted of 19 VR2W stations; 11 stations were located between Big Eddy (RKm 228.3) and Arrowhead (RKm 184), 5 were located in the Beaton

Flats and mouth of Beaton Arm area, and 3 were located at the Narrows (Burton area, RKm 112 - 110). The design of the array allowed collection of large scale movements and general timing of movements within the study area after fish release. Two hundred sonic-tagged juvenile White Sturgeon (50 each in 2007, 2008, 2009, and 2010) were released into the MCR. The life expectancy of these tags is less than one year, so tags released the previous year had expired prior to the release of fish the following year.

Preferred locations for passive acoustic receiver deployment were areas with low water velocities and smooth channel bottom configurations to reduce background noise and interference from islands or underwater obstructions, and help prevent damage or loss of the units. Prior to deployment, VR2Ws were checked *in situ* using a reference tag to confirm their operation. VR2Ws were deployed such that their position in the water column was below the thermocline depth during the summer, as water density changes can interfere with acoustic signal reception.

2.4.3 Mobile Tracking

Mobile tracking surveys were conducted to identify locations that acoustic-tagged juveniles were utilizing in sections of river between the VR2W stations, as well as determining sites to sample for specific preferred habitat parameters. Tracking was conducted from a boat using a Vemco VR28T acoustic receiver and towed V-fin. In areas with fast current, the boat was allowed to drift in the middle of the channel to reduce noise from the engine that could interfere with the reception of the acoustic tag signals. In areas where the river channel was narrow, mobile tracking was conducted by towing the V-fin in the middle of the channel. In areas where the river channel was wider, a "zigzag" pattern was followed, with priority given to coverage of the thalweg.

When an acoustic-tagged juvenile was detected, the directional hydrophone data provided by the receiver were used to "zero in" on the fish. When a strong signal was received indicating close proximity to the tagged fish, the boat was anchored in position over the fish, the location marked using a Garmin 12 GPS unit, and habitat data were obtained. Underwater video surveys (Section 3.3.5) and gill net sampling (Section 3.4.1.2) also were conducted in association with mobile tracking surveys.

During a separate WUP project (CLBMON-31), LGL Limited conducted mobile tracking surveys for acoustic-tagged Burbot from February 8 to 11, 2010. The surveys were focused within the ALR; though juvenile White Sturgeon were also detected (Robichaud *et. al*. 2010) and the tag numbers supplied to this program.

2.4.4 Fine Scale Movement Array

The purpose of the 2012 (Year 6) monitoring program was to deploy a VPS array in the MCR to monitor the seasonal (spring, summer, and fall) movements of 50 acoustic-tagged juvenile White Sturgeon released within the array. The array configuration was based on results from the 2011 feasibility assessment and recommendations from Vemco technical advisors, as well as previous studies, which indicated high use of this area by acoustic-tagged hatchery juvenile White Sturgeon (Golder 2008, 2009a, 2010, 2011). The specific objectives were; 1) to describe fine scale movements (<10 m positional accuracy) and associated habitat use by juvenile White Sturgeon and determine if there is a relationship between the movements observed and variables of daylight, flow, and seasonal changes in ALR water surface elevation; and 2) use the movement data obtained to recommend refinements to future capture programs to obtain data on juvenile White Sturgeon life history, population abundance and survival metrics.

The preliminary receiver and reference tag locations within the VPS array were pre-determined in the office in consultation with Vemco Ltd. and plotted on aerial photos of the study area. Twenty-six telemetry receivers were deployed on May 1 and 2, 2012. The pre-selected locations of many receivers had to be adjusted from the original array design because portions of the study area were de-watered at this time due to low ALR water levels (Appendix C). To expand coverage of the array into recently inundated habitats, three additional receiver stations (R27, R28, and R29) were deployed on September 19, 2012. The calculation of a fish's position within the array required detection by a minimum of three co-located receivers. To facilitate triangulation of fish positions, receivers were deployed in a triangular pattern with a target distance of 300 m between receivers along the "sides" of each triangle. Reference tags (*n* = 3) were deployed on May 1, 2012 and were placed within three of the VPS triangles to provide redundancy (i.e., to test the receivers' positional accuracy of tags at known positions).

The study area consists primarily of deep, low velocity habitat, and is constricted at the downstream end, which facilitates the identification of tagged fish moving downstream and out of the study area. The study area is far enough downstream of Revelstoke Dam for diel discharge effects to be attenuated, although some minor changes in water velocity and water surface elevations can occur. Individual receivers within the VPS array consisted of an anchor, float line, the VR2W receiver, and a float. Receivers were affixed to the float lines approximately 2 m off the bottom using heavy duty cable ties and submerged with the hydrophone pointing up. A small subsurface float attached to the float line above the receiver maintained the vertical position of the receiver and kept it off the river bottom. Synchronization tags (sync tags) were affixed to the float line approximately 1 m above the receivers. Sync tags were necessary within the VPS array for receiver time synchronization; if a receiver could not be time synced with at least one other receiver, it was not used for signal positioning.

Three additional receiver stations were deployed in the fall to expand coverage of the array into recently inundated habitats. The calculation of a fish's position within the array required detection by a minimum of three co-located receivers. To facilitate triangulation of fish positions, receivers were deployed in a triangular pattern with a target distance of 300 m between receivers along the "sides" of each triangle. Sync tags were necessary within the VPS array for receiver time synchronization; if a receiver could not be time synced with at least one other receiver, it was not used for tag positioning.

2.4.4.1 Acoustic Receiver Range Testing

Range testing was completed for all three phases of the acoustic tag tracking program to assess the tag detection efficiency of the receivers. Range testing involved *in-situ* movements at different distances around VR2W receivers using a tester acoustic tag, either lowered in place and held stationary, or towed by a boat. For the fine-scale array, the efficiency of tag detections within the VPS was tested on May 3 and 14, 2012. Drag tests were conducted by suspending a test tag (Vemco V9-2x) from a boat at approximately 3 m depth and moving through the VPS array either by drifting or under power. Drop tests were conducted by affixing a test tag to an anchored float line and deploying the tag (Vemco V9-2x) at a location for a period of time. A drop test was conducted within a receiver triangle and at the edge of a receiver triangle. Upon completion of the testing, the downloaded data were submitted to Vemco Ltd. for post-processing. The resulting estimated positions indicated VPS effectiveness of 55-78% (ONA and Golder 2013), which is considered at or above the expected rate of positioning success (Vemco analyst, pers. comm.). Specific details regarding range testing activities and results can be found in the CLBMON-21 annual report series.

2.4.5 Dispersal and General Movements

Total, upstream, downstream, and net movements were calculated for acoustic-tagged juvenile White Sturgeon released in the MCR in 2009 and 2010 (Golder 2011). The movements analyzed were defined as:

1. total movement: sum of all detected movements, regardless of direction;
2. upstream movement: sum of all detected movements in an upstream direction;
3. downstream movement: sum of all detected movements in a downstream direction; and,
4. net movement: distance between the furthest upstream and furthest downstream locations a fish was detected (i.e., a representation of the range of a particular fish or group of fish).

To assess differences in post-release dispersal patterns of acoustic-tagged juvenile White Sturgeon, two release strategies have been employed in the MCR:

- 2007 and 2008, acoustic-tagged fish were released at or above Big Eddy (RKm 228.3),
- 2009 and 2010, acoustic-tagged fish were released in groups of 10 fish at 10 km intervals between Big Eddy (RKm 228. 3) and Arrowhead (RKm 184).

2.4.6 General Macro-Habitat Use

General macro-habitat selection by acoustic-tagged juvenile White Sturgeon was examined by calculating the number of tag days (one tag day = one fish detected at a particular station for any portion of a particular day) at VR2W stations in the MCR in 2010 (Golder 2011). This provided data on the temporal (days used) and spatial (the area within approximately 500 m of a particular receiver) use of macro-habitats in the vicinity of the receiver locations. However, since past studies have shown that acoustic tag detection ranges in the MCR can vary substantially on a daily or seasonal basis (Golder 2006b), the tag day data likely represented the minimum period that a tagged fish was present in the area of a particular receiver.

2.4.7 Statistical Analyses of Movement

A summary of the methods used to analyze the movement data obtained from the acoustic telemetry receivers is provided. Additional details are provided in the annual report (Golder 2011).

Juvenile White Sturgeon movement data from 2007 to 2010 were condensed from several million detections from the VR2W receivers to several thousand records that identified the time and location of fish when they first arrived at a station and when they moved out of detection range. For example, if a fish was detected 100 times by a VR2W station and not detected at another station during that time, these 100 detections were reduced to two records - when the fish arrived and when the fish moved out of range (the first and last detection).

The time spent near each station between movements and the direction, magnitude, and rate of movements were calculated. The time spent at station parameter has advantages in that it is not dependent upon the location of potential relocation sites, which could bias interpretation of movement data collected after a fish left a particular site. The selected model used release site, month and an interactive term between month and release site as the independent variable and is depicted by the following equation:

Log (Time at Station) = B0 + B1 (Release Site) + B2 (Month) + B3 (Release Site x Month) + e

where: e = normally distributed error term with $u = 0$

The net mean distance moved and the mean residence time at station were selected as the dependent variables after exploratory graphical analysis of the data.

The influence of time of day on movements was examined among seasons and years. Movement frequencies were summarized by hour, month, and year. For the purposes of this analysis, only those fish that left the vicinity of one receiver (departure) and were subsequently detected at another receiver (arrival) were used to represent an actual movement. The onset of the movement was defined as the time that a fish was last detected at the departure receiver. Data from fish that simply “disappeared” from one receiver but were either never relocated or were subsequently relocated at the same receiver were not used since these data may simply have reflected daily differences in the detection range of the receiver.

The hourly discharge rate from REV was used to calculate the average flow in the relationship between flows and fish movements.

Diel patterns of light intensity (solar radiation) were estimated using the SOPOS (Solar Position) model available at the National Renewable Energy Laboratory’s Measurement and Instrument Data Center (http://www.nrel.gov/midc/solpos/solpos.html). Extraterrestrial Global Horizontal Solar Irradiance values (W / m^2) were extracted for further analyses. The model was run using 10-minute intervals to predict solar radiation at Revelstoke, BC. After examining the frequency distribution of solar irradiance for each year at the onset of movement, the lack of variation during daylight resulted in the decision to convert these data to a binary variable where 0 = dark and 1 = light. The binary variable was used in subsequent analyses.

The effect of release location on the movements of acoustic-tagged juvenile White Sturgeon was analyzed for Years 3 and 4 (2009 and 2010) and not Years 1 and 2 (2007 and 2008) due to placement of receivers and a larger dataset from more release sites spread over the entire study area. The two release strategies were not otherwise comparable. To provide additional information on the effect of release location on subsequent dispersal patterns and habitat selection, acoustic-tagged fish were released in groups of ten fish at five locations approximately 10 km apart:

- Big Eddy (RKm 228.3);

- near Begbie Creek (RKm 216);
- near Mulvehill Creek (RKm 206.1);
- near Tree Island (RKm 194.1); and,
- near Arrowhead (RKm 184).

2.4.8 Movement GLM Model Development

A general linear regression model was developed that included standardized distance travelled after the onset of movement as the dependent variable and independent variables of: daylight (binary day/night), hourly Revelstoke discharge at time of movement initiation, hourly ALR water surface elevation at Nakusp, month, year, and release site. All variables were categorical except for Revelstoke discharge (Q in m^3/s) and ALR water surface elevations (masl). AIC_c scores for a set of plausible models were used to select the final model with AIC_c weights calculated for the set of models used in the analysis (model details are described in Golder 2011). Hourly ALR water surface elevations (m above sea level; masl) at Nakusp were used as an independent variable in the analysis.

2.4.9 Fine-scale Array Location Analysis

The VPS is based on the principle of range difference positioning (also known as time-difference-of-arrival [TDOA], hyperbolic positioning, and multi-lateration). If a signal transmitted by the object to be located is detected by two receivers at two different times, the difference between the arrival times was converted into a range difference, using information collected in the testing phase during Year 5 (2011) of the program. In 2-D positioning, each range difference was defined as a hyperbola along which the acoustic signal may be found. By using the overlap of multiple hyperbolas, from different receiver locations, the 2-D position was estimated. For further data analysis details refer to Golder and ONA (2013).

The accuracy of the HPE (horizontal positioning error) values as descriptors of positioning error was examined using sync and reference tags, for which the true position of the tag is known. The error between the VPS estimated position and the true position was defined as HPEm (measured horizontal position error). The relationship between HPE and HPEm values for sync and reference tags was examined to describe error in the estimated positions of tagged fish. Generally, when HPE values were at or below 7, more than 95% of the empirical error values (HPEm) were smaller than the HPE value. Applying this to VPS-generated tagged White Sturgeon locations, the HPE values reported with estimates of tag positions could be viewed as liberal estimates of positioning error, as they will likely overestimate the actual position error in at least 95% of the cases while HPE ≤ 7.

Using the cumulative proportion plot, three HPE values were chosen (HPE = 5, 6, and 7) as the most desirable combination of fine scale positional accuracy. A sensitivity analysis was then conducted to determine the most appropriate cut-off value among these three candidates and its effect on the results. Based on the results of the sensitivity analysis and the cumulative distribution, a threshold HPE value of 7 was chosen, and all tag locations with HPE > 7 were omitted from all subsequent analyses.

2.4.10 Analyses of Fine-scale Movement Data

Over the VPS study area, maximum depths in the thalweg area were typically > 10 m (range between approximately 8 and 21 m). Maximum depths in the floodplain area over the same period were typically from 5 to 10 m (range between approximately 1 and 16 m) and maximum depths in the shallows area were typically < 5 m (range between approximately 1 and 11 m).

To describe fish movements relative to habitat and environmental variables, the following metrics were determined for each White Sturgeon tag location:

- minimum distance traveled from previous tag location (m),
- movement speed from previous tag location (m/s),
- the time of day (i.e., day or at night); defined using sunrise and sunset times for each day of the study as obtained from http://aa.usno.navy.mil/data/docs/RS_OneYear.php,
- the season:
  - spring (May 15 to June 20)
  - summer (June 21 to September 20)
  - or fall (September 21 to October 30),
- the month, since sample periods in spring and fall were considerably shorter than in the summer, monthly analysis was considered to provide better insight into temporal changes in behaviour,
- whether ALR was:
  - filling
  - full
  - emptying
  - or stable,
- what the ALR water surface elevation (masl) stage was:
  - low (430.34 to 433.74 masl)
  - moderate (433.75 to 437.13 masl)
  - or high (437.14 to 440.53 masl),
- the habitat classification where the fish was positioned:
  - the old river channel thalweg (defined as below the 424.0 masl contour)
  - the old river floodplain (defined as within the 424.1 to 429.0 masl contours)
  - the reservoir shallows (defined as between the 429.0 to 440.5 masl contours)

The last metric was used to assign fish position to a defined geomorphic feature and as an indirect means of assessing fish depth selection. The geodetic elevations of these macro-habitat divisions were obtained from Canadian Hydrographic Service chart datum (Chart 3058, Columbia River, Arrowhead to Blanket Creek, 1991), scanned and digitized using ArcGIS 10.1. These data were then used to develop depth ranges for the three channel types over the May 30 to October 30, 2012 monitoring period. The old pre-regulation river channel (thalweg area) provides the greatest depths available in all seasons and since this habitat remains wetted throughout the year, would exhibit the greatest benthic productivity. The floodplain area represents the historical river floodplain that would have been inundated during typical spring freshet levels but is now flooded by reservoir filling during the spring and remains wetted until late fall. The reservoir shallows area represents the area above the historical active floodplain that is now flooded during the late spring to early fall period due to reservoir filling.

The study area was divided into the three habitat classifications and each tag position was categorized into one of these habitat types. To provide confidence intervals for the assignment of habitat type to a fish position, the distance from every estimated fish position to each elevation contour was calculated. The associated HPE values (HPE ≤ 7) were used as liberal 95% confidence intervals, as suggested by the results of quantile regression of synchronization and reference tag HPEm versus HPE. For each fish position, the distance from the position to the nearest habitat classification elevation contour line was compared to the HPE values associated with the VPS position estimate. If distance from the contour line was greater than the HPE, the fish was assigned to the type of habitat it was positioned in (thalweg, floodplain or shallow). If the distance from the contour line was smaller than the HPE value, the habitat assignment was considered uncertain and was not assigned to a specific habitat classification.

The study area includes the mouth of the Akolkolex River, a major tributary to Revelstoke Reach, which represents a potential source of food (i.e., benthic drift) for juvenile white Sturgeon. This potential food source may serve to attract juvenile White Sturgeon into the shallow bay at the river-reservoir confluence. The depths in the bay were typically < 5 m in the spring and fall periods and < 10 m in the summer at peak ALR levels of 440.5 masl. To describe the extent of movement between the main VPS array and the large shallow bay at the mouth of the Akolkolex River, fish positions using detections at the three receivers closest to the river mouth (R27, R28, and R08; Appendix C) were summarized. All detections at one of the three receivers were categorized by time of day (day or night) and season (spring, summer or fall). In addition, detections were categorized based on whether the fish remained within the VPS array near the Akolkolex (continually detected on at least one of the three receivers), left the VPS array (presumably moved into the Akolkolex bay area) for more than 0.5 h, or returned into the VPS array after leaving for longer than 0.5 h.

2.4.11 Underwater Video Surveys

In 2007 and 2009, an Aqua-Vu SV-120™ (Aqua-Vu) was used to assess the substrate characteristics and cover types and availability at locations where habitat measurements were obtained (Golder 2008, 2010). The Aqua-Vu unit consisted of a compact camera in a plastic housing (equipped with multi-coloured lights), a 30 m cable, and a weather resistant 10 cm^2 monitor. The camera was also used for an underwater video survey of Big Eddy in 2007 to check for the presence of juvenile White Sturgeon. In 2009, The Aqua-Vu camera was used to look for juvenile Sturgeon presence at multiple locations in the Revelstoke Reach.

2.5 Juvenile Sturgeon Capture Efforts to Estimate Growth and Survival

2.5.1 Study Design

The objective of the juvenile White Sturgeon capture program was to estimate the growth and survival of fish released from the conservation aquaculture program. For the first four years (2007 to 2010), the capture and habitat assessment components of the study were limited to Revelstoke Reach, between Beaton Flats and Big Eddy, (RKm 182 – 228) and were closely informed by the movement monitoring results (Table 6). Capture activities for juvenile Sturgeon were conducted from mid-August to early October (Table 7). In 2013, an abbreviated sampling period was conducted during the last week of September and the first week of October with sample sites only in the ALR (RKm 120 – 186). In 2014 and 2015, the sampling period was extended earlier in the year, from late July to early October, while the study location included sites from Greenslide Creek (RKm 214) to the ALR and Beaton Flats (RKm 185). From 2015 to 2018 the study period was expanded to include sampling efforts from early June to October (Table 7). For these years, the upstream extent of the study location was Greenslide Creek (RKm 214) and included a more concentrated effort along the shoreline of the ALR down to RKm 120. In 2017, sampling also included sites in the Arrow Lake Narrows (between Upper and Lower Arrow Lakes; RKm 107-119).

Table 6: Growth and survival sample site distribution by year for each river section of the MCR from 2007 to 2018. Grayed area indicates juvenile White Sturgeon capture effort occurred in that river section.

River Section Description	U/S RKm	D/S RKm	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1 km d/s Hwy 1 bridge - Big Eddy	228.3	226.1	-				-	-	-	-	-	-	-	-
1 km d/s Wells Cr. - 1 km d/s Hwy 1 bridge	226	220	-				-	-	-	-	-	-	-	-
3.5 km d/s Begbie Ck - 1 km d/s Wells Creek	219.9	214.1			-		-	-	-	-	-	-	-	-
0.8 km d/s Greenslide Ck - 1 km d/s Begbie Ck	214	209.8					-	-	-					
0.7 km u/s Blanket Ck - 0.8 km d/s Greenslide Ck	209.7	205.6					-	-	-					
0.6 km u/s Walter Hardman - 0.7 km u/s Blanket Ck	205.5	201.9					-	-	-					
Tree Island - 0.6 km u/s Walter Hardman	201.8	197.6	-				-	-	-					
1 km u/s Crawford Ck - Tree Island	197.5	192.1	-	-			-	-	-					
1.5 km d/s Wallis Ck - 1 km u/s Crawford Ck	192	186.6	-				-	-	-					
Arrowhead - 1.5 km d/s Wallis Ck	186.5	182.1	-	-		-	-	-						
Beaton Arm			-	-			-	-		-	-		-	-
Beaton Flats	182	179	-	-	-	-	-	-						-
Arrow Lake to Nakusp	179	134	-	-	-	-	-	-						-
Nakusp to u/s Arrow Lake Narrows	133.9	119	-	-	-	-	-	-						-
Arrow Lake Narrows	118.9	107	-	-	-	-	-	-	-	-	-	-		-

Table 7: Seasonal distribution of juvenile White Sturgeon capture sample effort by week time period in the MCR from 2007 to 2018. Grayed area indicates sampling occurred for at least 3 days during that week.

Season	Month	Week	2007	2008	2009		2010		2011	2012	2013		2014		2015		2016		2017		2018	
			Gill	Gill	Gill	Set	Gill	Set	-	-	Gill	Set	Gill	Set	Gill	Set	Gill	Set	Gill	Set	Gill	Set
Spring	June	1																				
		2																				
		3																				
Summer		4																				
	July	1																				
		2																				
		3																				
		4																				
	August	1																				
		2																				
		3																				
		4																				
	September	1																				
		2																				
		3																				
Fall		4																				
	October	1																				
		2																				

2.5.2 Equipment

Gill nets were chosen as the primary method for initial sampling, based on the success of this method to capture juvenile Sturgeon in the Transboundary Reach (Columbia River downstream from HLK to Grand Coulee Dam). Gill net sites were selected based on gear limitations (i.e., lower velocity habitats where gill nets can be fished effectively) and the presence of habitat types (deep, slow moving eddies) known to be used by juvenile White Sturgeon in the lower Columbia River (Golder 2007). Gill nets also were deployed in the immediate vicinity of where acoustic-tagged juvenile White Sturgeon were located during mobile tracking surveys. Based on the results of other juvenile White Sturgeon monitoring programs in the Columbia River (i.e. Keenleyside Reach and the Roosevelt Reach; Golder 2007, Howell and McLellan 2013) sampling was focused on the thalweg, but shallower areas also were sampled to assess juvenile use of these habitats. Capture sessions were not conducted in Years 5 and 6 (2011 and 2012) to focus effort on the fine scale movement study.

During Years 8 to 12 (2014 to 2018) sampling, 200 gill net and 200 setline sites were generated using the general random tessellation stratified (GRTS; Stevens and Olsen, 2004) method design in the statistical package R (R Development Core Team, 2013). This method provided spatially balanced randomly chosen sample locations distributed along the centerline of the Revelstoke Reach and upper ALR, and assigned a sampling gear type (setline or gill net). Extra sites were also generated, that allowed for the substitution of sites that were rejected in the field due to logistical concerns (depth, velocity, obstructions) to ensure that randomness and spatial representation were maintained within the study design. The generated GRTS sites were used as a guideline, and once in the field, near shore sample locations were selected perpendicular to the center line at targeted water depths (10 – 30 m).

2.5.2.1 Gill Nets

Gill nets were 5.1 cm stretch measure monofilament, horizontal nets but net dimensions and area varied over the course of the program. From 2001 to 2010, 15.2 m long by 1.8 m deep (27.9 m^2) and 45.7 m long by 1.8 m deep (83.6 m^2) nets were used. From 2013 to 2018 larger nets of 91.5 m long by 1.8 m deep (164.7 m^2) were used, having a float and float line and anchors attached to each end of the net. Habitat measurements were recorded at each gill net site (see Section 3.1.3).

Because of the potential risks of injury or mortality to adult White Sturgeon and in consideration of the endangered status of the population, overnight gill net sets were not used in Year 1 (2007) of the study. Based on the lack of capture success using daytime gill nets in 2007, the SARA sampling permit was amended to allow the use of overnight gill nets (with a target 12 hour set duration) in areas where adult White Sturgeon were not likely to be present. During Year 2 (2008) sampling, gill nets were initially deployed overnight, but direct mortality of Bull Trout captured in these overnight sets was high (Golder 2009). Due to this high by-catch mortality, gill net sampling in 2009 and 2010 was changed to short nighttime duration sets of approximately four hours, which reduced direct by-catch mortality. Both full overnight and short duration night time gill nets were used in 2010. From 2013 to 2018, four or five gill nets would typically be set out each day in the morning and retrieved mid-afternoon, with a target soak time of 4 hours.

Occasionally, sections of net were damaged due to underwater debris. When time allowed, these damaged areas were repaired. Gill nets not fishing effectively over the full net area were noted and the area of net being fished was correspondingly reduced for effort calculations. A list of UTM coordinates for all gill net sites are provided in the CLBMON-21 annual report series.

2.5.2.2 Setlines

Based on the low numbers of prey items recorded in juvenile White Sturgeon stomach samples obtained from the MCR in Year 2 (2008) and relatively slow growth of juveniles captured during Years 1 to 4, food availability was initially considered a potential limiting factor for juvenile White Sturgeon in the MCR (Golder 2009). Therefore, in Year 3 (2009), baited setlines were tested as an alternate method for capturing juvenile White Sturgeon. Setlines were originally deployed similar to gill nets, but fewer in number (e.g., eight gill nets and two setlines per night). As setline sampling continued during the 2009 sampling, but failed to capture any fish, the hook size was reduced from size 10 and 12, to size 5 and 6.

Setlines initially consisted of a 90 m mainline with 30 hooks spaced 3 m apart, an anchor, float line, and an LD-2 float affixed to each end. The mainline was marked at 3 m intervals to ensure that hooks were spaced evenly along the length of each setline during deployment. During Session 1 in 2009, small, barbless halibut hooks (size 10, 11 and 12) baited with worms, roe bags or Kokanee (*Oncorhynchus nerka*) were clipped to the setlines. Based on a lack of captures using these hooks, barbless “J” hooks (size 6 and 7) baited with worms, roe bags, Kokanee, Mountain Whitefish (*Prosopium williamsoni*) or Burbot (*Lota lota*) were used in Session 2. Setlines were deployed perpendicular to the current to increase downstream scent dispersal and were fished overnight. Fishing setlines overnight was initially conducted within a specific river section, not randomized over the entire study area.

Setlines became the main sample method used in Years 7 to 12 (2013-2018) due to lower bycatch mortality compared to gill netting. Each day, five to eight setlines were deployed. Setlines ranged from 50 to 120 m in length with 10-20 size 5 or 6 barbless 'J' hooks per line baited with worms (night crawlers). The mainline was marked at 4 m intervals to ensure hooks were evenly spaced on the line. Setlines were set in the afternoon perpendicular to the flow, left to fish overnight, and pulled the following morning. An anchor, float line and LD-2 float were attached to either end of the setline.

Set and pull times, hook sizes and numbers, bait types, UTM coordinates, surface water temperature, the minimum and maximum depth of the setline, the number of fouled and baitless hooks and catch details of note were recorded for each setline. A list of UTM coordinates for setline sites are provided in the CLBMON-21 annual report series.

2.5.2.3 Gear Efficacy Testing

In 2016, due to low capture rates in previous study years, additional gear testing to compare efficacy of gear types was conducted from May 2 – 6. The testing was concurrent with the juvenile White Sturgeon release at Shelter Bay (May 3 and 5) to optimize the chances of capture while the density of juvenile Sturgeon was still high near the release site.

Gear efficacy testing was conducted using 4-hour gill net sets and overnight setline sets. Gill nets 91.45 m long by 3.05 m deep (278.9 m^2) were used and deployed at the bottom of the water column perpendicular to the shoreline. For setlines, different size hooks (4, 5 and 6) and bait types (shrimp, Kokanee and worms) were tested on setlines to test preference in prey items and recruitment to different sizes of gear. Hook sizes and bait types were differentiated on each setline clip using coloured electrical tape. Hook sizes and bait types were also randomized on each setline.

A total of ten gill net sets and five overnight setline sets were sampled during this test. Gill nets were set for an average duration of four hours, except for three gill net sets that were left sampling for 24 hours due to emergency boat issues.

2.5.3 Fish Handling

Captured White Sturgeon were weighed (grams), measured for fork length (centimetres), photographed, examined for health and external markings (missing scutes) and scanned for the presence of a PIT tag. Handling methods were consistent with those set by the UCWSRI in the Upper Columbia River Adult White Sturgeon Capture, Transport and Handling Manual (2006). All bycatch were identified to species, measured for length, and if in good condition, released. Bycatch mortalities were disposed of by puncturing the swim bladder and returning to the water. One juvenile White Sturgeon captured was sacrificed for stomach content analysis and the digestive tract fixed in 10% formalin in 2010 (Golder 2011).

2.5.3.1 Gastric Lavage

In 2016, gastric lavage was attempted on two of the captured Sturgeon with the objective of flushing the Sturgeon's stomach to identify prey items (Crossman et al. 2016). In 2017 and 2018, all captured Sturgeon were lavaged except one Sturgeon that was captured in an unplanned overnight gill net set in 2017. To reduce handling stress, this fish was only weighed and measured.

Gastric lavage was conducted using a Chapin SureSpray Select 8.0 L pump/bladder and a VWR size 8 standard testing sieve (#140). Food items collected were placed in glass jars, preserved with 90% alcohol, and labelled with the following information: date of collection, collection site, UTM's of site, Sturgeon weight (kg) and FL (cm).

2.5.4 Capture Effort and CPUE

Catch per unit effort (CPUE) was calculated for each year as total juvenile White Sturgeon captures per effort depending on gear type. Gill net hours were calculated to compare different gill net lengths, with and without damaged panels, over the years of the program. Gill net hours were calculated using the formula:

$$(A / 100\ m^2) * (T / 24\ h) * D$$

where A = the area of net mesh actively fishing in m^2, T = the soak time in hours and D = the estimated percent of intact net mesh. If the gill net was damaged, the damaged area was estimated as a percentage of the total net area and this value was deducted from the total net area to determine D.

Setline hook hours were calculated by the multiplying the number of hooks on each setline that still had bait attached upon retrieval or had captured a fish by the total hours the setline had been actively fishing. Hooks retrieved that were baitless were conservatively assumed to have not been fishing for the duration of the set. This method was standardized across all years of data.

2.5.5 Relative Weight

The relative weight index (Wr) is a commonly used method for comparing the body condition of different fish populations (Murphy et al. 1991, Beamesderfer 1993). The relative weight index is expressed as a percent and is modelled on the 75th percentile weight data of the species' entire geographic range, therefore a Wr of 100% would represent a White Sturgeon in better condition than 75% of the fish that were used as the basis for developing the length specific standard weight value. Relative weight is not affected by size-at-age, but rather provides an indication of condition based on length and weight. Because researchers often use different methods to measure the length of White Sturgeon and only fork length data were available from previously released hatchery juveniles, relative weights were calculated using fork length during this program.

The relative weight index is expressed as a percent and is calculated as:

$$W_r = (W / W_s) \times 100$$

where W is the weight of the sampled fish in kilograms, and W_s is the length-specific standard-weight value for a particular species. For the purposes of this report, the W_s used for calculating W_r was from Beamesderfer (1993):

$$W_S = \alpha \times L^{ß}$$

where α = 2.735 E-6, ß = 3.232 and L is the fork length of the individual fish in cm. This growth relationship was calculated using growth information from 15 populations of White Sturgeon from the Fraser, Sacramento and Columbia Rivers (Beamesderfer 1993).

2.5.6 Growth

Total and annual growth (fork length [cm] and weight [g]) were calculated for each individual and combined into mean growth metrics by year class. Total growth was calculated by subtracting the size at release (FL and weight) from the capture size. Annual growth was calculated by dividing the total growth by the number of days at large and multiplying by 365 days. The assumption for annual growth is the total daily growth is constant between release and recapture; we realize growth may vary seasonally and/or with size, but this assumption allows us to compare fish at large for more than one year. Percent growth was calculated by dividing total growth to initial size-at-release.

2.5.7 Survival

To date, capture and recapture rates are too low to enable an estimate of survival. Low recapture rates are attributed to a large study area and low capture efficiency. A larger number of recaptures is required to effectively estimate survival.

2.5.8 Diet Analysis

The numbers of individual prey items within each taxon represented in the foregut were counted. Only foregut contents were enumerated and identified. Hindgut contents were not relied upon for accurate taxonomic identification, as digestive processes made identification efforts difficult.

Benthic substrates were physically collected at a subsample of Sturgeon capture sites from 2014 to 2018 using a Ponar Grab and were stored in glass containers with ethanol preservative until processing. Samples were sorted using size 105 or 500 micron stainless steel screening depending on sample type. All invertebrates in the sorted samples were stored in micro-centrifuge tubes with ethanol preservative. Invertebrates were identified to preliminary taxonomic order in the ONA lab using a dissecting microscope (Motic SMZ-143 Series) and the Guide to Common Freshwater Invertebrates of North America (Voshell 2002).

2.5.9 Incidental Catch

All incidentally captured species were identified and measured (fork length or total length as appropriate). Captured Bull Trout were measured for fork length (FL) and weight, and scanned for PIT tags that had either been applied during concurrent sampling programs in the study area (CLBMON-16; Golder and ONA 2017) or that had been applied to hatchery juvenile White Sturgeon that may have been eaten by the Bull Trout. Scale and otolith samples were collected from Bull Trout that succumbed to the sample procedure from 2008 to 2010, and stomach contents were examined for evidence of juvenile White Sturgeon.

2.6 Adult White Sturgeon Movement

2.6.1 Mobile Tracking

Monitoring adult White Sturgeon equipped with acoustic tags was added as a minor component of CLBMON-21 to increase the data obtained from the previous adult program (Golder 2006b). In an attempt to detect movements of acoustic-tagged adult White Sturgeon into the Revelstoke spawning area, mobile tracking surveys using a Sonotronics receiver were conducted from August 16 and September 4, 2007 and again in 2008 between Revelstoke Dam and Big Eddy (Golder 2008, 2009). Mobile tracking was discontinued as all adult tags were past the battery life expectations.

2.6.2 Passive Array Detection

Of the 26 adult White Sturgeon implanted with acoustic tags in ALR since 1997, six Vemco coded pingers and one Sonotronics tag (Code 5-5-5) were potentially still functional (Golder 2006b, Golder 2008). Four adult White Sturgeon in the ALR were expected to still have functional acoustic tags during the 2008 spawning period. The VR2W linear array was checked for adult signals as long as the array was deployed (four years). Further details on adult White Sturgeon detection during the CLBMON-21 program can be found in Golder (2008, 2009).

3.0 Results

3.1 Physical Habitat Parameters

3.1.1 Discharge and Reservoir Elevations

Mean daily discharge levels (cubic meters per second; m^3/s) recorded at REV showed different trends when grouped before the REV5 flow regime change (Years 1 to 4; 2007 to 2010) and after the flow regime change (Years 5-12; 2011-2018). During the pre-REV5 flow period, mean daily discharge from REV ranged from 500 to 1100 m^3/s, with longer periods of lower discharge, (corresponding to reduced power demand) in July and August (Figure 3). During this time the White Sturgeon spawning period, which typically occurs from late July- early August, experienced variable daily average flows between 500 and 900 m^3/s. After the flow regime change (2011 to 2018), daily average discharge from REV ranged between 600 and 1200 m^3/s (Figure 3). The daily mean discharge ranged between 300 and 1200 m^3/s, with longer periods of lower discharge in July and August (Figure 3). During the White Sturgeon spawning period in late July-early August, REV operations experienced variable daily average flows between 600 and 900 m^3/s, which is similar to pre-minimum flow daily mean discharges. Juvenile Sturgeon were generally captured in late August to early October when daily mean discharges were less variable and similar between pre and post minimum flow periods.

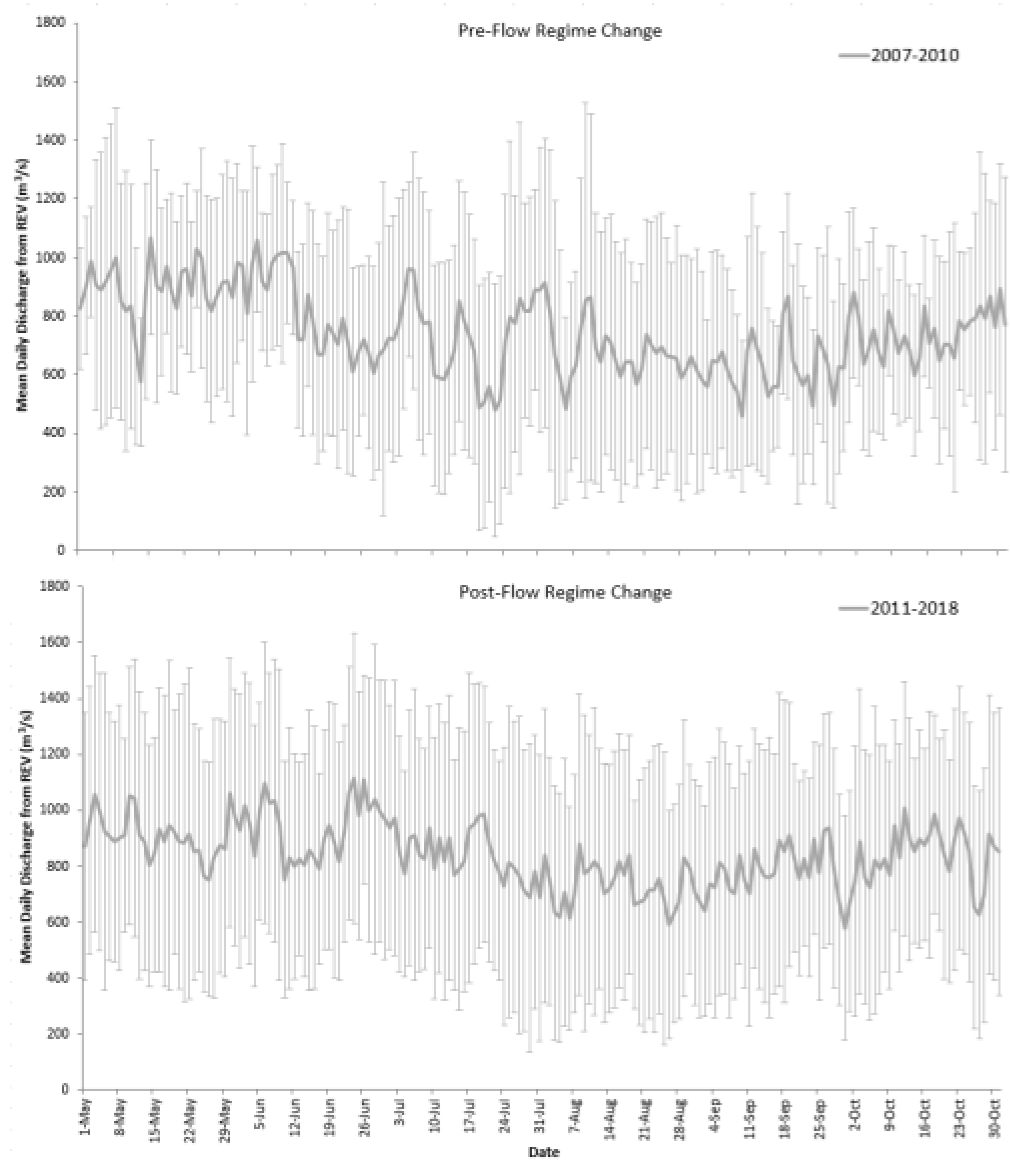

Figure 3: Mean daily discharge at Revelstoke Dam from during the CLBMON-21 study period from 2007 to 2010 (grey line) before the implementation of flow regime change (top graph) and from 2011 to 2018 (grey line) after the implementation of flow regime change (bottom graph).

ALR surface elevations (metres above sea level, MASL, measured at the Nakusp gauge site) varied in peak summer elevation between 2007 and 2018 during the May to October study periods; Figure 4). ALR elevations reached the highest peaks in June and July in 2018, 2012, and 2007; the lowest reservoir elevation occurred in 2015. A similar trend can be seen between most years with increasing water levels beginning in August and continuing into the fall; an exception to this trend is in 2016 when water levels declined from early June into October.

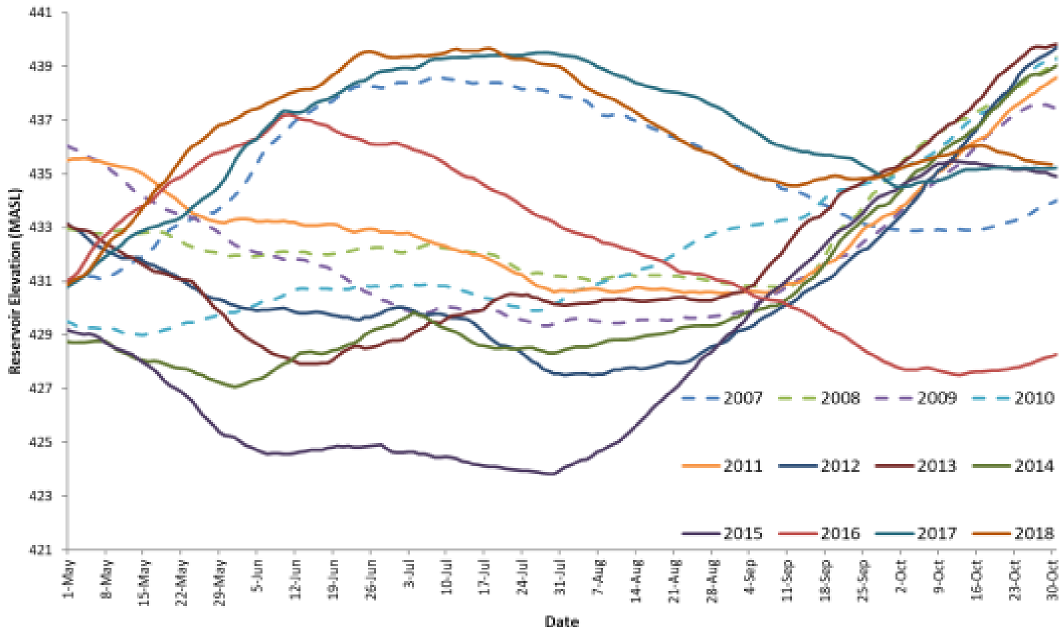

Figure 4: Water surface elevations of Arrow Lakes Reservoir measured at Nakusp, BC from 1 May to 31 October for the 2007-2018 study periods. 2007-2010 lines are dashed to distinguish between pre- and post-flow regime change years.

3.1.1.1 Reservoir Elevations during Movement Studies

Years 1 to 4 (2007-2010) and Year 6 (2012) reservoir elevations are graphed separately in Figure 5 to highlight effects on acoustic-tagged juvenile Sturgeon movement. The peak ALR elevation for Years 1-4 (2007-2010) ranged from 437 to 439.8 masl during the dispersal and general movement study, while the peak ALR elevation during the fine-scale movement study in Year 6 (2012) reached a high of 440.5 masl.

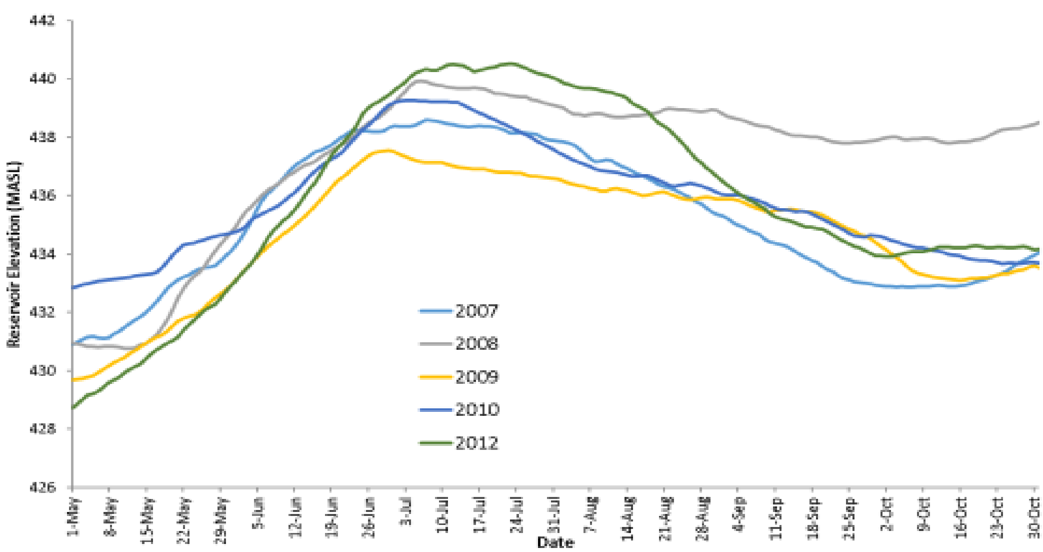

Figure 5: Water surface elevations of Arrow Lakes Reservoir measured at Nakusp, BC from 1 May to 31 October for the 2007 – 2010 and 2012 movement study periods

In 2012, water elevations in ALR (measured at the BC Hydro gauge at Nakusp) were near average from January to the end of May, increased to above the 10 year maximum in July and August, and were slightly above average during the fall (Figure 6). This general pattern was similar to that observed in past study years (2007 to 2010), except that during 2012, the peak reservoir level was higher. During the 2012 filling period, ALR levels increased by approximately 10 m from mid-May (430.3 masl) to early July (440.5 masl) and then declined approximately 6 m from late July to early October.

Over the study period, maximum measured depths in the thalweg area were typically > 10 m (range between approximately 8 and 21 m; Figure 6). Maximum depths in the floodplain area over the same period were typically from 5 to 10 m (range between approximately 1 and 16 m) and maximum depths in the shallows area were typically < 5 m (range between approximately 1 and 11 m).

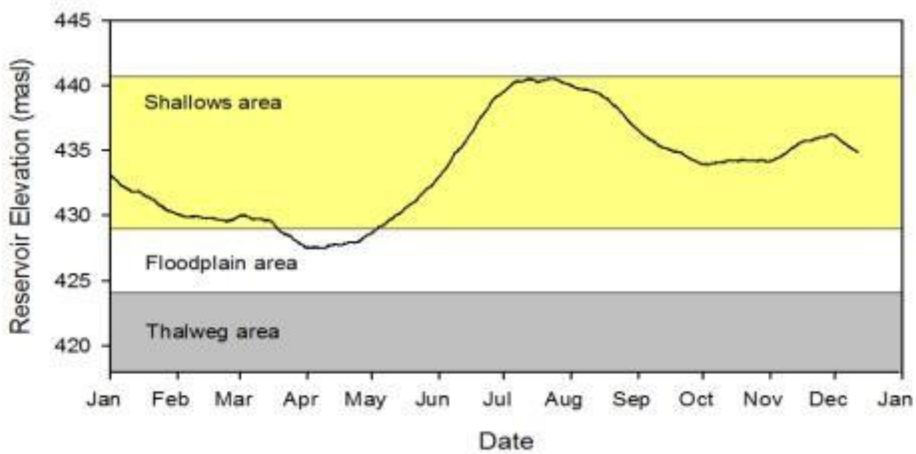

Figure 6: Mean 2012 daily water elevation (metres above sea level) of the Arrow Lakes Reservoir, and the resultant depths at the three habitat classifications (thalweg, floodplain, shallows) available near the Walter Hardman Generation Station for the fine-scale movement study.

3.1.2 Water Temperature

As temperatures have been observed to have a strong effect on Sturgeon movements, the effect of the REV5 flow regime change on downstream water temperatures and monitored temperatures in the ALR was reviewed. Mean daily water temperatures over the 1 May to 30 October period were calculated separately for the pre-flow regime change (2007 to 2010) and post-flow regime change (2011 to 2017; Figure 7). In general, both periods had similar water temperature patterns with increases during the summer months. Temperature peaks were evident in 2009, 2010, and 2016 which may be attributed to either reductions in ALR levels, or changes in the water layer REV intakes are drawing from (i.e., epilimnion metalimnion, hypolimnion).

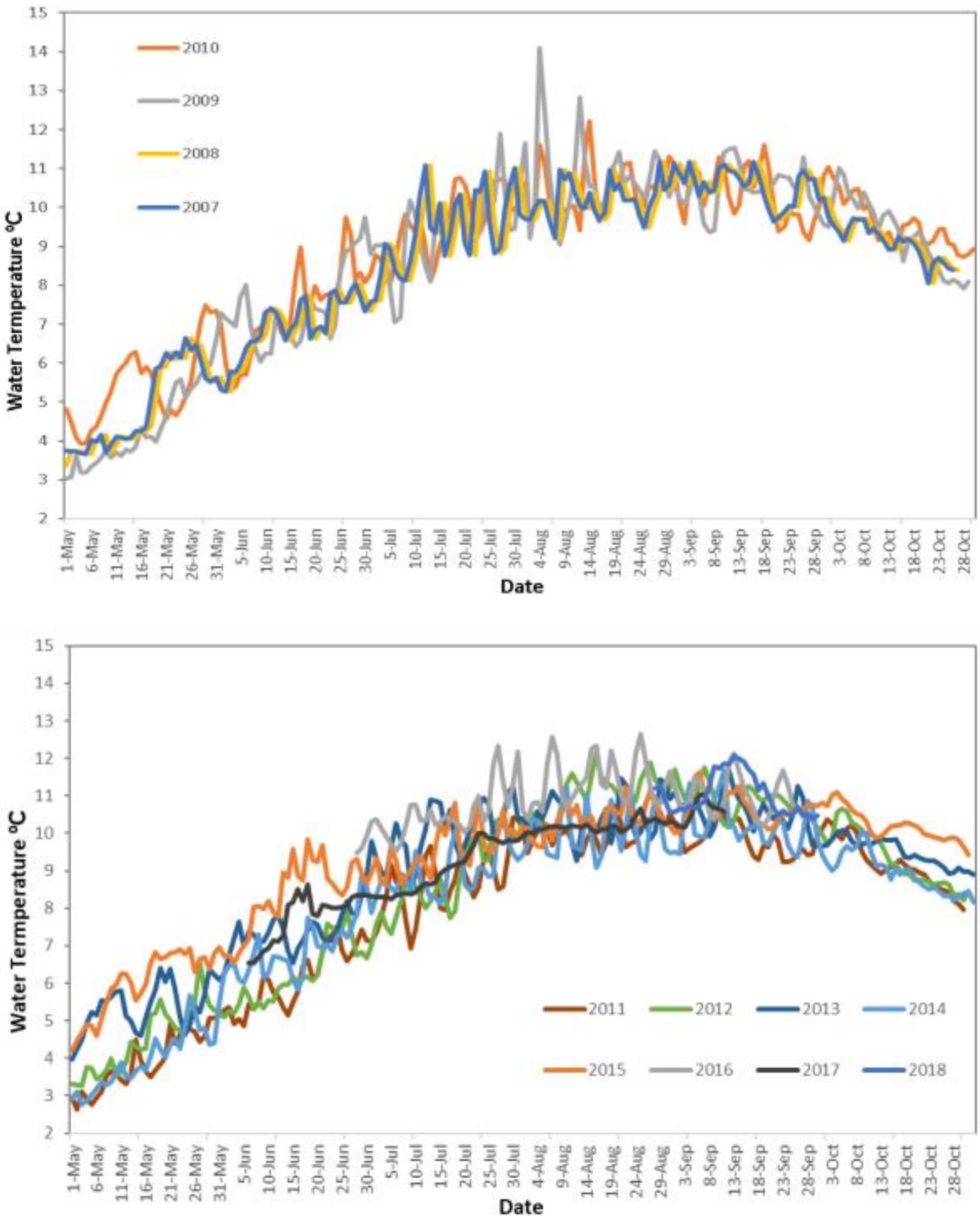

Figure 7: Mean daily water temperature for the Revelstoke Reach from May 1 to Oct 31 for 2007 to 2010 (pre-minimum flow; upper graph) and May 1 to Oct 31 for 2011 to 2018 (post-minimum flow; lower graph). Data for 2007 and 2009-2014 are from Station 6 (CLBMON-15), data for 2008 are from Station 5 (CLBMON-15a), data for 2015 are from Station 3 (BC Hydro), and data for 2016-2018 are from portable thermistors moored seasonally downstream from Greenslide Creek.

In 2018, moored temperature thermistors programmed to record hourly were deployed at two locations within the ALR at an average water depth of 10.8 m. Loggers were deployed on August 28 and collected on September 30, 2018 (Figure 8). Water temperatures at Greenslide Creek ranged between 10-12.5°C and between 8.5-12.9°C, at Shelter Bay. Temperature oscillation patterns were evident at both stations; in a previous ALR limnology study, Pieters *et al*. (1998) observed similar temperature oscillations, even at depths of over 30 m. Pieters *et al.* (1998) suggested that large wind storms create patterns of 'internal seiche'; lower density warmer water being pushed to one side by the wind combined with the Coriolis effect, starting a 'rocking' of the water layers back and forth as the system tries to equilibrate.

Shorter term variations in temperature over a few hours were also recorded, potentially indicating that flow through the reservoir is turbulent. These variations are likely associated with changes in weather patterns and variations in the passage through the system (Pieters *et al.*1998). As water temperature can have a strong influence on Sturgeon movement, these temperature swings may affect Sturgeon movement behaviour in the reservoir in less than 30 m.

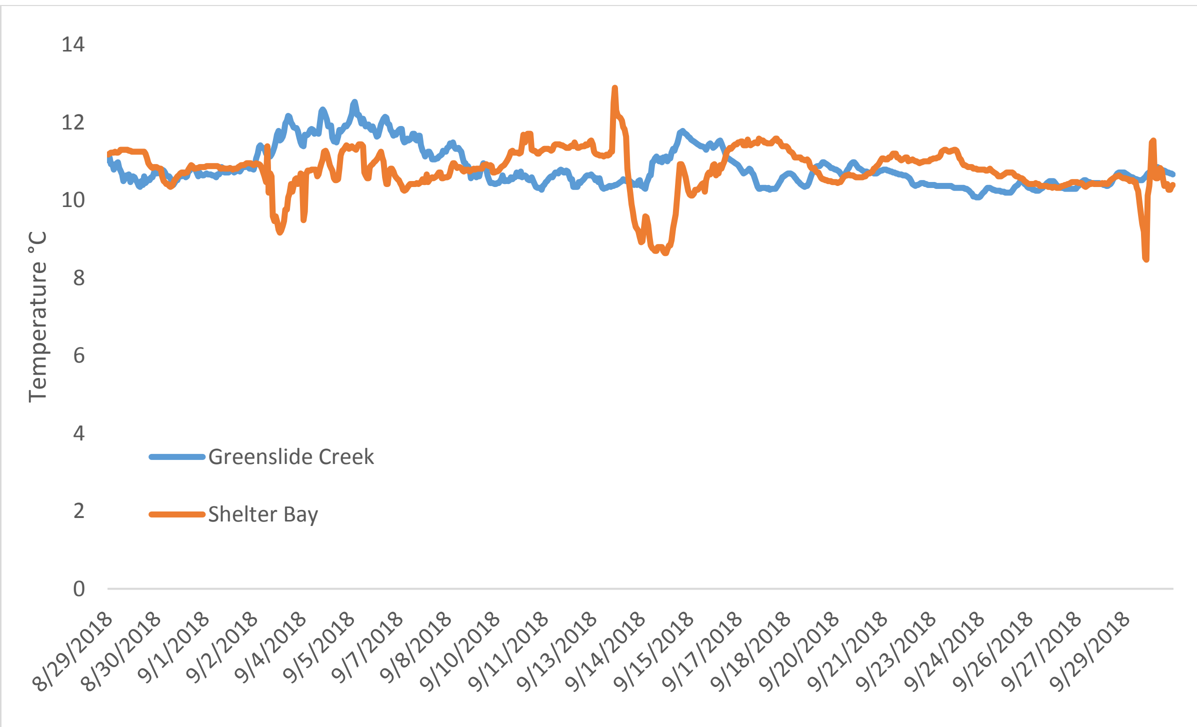

Figure 8: Mean hourly water temperature at two stations in upper Arrow Lakes Reservoir (ALR). Loggers were deployed only in the focal study area for 2018 (Shelter Bay to Greenslide Creek).

3.1.3 Meso-Habitat Measurements

In general, surface water velocities in the study area were low (<1 m/s) at all sites and sampling dates but varied seasonally, with the highest velocities during August. Bottom water velocities at the meso-habitat measurement stations associated with the gear that captured juvenile White Sturgeon ranged from 0.0 to 1.0 m/s (Golder 2010). Habitat conditions at juvenile Sturgeon capture locations were similar throughout the years, and averaged a water depth of 12.2 m and water temperature of 10.8°C. A summary of meso-habitat conditions taken at sturgeon capture locations can be found in Appendix C.

Turbidity was typically low (≤3 NTU) at all sites except during the one July sampling session (6 NTU) when ALR elevations rose and inundated the exposed shallower sections with predominantly silt-sand substrates (Figure 9). Secchi depth readings (range from 2.1 m to 5.1 m) supported the general seasonal pattern of water clarity as indicated by the turbidity data.

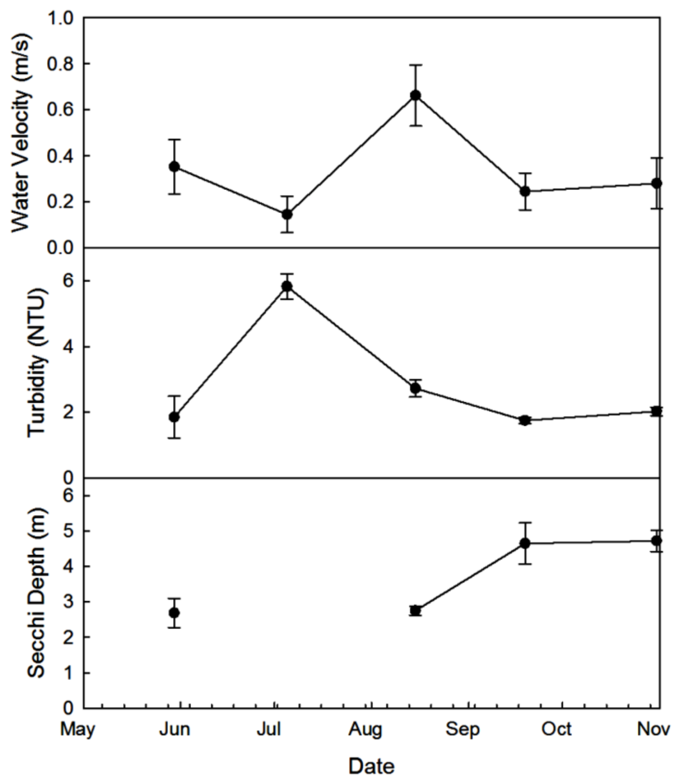

Figure 9: Physical habitat variables measured at four locations within the Middle Columbia River VPS study area at approximately monthly intervals between May 30 and October 30, 2012. Black dots represent the mean values and horizontal bars are standard deviations (graph from ONA and Golder 2013).

3.2 Juvenile Sturgeon Releases

An important aspect of the CLBMON-21 program has been to evaluate juvenile growth and survival after release from the hatchery, as well as describe the availability and suitability of habitat for juvenile White Sturgeon in the Arrow Lakes Reservoir. These data gaps have been investigated through monitoring of juveniles following release using acoustic telemetry or by direct capture.

3.2.1 Larval Releases

Under a different program (CLBWORKS-24), the BC Hydro WUP required the release of larval Sturgeon (under 60 days old) into the upper Revelstoke Reach (Table 8). From 2008 to 2009, larval sturgeon were to either a stage just before hatchery feeding would commence (unfed larvae), or after a few weeks of feeding had occurred (fed larvae; FFSBC 2011). These larvae were released at the confluence of the Jordan River and the Columbia River.

In 2010, larval releases also occurred as part of an experiment to assess the effects of substrate modifications in the White Sturgeon spawning area below REV on larval retention and growth (Table 8). One day old unfed larvae were raised at the KTSH then transported to the MCR for release over modified (clean coarse materials placed on the river bottom) and unmodified (natural riverbed) substrates (FFSBC 2011).

Table 8: Summary of unfed and fed larvae from the Kootenay Trout and Sturgeon Hatchery and release location in the MCR.

Study Year	Date of Release	Release Location	River Kilometer	No. Juvenile Sturgeon Released	Larval Stage	Number of Families
2008	4-Jul	Jordon River mouth	229	335,631	unfed	2
	25-Jul	Jordon River mouth	229	283,848	fed	
2009	5-Jul	Jordon River mouth	229	180,000	unfed	1
	8-Aug	Jordon River mouth	229	80,000	fed	
2010	3-Jul	Revelstoke Spawning Area - Control Site (first release)	228.5	168,135	unfed	6
	3-Jul	Revelstoke Spawning Area - Control Site (second release)	228.5	168,135	unfed	
	@	Centennial Park	225.2	155,000	fed	
		Total Released		1,370,749		

Results from this study demonstrated that modifications to embedded substrates at known White Sturgeon spawning locations can enhance conditions required for hiding at the yolk sac larvae stage (Crossman and Hildebrand 2012). Fed larvae also were released in 2010 at the Centennial Park boat launch in the Revelstoke town site (Table 8).

All of the ~1.3 million larval released in the MCR were unmarked. No unmarked juveniles have been captured during the sampling program, though it was expected to take a while before these fish reached a size that would recruit to the sampling gear.

3.2.2 Juvenile Releases

In total, 61,964 10 to 22-month-old PIT-tagged juvenile White Sturgeon have been released into the MCR from 2007 to 2018 (Table 9). The number of juveniles released annually between REV and Shelter Bay has varied between 977 and 9,175 individuals. Between 2007 and 2012, the annual releases included 50 acoustic-tagged fish (250 fish in total;

Table 10). With the exception of the 2,566 wild origin juveniles released in May 2017 and 2018 at the Shelter Bay boat launch, all other releases have been hatchery-origin juveniles.

Table 9: Summary of PIT-tagged juvenile White Sturgeon including origin, release date, location, number released, and average length (mm) and weight (g). Acoustically-tagged juveniles not included.

Study Year	Origin of Juveniles	Age at release (months)[a]	Date of Release	Release Location	River Kilo-metre	No. Juvenile Sturgeon Released	Average length	Average weight
							mm	grams
2007	Hatchery	10	3-May	Moses Creek- Day	233	1,884	19.9	59
			3-May	Moses Creek- Night	233	2,172		
2008	Hatchery	10	29-Apr	Big Eddy	228.3	5,884	20.0	61
			29-Apr	Centennial Launch	225.8	600		
2009	Hatchery	10	23-Apr	Big Eddy	228.3	7,518	20.8	67
			23-Apr	Centennial Launch	225.8	600		
2010	Hatchery	10	23-Apr	Big Eddy	228.3	9,175	21.6	81
			23-Apr	Centennial Launch	225.8	400		
2011	Hatchery	10	20-Apr	Shelter Bay	177	7,578	20.0	55
			20-Apr	Centennial Launch	225.8	500		
2012	Hatchery	10	8-May	Shelter Bay	177	6,517	22.2	81
2013	Hatchery	10-L	8-May	Shelter Bay	177	5,944	27.4	159
2014	Hatchery	10-L	8-May	Shelter Bay	177	3,288	28.0	202
2015	Hatchery	10-L	5-May	Shelter Bay	177	6,013	27.2	144
2016	Hatchery	22	3-May	Shelter Bay	177	750	40.3	451
			5-May	Shelter Bay	177	575	39.6	442
2017	Wild	22	7-May	Shelter Bay	177	1,589	38.0	313
2018	Wild	22	8-May	Shelter Bay	177	977	39.5	423
Total juvenile White Sturgeon Released All Years						**61,964**		

[a] Fish aged 10-L are 10 months but raised on increased feed to grow to larger body size

Table 10: Summary of acoustic-tagged juvenile White Sturgeon origin, release date, release location, number of juveniles released and average length (mm) and weight (g).

Study Year	Origin of Juvenile	Date of Release	Release Location	RKm	No. Juvenile Sturgeon Released	Average Length	Average Weight
						mm	grams
2007	Hatchery	3-May	Moses Creek	233	50	31	211
2008	Hatchery	29-Apr	Big Eddy	228.3	50	31.6	229.2
2009	Hatchery	23-Apr	Big Eddy	228.3	10	35.1	280.9
			Begbie Creek	216	10		
			Mulvehill Creek	206.1	10		
			Tree Island	194.1	10		
			Arrowhead	184	10		
2010	Hatchery	22-Apr	Big Eddy	228.3	10	31.5	244.8
			Begbie Creek	216	10		
			Mulvehill Creek	206.1	10		
			Tree Island	194.1	10		
			Arrowhead	184	10		
2011	No acoustic-tagged juveniles released						
2012		15-May	Akolkolex/ Walter Hardman	203	50	32	250
Total acoustic-tagged White Sturgeon released - All Years					250		

3.2.2 Size at Release

The release size of White Sturgeon juveniles has changed over the 12 years of the program. To observe the effect of size at release, four size categories were released over the study period for a total of 1,370,749 larvae, 42,828 small bodied Age-1 (2007-2012), 15,245 large bodied Age-1 (2013-2015), and 3,891 Age-2 (2016-2018) individuals being released. The hatchery originally produced 10 month old juveniles that averaged approximately 50 to 80 g and were large enough to receive a PIT tag (Table 9). Additional fish were raised to 22 months (Age-2) at a weight of 200 to 300 g, a size large enough to accommodate the implantation of acoustic tags (

Table 10). For juvenile Sturgeon released in 2012 to 2015, average weight at release for 10-month-old fish increased to approximately 170 grams, categorized as large bodied Age-1. For 2016-2018 releases, fish were reared at the hatchery for 22 months (Age-2), which increased weight at release to between 300-450 g (Table 9).

Due to low recaptures of fish released into the MCR it has been difficult to determine the effect of size at release on expected survival. Four hatchery released juvenile white Sturgeon were captured in 2010, for a total of 10 fish captured during the 2007 to 2010 study. Of note, 4 of the ten juveniles captured have been fish equipped with sonic tags at release. These fish were larger at release and grew faster compared to fish without sonic tags. In the MCR, size at release may influence survival. Further discussion on size at release differences in growth are incorporated into the life history results (Section 4.3.1).

3.3 Juvenile White Sturgeon Movements and General Habitat Use

At the onset of this program, a fine-scale telemetry study was implemented to track daily movements of acoustically-tagged juvenile White Sturgeon with the objective of investigating movement and habitat use. This study was divided into two components: a longer range dispersal and general movement study (2007-2010), and a fine-scale telemetry study to track daily movements over three seasons at a section of river that was associated with high juvenile Sturgeon detection (2011-2012). As well, mobile tracking for adult White Sturgeon with acoustic tags that were still active from a previous monitoring program were recorded in this program.

3.3.1 Passive Array Detection

Movements of acoustic-tagged juvenile White Sturgeon in the study area were continuously monitored by the VR2W linear array from May 2007 to November 2010 (see Golder 2011 for additional details). All 200 acoustic-tagged juvenile White Sturgeon released below Revelstoke Dam between 2007 and 2010 were detected at least once by the array. In total, 3,106,943 detections have been recorded by the array since April 2007. Of these, 1,965,248 detections were juvenile White Sturgeon, 48,795 were adult White Sturgeon, 1,091,771 were Burbot (tagged in 2009 and 2010 in the MCR as part of a separate study program, CLBMON 31), and 1129 were considered false detections (i.e., noise). The approximately 2 million juvenile White Sturgeon detections were reduced down to 3705 (as described in Golder 2011) for the statistical analyses of movement data. The percentage of false presence tag IDs (i.e., noise) recorded by the array was 0.04%, a very low frequency compared to detections accepted as valid.

The number of detections of acoustic-tagged juvenile White Sturgeon recorded in 2010 (450,955) was less than that recorded in 2009 (757,687), but more than in 2008 (402,279) and 2007 (354,327). The greater number of detections in 2009 was initially thought to result from the five release locations that year, compared to one release location in each of 2007 and 2008 (Golder 2010). However, other potential reasons may include natural variation or the much greater number of tagged Burbot detections in 2010 (1,048,307) compared to 2009 (43,464) that reduced the number of juvenile White Sturgeon tags that could successfully be coded out by the receivers.

3.3.2 Dispersal for Release Locations

Dispersal patterns of acoustic-tagged Sturgeon were observed by comparing single release upstream locations that were used in 2007 and 2008 with multiple release locations (spaced approximately every 10 km) covering the entire Revelstoke Reach, used in 2009 and 2010. In April of 2008, 2009, and 2010, downstream dispersal was apparent at all stations (Golder 2011). In 2008, when all acoustic-tagged juveniles were released at Big Eddy, fish were detected as far downstream as Station 212.0 (near Greenslide Creek) within 2 days of release. A similar pattern was apparent in May 2007, when all acoustic-tagged juveniles were released at Moses Creek (RKm 233). These fish exhibited rapid downstream movement past the seven most upstream VR2W stations (Stations 232.3 to 212.0), then spent more time in the vicinity of VR2W stations in deeper, lower velocity habitats near Mulvehill Creek (RKm 207.4) and downstream. A similar pattern was observed in May 2008, as fish released in Big Eddy continued their downstream dispersal, and then began to spend more time near Mulvehill Creek and downstream areas.

In 2009 and 2010, acoustic-tagged juvenile White Sturgeon were released in groups of 10 fish at approximately 10 km intervals in the middle Columbia River between Big Eddy and Arrowhead (

Table 10). The general post-release dispersal pattern of acoustic-tagged juveniles released at the two most upstream locations (Big Eddy, RKm 228.3 and near Begbie Creek, RKm 216) was characterized by rapid downstream movements through the riverine section of the middle Columbia River to deeper areas with lower water velocities (Golder 2011). These downstream movements were fastest and occurred over the longest distances for fish released at Big Eddy. After these initial movements, the speed and distance travelled decreased and fish generally spent longer periods of time in particular areas. These dispersal patterns (especially for fish released at Big Eddy) were similar to those of fish released at Big Eddy in 2009 (n = 10) and 2008 (n = 50) and upstream at Moses Creek (RKm 233) in 2007 (n = 50).

The dispersal patterns of fish released in 2010 at the three downstream locations (near Mulvehill Creek, RKm 206.1, Tree Island, RKm 194.1, and Arrowhead, RKm 184) were more variable (Golder 2011). A portion of these fish moved rapidly downstream shortly after release, while others remained in the vicinity of their release location. Several fish released at Arrowhead moved upstream within a few weeks of release.

Of the 50 sonic-tagged juveniles released in 2010, 13 (26%) were not detected after May 17 (24 days after release). These fish were represented by fish from each release location: Big Eddy (n = 2), near Begbie Creek (n = 3), near Mulvehill Creek (n = 1), near Tree Island (n = 4), and Arrowhead (n = 3). This was a higher "early disappearance" rate than the eight (16%) sonic-tagged juveniles released in 2009, but less than the 17 (34%) released in 2008 and the 18 (36%) released in 2007 that were not detected after one month post-release (Golder 2010b). The number of sonic-tagged juveniles not detected after one month post release in 2009 was reduced because three fish that were not detected by the VR2W array after May 11, 2009 were later detected between acoustic receiver locations during mobile tracking surveys. Many of the fish were last detected at the downstream end of the study area, located in the upper ALR.

3.3.3 Effect of Release Sites

The analysis focused on an evaluation of the effect of release sites on subsequent Sturgeon behaviour. Initially, all four years of data were examined; however, during initial exploratory analysis there were sufficient differences in other factors (e.g., reservoir water levels) so Year 1 and Year 2 were excluded from the analysis. The variables examined included: time spent on station and movement magnitude and direction after departing station until relocated. Absolute distance travelled was not used as a fish released at a site near the most upstream VR2W station could not be relocated at an upstream site as there were no more receivers. As this bias also affects relative distance travelled following departure from a VR2W station, the time spent on site after arrival would be a stronger parameter on which to evaluate the effects of release site on subsequent behaviour. The parameters and statistical analysis for the two selected models (Log Time at Station and Standardized Distance Travelled) are described in Golder (2011).

There were significant differences in distances moved among release sites (Figure 10). Movements in April and May were generally downstream while there was a general tendency to move upstream after June, although sample sizes (number of detections of tagged fish) decreased, which resulted in greater uncertainty. The Begbie Creek release location (RKm 216) had individuals that were more likely to move upstream in the fall.

With the top ranked models (AIC_c weights >0.1), arrival time (day/night), year, REV discharge (Q), and ALR water surface elevation influenced the time spent on station (Table 11; Golder 2011). As there were considerable covariation in the variables month and ALR water surface elevation, the temporal component may contain changes in behaviour related to water levels or discharge. Time spent on site generally increased each month and varied by release site. All years were pooled for the selected model (Figure 11; Golder 2011). Average time spent on station in 2007 was significantly less than in the other years, so the data from fish released at Moses Creek (RKm 232.3) may not reflect site differences, but rather differences among years.

Overall, fish tended to move upstream more often and to stay longer on station during the course of the summer and into the fall. Fish released at RKm 216 tended to be more likely to move upstream and stay on site longer than fish released at other sites. Fish released at the most upstream and downstream sites would be biased to move downstream or upstream, respectively, because of the lack of receivers beyond these release locations (Golder 2011).

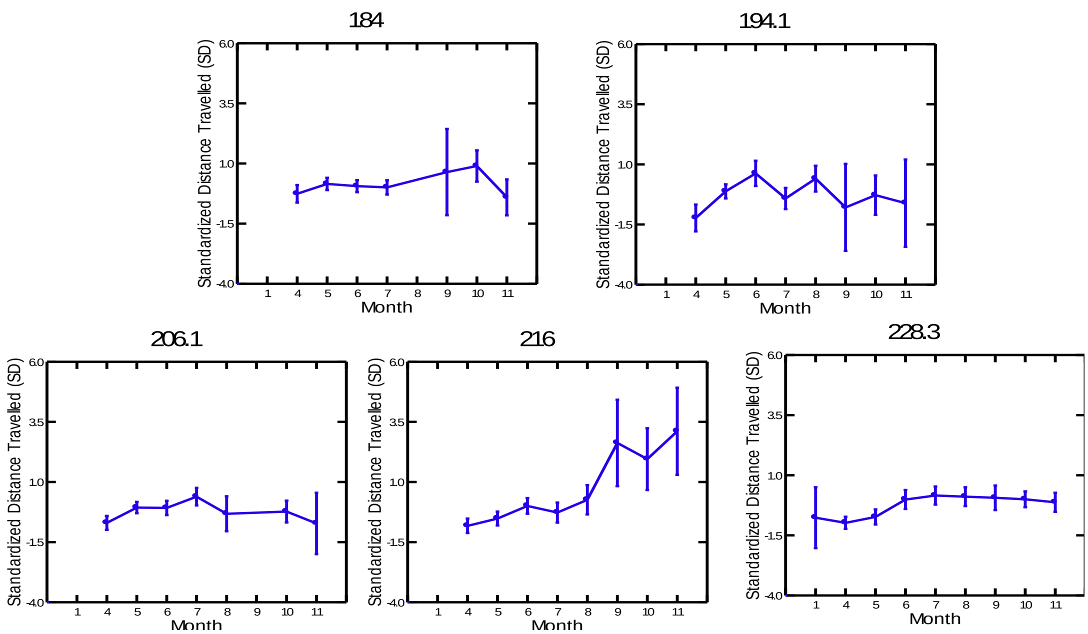

Figure 10: Least Square Means of the standardized distance travelled variable of the selected model of acoustic-tagged juvenile White Sturgeon in the middle Columbia River by month of detection for fish from the five release locations (River kilometre numbers at the top of each graph). Values reflect standardized net distances (positive = upstream movement; negative = downstream movement). The data are from the 2009 and 2010 study years combined. Error bars are SE of the least square means from the general linear model. Graph is from Golder (2011).

Table 11: AIC_c ranking of candidate models for predicting Log of Time at Station after arrival of an acoustic-tagged juvenile White Sturgeon at a station in the MCR. Independent variables are categorical except for REV discharge and Arrow Lakes Reservoir water surface elevation. Table from Golder (2011).

Dependent Variable	Multiple R^2	AIC_c Weight	AIC_c	Independent Variables						
				Release Site	Year	Month	Month x Release Site	Daylight (Day/ Night)	ALR Water Surface Elevation	REV Discharge
Log Time at Station	**0.2**	**0.294**	**4965.268**	**x**		**x**	**x**			
	0.202	0.241	4965.663	x		x	x		x	
	0.201	0.171	4966.352	x		x	x	x		
	0.201	0.11	4967.236	x		x	x			x
	0.2	0.102	4967.387	x	x	x	x			
	0.202	0.082	4967.809	x		x	x	x		x
	0.12	>0.001	5010.165	x		x				
	0.122	>0.001	5011.163	x		x		x		x
	0.121	>0.001	5011.171	x		x				x
	0.121	>0.001	5011.199	x		x		x		
	0.123	>0.001	5013.156	x	x	x		x		x
	0.131	>0.001	5041.358	x			x			

Although the trends described are statistically significant, the overall selected models explained only a small amount of the variability observed (R^2 ~ 0.2; Golder 2011). Other variables examined for effect on juvenile White Sturgeon movements included: solar radiation (day/night), REV hourly discharge, and ALR water surface elevations. Although there were some slight statistical significance to these parameters (ALR water surface elevations was the strongest), the relationship was confounded by the temporal correlation with fish growth and explained very little of the variability observed in movement patterns. Although thousands of relocations were observed at the various stations, the bulk of the data was from a small number of individuals.

In addition, the dependent variable used (the magnitude and direction of movements and time spent on station) do not have obvious biological interpretations, i.e., is less movement or upstream movement better than more frequent movement or downstream movement? A plausible interpretation is that the extended time spent on station indicated the presence of preferred habitat and food resources, whereas upstream or downstream movements could have indicated that the individual was required to more actively search for food. However, the influence of other factors (e.g., fish in poor condition tend to migrate less frequently) cannot be discounted.

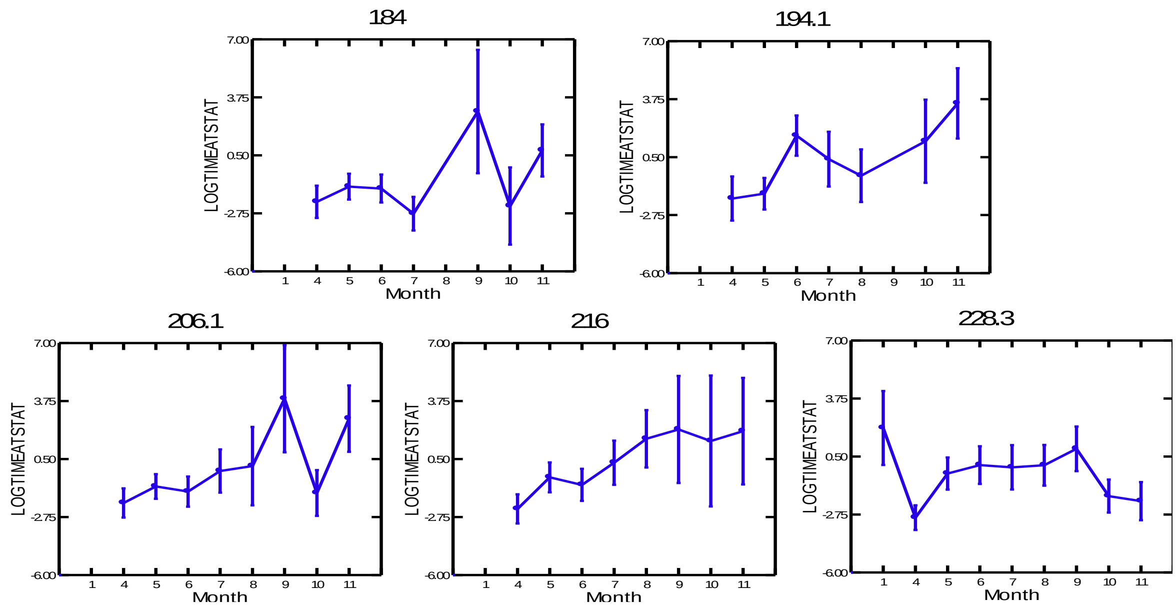

Figure 11: Least Square Means of the Log (Time at Station) by acoustic-tagged juvenile White Sturgeon in the middle Columbia River over each month (River kilometre numbers at the top of each graph). The data are from the 2009 and 2010 study years combined. Graph from Golder (2011).

3.3.4 Movements and Macro-Habitat Use

The number of tag days recorded at each VR2W station from 2007 to 2010 provided an indirect indication of rearing use of macro-habitats by juvenile White Sturgeon in the MCR. Macro-habitat in this context is defined as the sum of all meso- or micro-habitat types within the detection range of the station. The presence of a tagged juvenile White Sturgeon in the vicinity of the station, even if only transitory, was considered as a use of available habitats within that area. Insufficient data were collected on habitat parameters occupied by individual fish to categorize habitats on smaller spatial scales.

The mean net movement of sonic-tagged juvenile White Sturgeon, an indication of the length of river used (or the range of these fish), was similar in all four study years despite the differences in release patterns (Table 12). This suggests an active selection for deeper, lower velocity habitat and an apparent avoidance of higher velocity habitats in the middle Columbia River. The sonic-tagged juveniles remained within an approximate 21 to 26 km length of river/reservoir. The movement of one fish downstream of the VR2Ws in the Beaton Flats area was confirmed by its detection at the Narrows; however, undetected movements downstream of this area likely occurred, which could have resulted in an increase in net and total movements. Additionally, undetected movements within the study area could also have occurred.

Table 12: Mean net movement of acoustic-tagged juvenile White Sturgeon after released in the middle Columbia River, 2007 to 2010.

Year	Mean net movement (km)	Range (km)	S.D.	Number of detections (±SD)
2007	23.9	0 - 52.3	16.2	7,087 (± 23,133)
2008	25.7	0 – 48.3	15.3	8,046 (± 11,455)
2009	21.4	2.6 – 68.3	14.1	15,154 (± 21,361)
2010	21.7	0 - 104	18.2	9,019 (± 19,552)

The average total distance moved by acoustic-tagged juvenile White Sturgeon varied between 2007 and 2010 but was highest in 2008 (49.1 km; Table 13). Mean total movements were lowest in 2009, which may be related to the low ALR elevations in 2009 (compared to 2007-08 and 2010). The statistical analysis of movements (described in Section 4.4.6) determined that ALR water surface elevations were a significant variable that affected net movement.

Table 13: Mean total movement of acoustic-tagged juvenile White Sturgeon after released in the middle Columbia River, 2007 to 2010.

Year	Mean Total Movement (km)	Range (km)	S.D.	Number of detections (±SD)
2007	44.1	0 – 214.3	46.5	7,087 (± 23,133)
2008	49.1	0 – 237.1	49.6	8,046 (± 11,455)
2009	37.9	2.6 – 136.0	30.3	15,154 (± 21,361)
2010	47.1	0 – 296.1	57.5	9,019 (± 19,552)

On average, the 50 acoustic-tagged juveniles released in 2010 moved approximately twice as far downstream (31 km) as upstream (16 km). Seven fish were detected more than 1.3 km upstream of their release location. One fish was detected at the Narrows (RKm 112; 68 km downstream of Beaton Flats and 104 km downstream of its release location), which is out of the study area. Eighteen juveniles did not exhibit any upstream movement, although nine of these fish were not detected after May 9, 2010 (18 days after their release).

Habitat use was higher at the lower end of the Robson Reach (Beaton Flats / Tree Island areas; RKm 180-195) in Spring (June) in years that water elevations were low (2009 and 2010). In years that spring water elevations were high (2007 and 2008), habitat use was higher further north near Mulvehill Creek (RKm 207.4) and the Akolkolex River / Blanket Creek areas (RKm 200-203.5). Similarly, use of the Tree Island area (RKm 195) was higher in summer (July/August) 2009 and 2010 when water levels remained low.

From 2007 to 2010, the stations where the highest use (measured as tag days on site) by sonic-tagged juvenile White Sturgeon was recorded were located between Station 212.0 (upstream of Greenslide Creek) and Station 195.0 (Tree Island area; 56% of total tag days), and the Beaton Flats area (RKm 180; 14% of total tag days; Figure 12). High use of the area between Stations 212.0 and 195.0 occurred during all study years (63% of total tag days in 2007, 71% in 2008, 43% in 2009, and 51% in 2010; Golder 2011). The multiple release locations in 2009 and 2010 resulted in lower overall use (47%) of this area than the single upstream release locations used in 2007 and 2008 (68%).

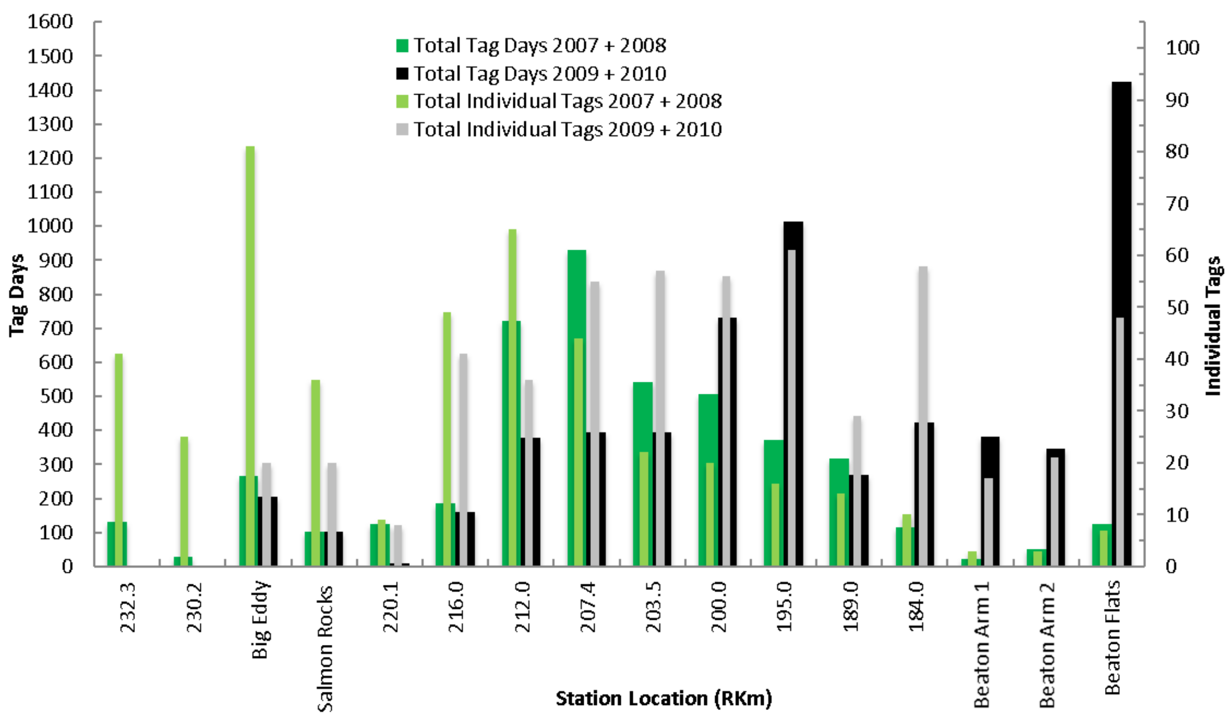

Figure 12: Total tag days and total individual tags recorded of acoustic-tagged juvenile White Sturgeon movements in the middle Columbia River for 2007 and 2008 fish (single release location at RKm 233) and 2009 and 2010 fish grouped (5 release locations spread from Big Eddy to RKm 184) recorded in the middle Columbia River, 2007 to 2010. Graph from Golder (2011).

The highest overall use occurred at Beaton Flats (14% of total tag days; Figure 12). This was due to a greater use of this area in 2009 and 2010 (23%) than in 2007 and 2008 (3%; Golder 2011). Use of the areas from Blanket Creek (Station 203.5) upstream was greater in 2007 and 2008 (67%), whereas use of the areas from the Akolkolex River (Station 200.0) downstream was greater in 2009 and 2010 (74%).

The macro-habitat conditions in the areas where the most tag days were recorded were similar in terms of depth, velocity, and substrate (Golder 2011). These areas were characterized by depths in excess of 10 m (and often 15 m), water velocities of less than 0.5 m/s, and substrates composed mainly of fines. These areas exhibited more lentic conditions for longer periods, as opposed to upstream areas that exhibited lotic conditions for longer periods of the year.

3.3.5 Movement Out of Study Area/Post-release Mortality

In 2007, five acoustic-tagged juvenile White Sturgeon moved steadily downstream after release, apparently past the Beaton Flats stations and out of the study area. In 2008, four acoustic-tagged fish exhibited the same movement pattern (Golder 2009). The detection of eight acoustic-tagged juveniles downstream of the Beaton Flats VR2W stations during mobile tracking in 2009 provided further verification that some hatchery-released juveniles move beyond the study area. In 2010, 30 tags were last located in either Arrowhead or Beaton Flats receiver stations at the downstream end of the Revelstoke Reach over the study period. The size and depth of ALR downstream of the study area (approximately 180 km long) presents substantial logistical difficulties in terms of monitoring juvenile White Sturgeon and their use of the reservoir.

The fate of acoustic-tagged juveniles remains unknown. Results from 2009 suggested that a portion of tag “disappearance” is due to fish moving downstream beyond coverage of the VR2W array. In 2007 and 2008, the relatively high proportion of tags that were not detected beyond one month post-release (36% and 34%, respectively) suggested potential post-release mortality (Golder 2009), though high ALR levels in 2008 could have allowed fish more river width to move undetected past the receiver array stations. However, this proportion was substantially lower in 2009 (16%), due in part to mobile tracking surveys that located three acoustic-tagged juveniles that had not been detected by the VR2W array for approximately 5 to 7 months. The four potential reasons for the disappearance of some tags shortly after release are:

1. Movement out of the study area (outside range of acoustic receivers).
2. The fish remain in portions of the study area that are out of all acoustic receiver station’s detection range (for example, one tag was located by mobile tracking after disappearing from station data.).
3. Post-release mortality (for example, fish dies in between stations or at stations and tag does not move any further for the year).
4. Occasional equipment malfunction or battery failure that may be responsible for tags disappearing, which is impossible to confirm without relocating tag.

It is possible that tag “disappearance” is due partly to all of these reasons. Additional VR2Ws were deployed in the Burton area (approximately 80 km downstream of the study area at a narrow point in ALR) in 2009. In 2010, one fish was identified at the Narrows station, but it was not possible to determine if this fish continued downstream or returned to ALR. Sampling in 2014 to 2017 was extended to the entire upper Arrow Lake basin. During these four years only one juvenile fish was captured in the ALR in a gill net on the west shoreline at RKm 124.0 in June, 2017 (Appendix A).

3.3.6 Diel Movement Analyses

Diel movements during Years 1 to 4 (2007 to 2010) were predominantly initiated during the periods of darkness from 21:00 until 06:00 (Figure 13). Downstream movements were more frequent than upstream movements (not illustrated), but both followed the same diel pattern. This pattern has been observed in each of the four years of the study (Golder 2008, 2009, 2010).

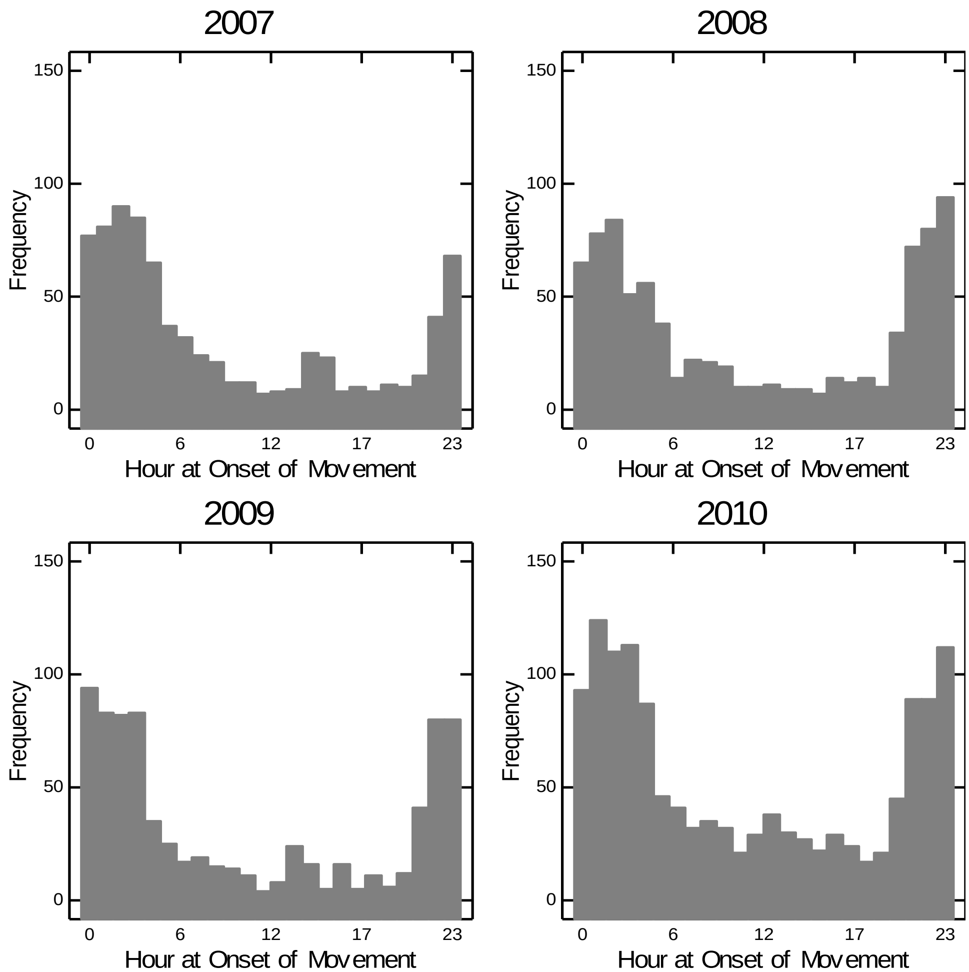

Figure 13: Frequency of the onset of movements by hour of the day (0 = midnight) of acoustic-tagged juvenile White Sturgeon in the Middle Columbia River, 2007 to 2010. Graph from Golder (2011).

Examination of the frequency distribution of light intensity [hourly diel solar radiation patterns (watts/m^2) measured at Revelstoke, BC] at the onset of movements did not indicate any variability in movements during daylight as a result of light intensity (Golder 2011). Consequently, daylight was used as a binary variable (day/night) during subsequent analyses.

3.3.7 Revelstoke Dam Discharge

Annual hourly average discharge (Q in m^3/s) from REV between 2007 and 2010 was also examined as it was related to the hour at the onset of movement (Figure 14; Golder 2011). The recorded flows at the onset of movements were less during 2010 and 2009 than 2008, and less in 2008 than 2007.

The REV discharge variable was positively related to downstream movement but was of minor significance. The results indicated that release site significantly affected movements, but only in the context of a particular month. The inclusion of an interactive term significantly improved the model but also was essential to evaluation of seasonal changes in behavior (Golder 2011).

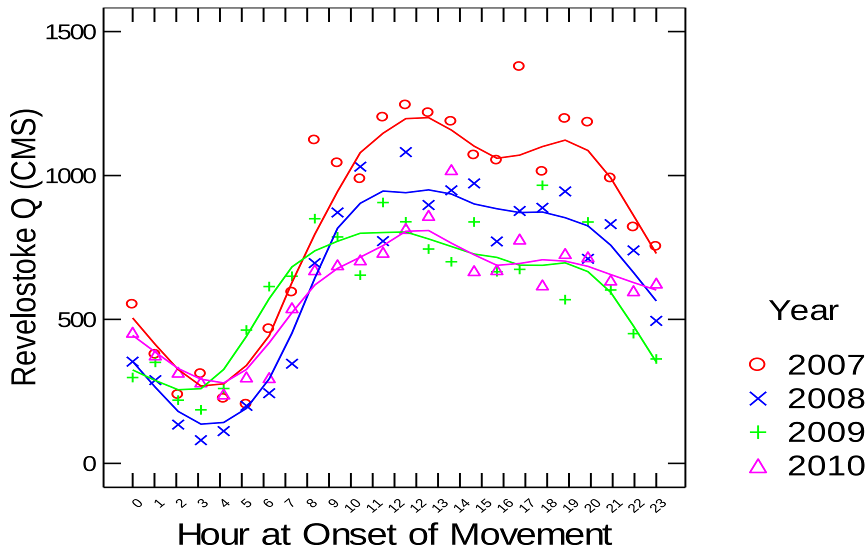

Figure 14: Annual hourly average discharge (m^3/s) from Revelstoke Dam vs. hour of the day in the middle Columbia River, 2007 to 2010. Curve fitting the data is from LOWESS (tension = 0.25). Graph from Golder (2011).

3.3.8 Fine-scale Array Detection

In total, 202,186 tag positions were calculated based on data collected during study period (May 15 to October 30, 2012). Out of the total dataset, 21% of the total number of tag positions had HPE ≤ 5, 60% had HPE ≤ 6, and 71% had HPE ≤ 7 (HPE defined in Section 3.3.4.4). In the restricted dataset (HPE ≤ 7) HPE values ranged from 2.5 to 7, with a mean of 5.3 and a median of 5.5. Once the first two weeks of data were removed to eliminate acclimation movements, the dataset included 128,601 tag positions estimated between May 29 and October 30, 2012.

Sensitivity analysis indicated little difference between HPE cutoff values of 5 and 6 (ONA and Golder 2013). However with a HPE cutoff value of 7, a few cases emerged where estimated swimming speed was high (> 2 m/s), as to be expected with lower positioning accuracy.

Using HPE values as a 95% confidence interval for fish positioning (Section 2.4.9), only 3.1% of the fish assigned to the thalweg were less than the HPE distance from the nearest floodplain/thalweg contour line; i.e., the position's confidence interval overlapped the thalweg/floodplain contour line in 3.1% of the cases. Therefore, 96.9% of the Sturgeon positions were assigned to the thalweg stratum. Out of the fish positions assigned to the floodplain, 5.6% were less than the HPE distance from the shallows/floodplain contour line; therefore, 94.4% were assigned to the floodplain stratum. Out of the fish positions assigned to the shallow stratum, only 0.1% was less than the HPE distance from the shallows/floodplain contour line, and therefore, could have been in deeper water than estimated

3.3.9 Fine-scale Movements

The data collected from the fine-scale array allowed analysis of movement patterns as related to daylight, habitat type, REV discharge effects at the study area, ALR elevation for 2012, and seasons. Half of the 50 acoustic-tagged juvenile White Sturgeon that were released into the vicinity of the VPS array on May 15, 2012 were only recorded during the spring session and were absent from the VPS study area in the summer and fall. Of the remaining 25 juveniles that stayed within range of the VPS system for more than two weeks, 12 fish left before the beginning of the summer. Thirteen individuals were present in the area during the summer, and only five were recorded in the fall. Throughout the May 29 to October 30, 2012 study period, juvenile White Sturgeon spent 0.03% to 25.3% of the time within the VPS array (mean = 4.8 ± 6.0%, median = 6.6%).

3.3.10 Meso-habitat Movements of RKm 203 to RKm 200

The fine-scale array allowed for detailed movement monitoring of tagged Sturgeon within a high use habitat area of RKm 203 to RKm 200 near Walter Hardman Generation Station. Tag locations by time of day, season, and habitat depth classification (Figure 15) clearly showed that juvenile White Sturgeon were found in shallow and floodplain sites in summer and fall but rarely in spring. Minimum distances traveled between consecutive positions within the array were usually less than 100 m throughout the study period (mean ± SD = 5.4 ± 10.6 m, median = 2.3 m). In the summer, minimum traveled distances were slightly longer than in the spring, with more cases of 50 to 100 m distances traveled between tag locations (spring: mean ± SD = 3.8 ± 6.9 m, median = 2.4 m; summer: mean ± SD = 6.04 ± 11.2 m, median = 2.8 m).

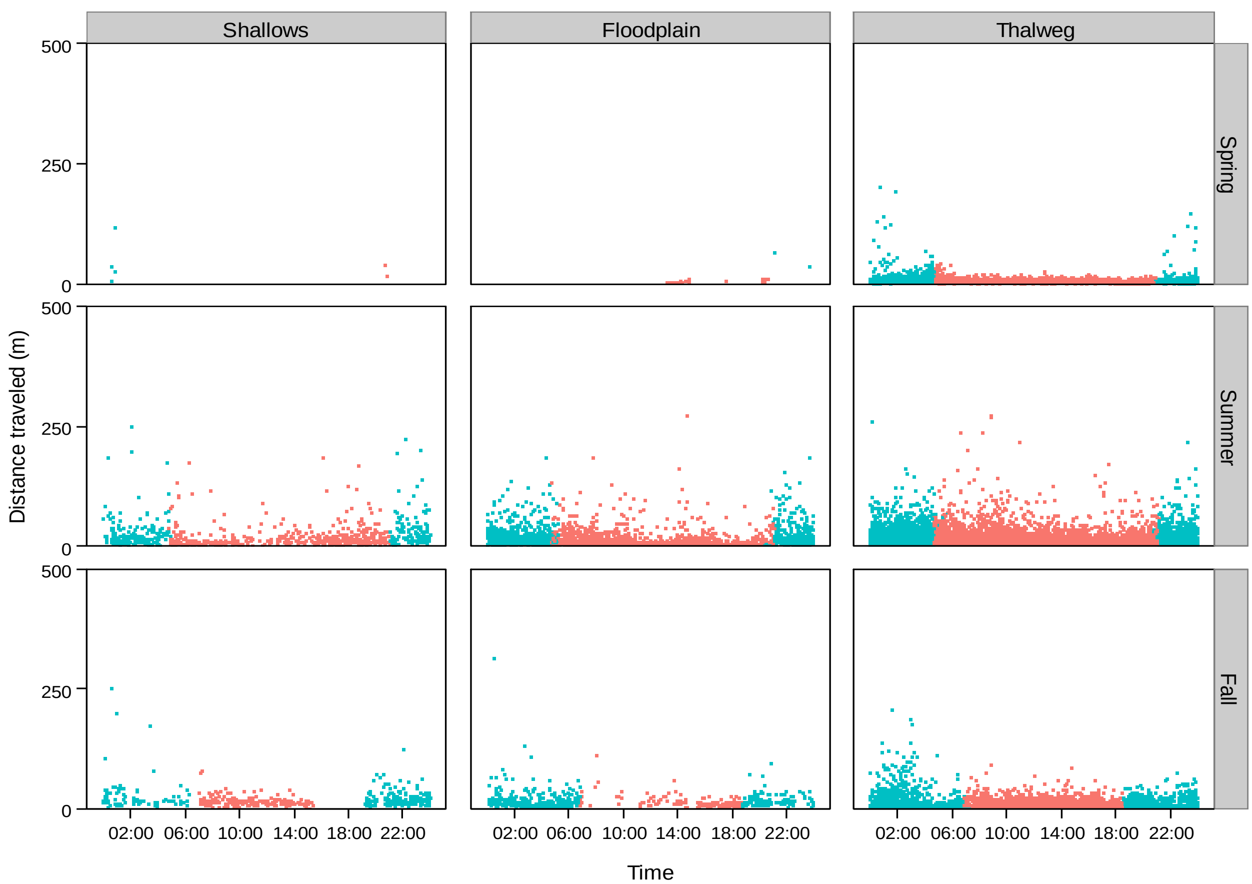

Figure 15: Minimum distance traveled between positions (m) of White Sturgeon juveniles in the VPS array, plotted by time of day, season, and habitat classification (thalweg, floodplain or shallows).

Minimum movement speeds changed seasonally, with highest rates estimated in the summer, in comparison to spring and fall months (Table 14). Estimated minimum movement speeds were 0.02 ± 0.03 m/s (mean ± SD, median = 0.01 m/s) in spring time, 0.03 ± 0.06 m/s (mean ± SD, median = 0.02 m/s) in summer time, and 0.02 ± 0.05 m/s (mean ± SD, median = 0.01 m/s) in the fall. Movement speeds were similar between nighttime and daytime. For example, in fish located in the thalweg at night time, swimming speed was 0.02 ± 0.05 m/s (mean ± SD, median = 0.01 m/s), while daytime swimming speed was 0.02 ± 0.04 m/s (mean ± SD, median = 0.01 m/s).

Table 14: Summary statistics of minimum movement speed (m/s) of juvenile White Sturgeon, separated by day/night, season, and habitat type (thalweg, floodplain, shallows); values are means ± standard deviations.

Habitat Classification	Spring (m/s)	Summer (m/s)	Fall (m/s)
Thalweg	0.04 ± 0.1	0.09 ± 0.48	0.02 ± 0.05
Floodplain	0.08 ± 0.17	0.30 ± 0.99	0.09 ± 0.07
Shallows	0.11 ± 0.10	0.18 ± 0.35	0.1 ± 0.05

When examining fine-scale data, juvenile White Sturgeon used shallow water under all ALR elevations (Figure 16). The longest, most consistent movements traveled in the shallows were observed when the reservoir was emptying. In the thalweg, the majority of the traveled distances were typically short (25^{th}, 50^{th}, and 75^{th} quantiles of 0, 0.9, 2.1, and 4.9 m; ONA and Golder 2013).

Seasonal differences in fish locations were apparent (Figure 16). During springtime, movements were usually restricted to the thalweg. In comparison, in summer and fall the fish took advantage of the increasing amount of habitat and were detected further from the thalweg. However, there was considerable individual variability in habitat use (described in Golder and ONA 2013). For example, in the summer, the Sturgeon with tag numbers WSG34 and WSG38 remained in the thalweg, while WSG19, WSG23, WSG26, and WSG30 had wider distributions. In the fall, WSG01 and WSG41 utilized the shallows, while WSG25 and WSG30 remained in the thalweg.

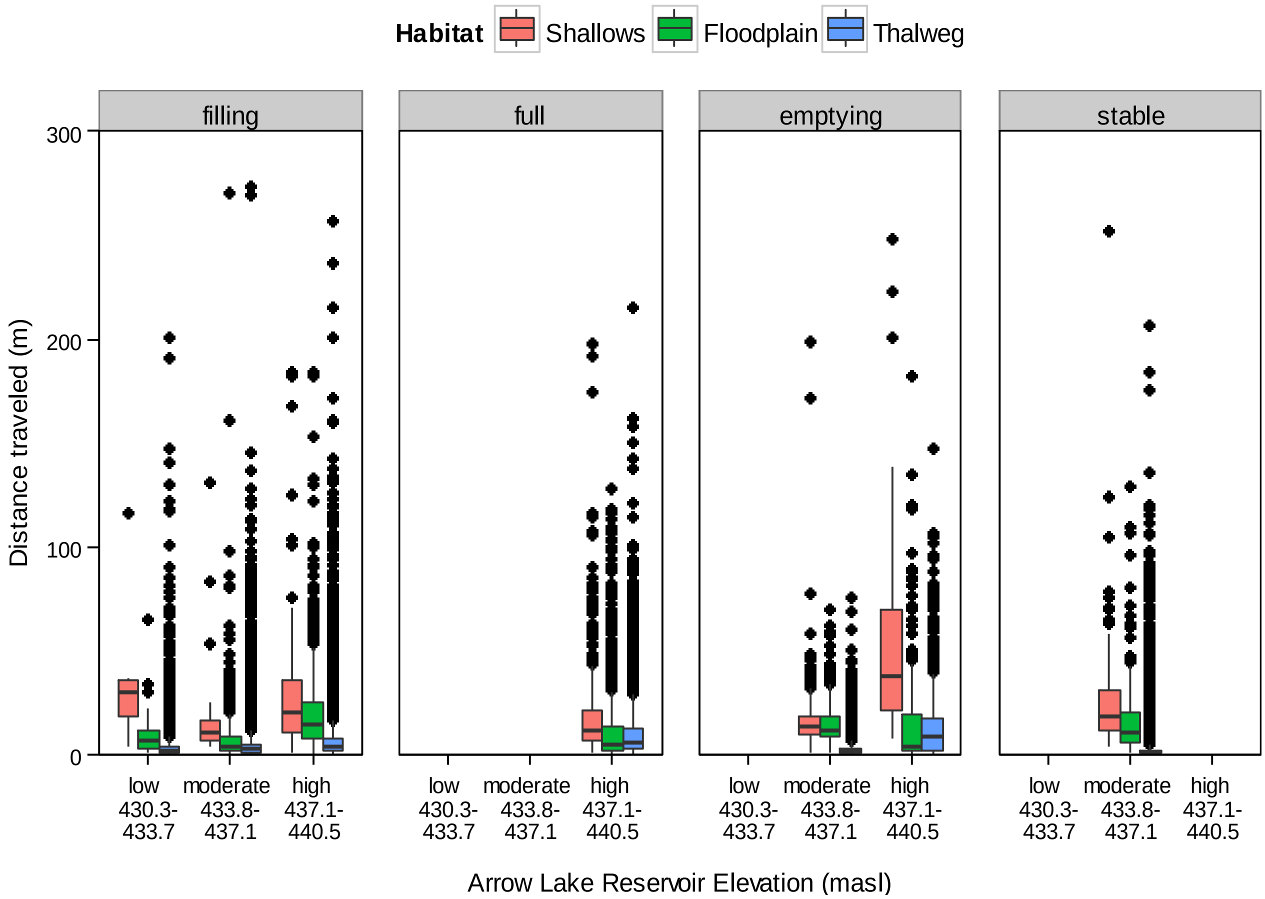

Figure 16: Minimum distance traveled between tag positions (m), separated by habitat classification (thalweg, floodplain or shallows), ALR elevation (low, moderate, and high), and ALR status (filling, full, emptying, and stable). Each box represents the 25th and 75th quantiles (bottom and top lines, respectively), and the median (middle, bold line); whiskers extend to 1.5 times the interquartile distance; outliers are shown as individual points.

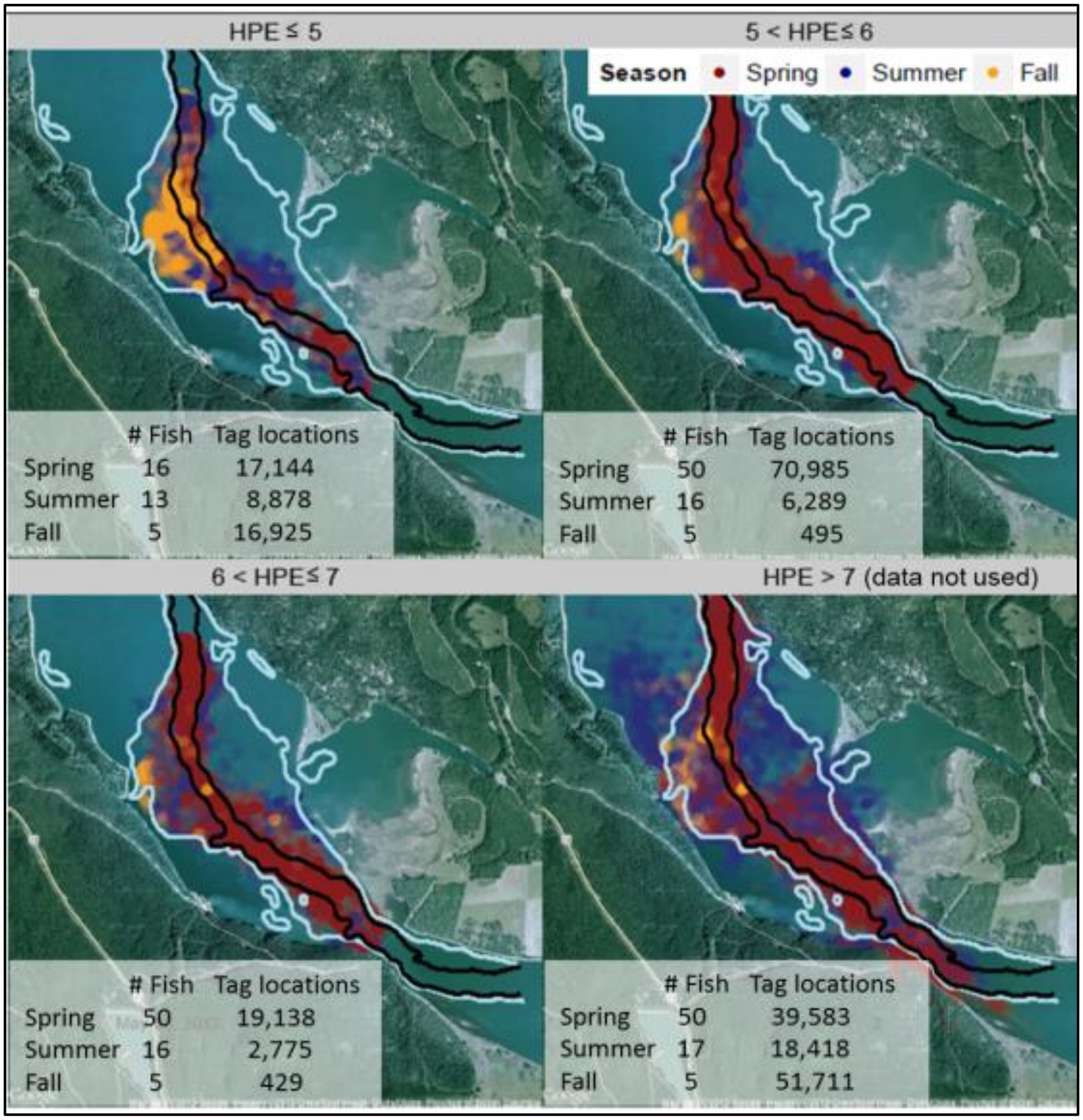

Figure 17: Positions of juvenile White Sturgeon within the VPS array. Panels show the positions included using various horizontal position cut-off (HPE) values (see Section 3.3.4.4). Point colour corresponds to season, and colour strength corresponds to use, with more solid colours representing heavier use. The thalweg is between the black lines, and floodplain is in between the black and light-blue lines. The number of fish and positions in each season within each HPE stratum are provided. Fish positions were plotted as partly transparent, to show differences between areas used rarely (transparent) and often (solid). Maps are based on Google Earth maps, taken Dec-31-2001, when ALR elevation at Nakusp was approximately 423 m. Only positions obtained from the third week post-release and onward are included. Figure from Golder and ONA 2013.

The extent of minimum daily movement (daily distance traveled by individual fish) varied by season and habitat type (Figure 18). In the spring, the majority of the recorded daily movement was less than 2 km, and 11 out of the 13 recorded fish remained in the thalweg. In the summer, the extent of fish movements increased, with daily movements up to 5 km; similar numbers of fish were recorded in the thalweg and the floodplain area, and 12 fish were recorded in the shallows, where they moved up to 2.5 km per day. In the fall, the patterns of movement appeared to be similar to those in the spring, although direct comparison was difficult due to the quickly decreasing sample size over time (only five juveniles were recorded in the thalweg in the fall).

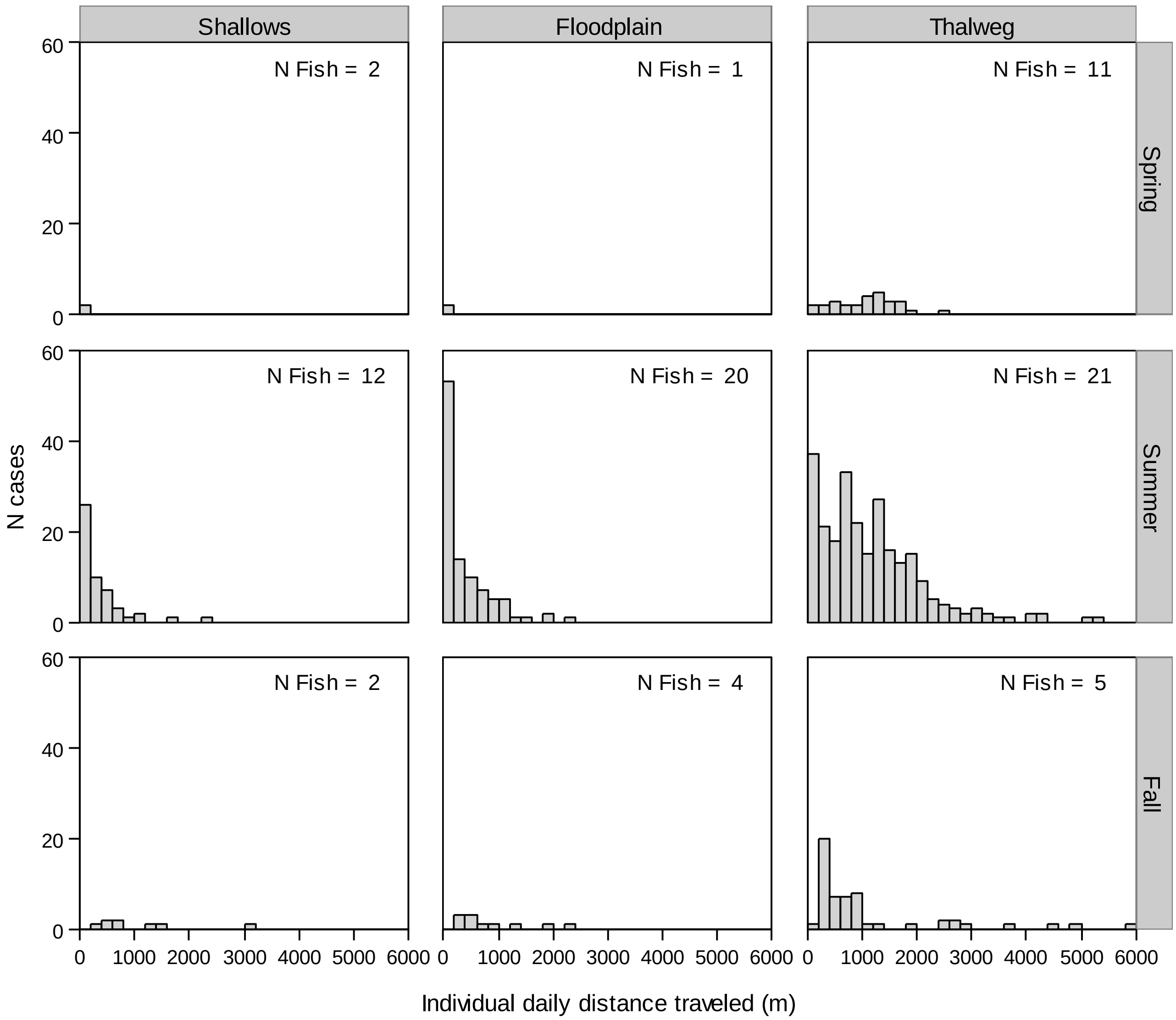

Figure 18: Histogram of minimum daily distances traveled by individual juvenile White Sturgeon, by season and habitat classification. (shallows, floodplain or thalweg). The number of fish (N cases) within each stratum is provided; plots include only positions that were at most 0.5 h apart. Figure from Golder and ONA (2013).

The total movement (minimum distance travelled throughout study period) ranged between 117 m and 50 770 m (median = 13 849 m). The minimum distance travelled by the five White Sturgeon that remained in the VPS area throughout the entire study ranged from 4872 m (WSG25) to 44 816 m (WSG41).

The breakdown of movement by month, rather than season, indicated that the shift between spring and summer behaviours occurred in late June, since early-mid June was classified as spring, when fish exhibited the majority of movement in the thalweg (Figure 18), whereas the total distribution of June movements shows increased use of shallows and thalweg (Figure 19). A decrease in use of non-thalweg habitat occurred in October. In September, juvenile White Sturgeon traveled over 2,000 m in the floodplain and shallow areas compared to October when only two movements, both at or below 500 m, were observed (Figure 18). The shifts in behaviour in late June and (likely) early October suggest that the division by season used in this analysis is appropriate.

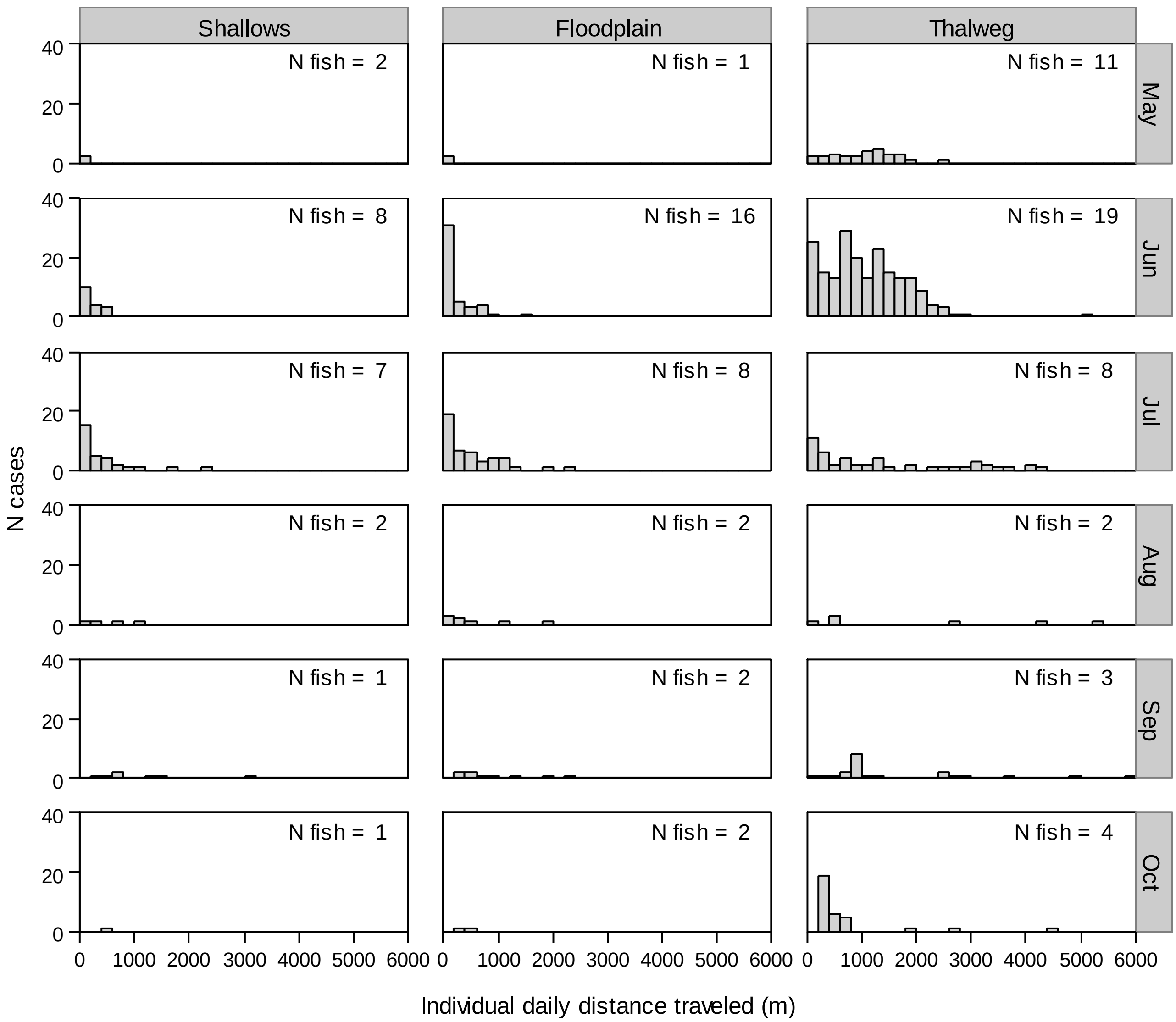

Figure 19: Histograms of daily distances traveled by individual juvenile White Sturgeon, classified by month (May to October) and habitat. The number of fish within each stratum is provided on each panel. Note that the period shown for May only includes May 29 - 31; plots include only positions that were at most 0.5 h apart. Figure from Golder and ONA 2013.

The division of time spent in different habitat classifications by month rather than by season provided similar findings (Figure 19). The shift from thalweg-only positions to use of floodplain and shallow habitats occurred in late June; throughout the summer, all three habitats were used, although juvenile White Sturgeon still spent the longest periods of time in the thalweg. In October, a shift from the floodplains and shallows to the thalweg occurred. Even though the number of fish observed in the array was similar between September and October, the amount of time spent in the shallows and floodplain decreased considerably, while the length of time spent in the thalweg increased (Figure 20). Based on a visual assessment of plotted data, there were no clear relationships between traveled distance or movement speed and REV discharge throughout the study period.

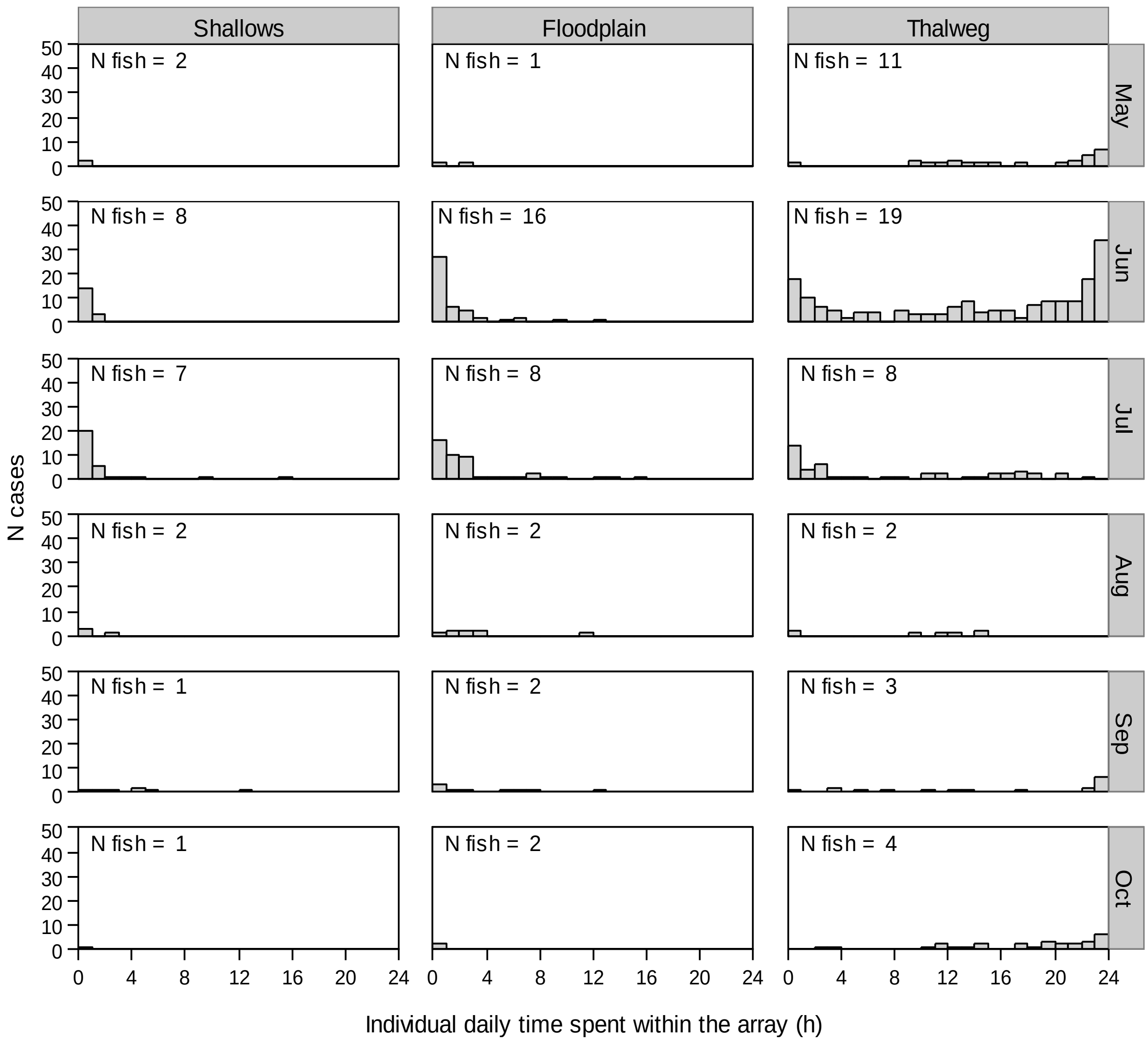

Figure 20: Histograms of daily lengths of time spent by individual juvenile White Sturgeon within each habitat classification in each month. The number of fish recorded within each stratum is provided within the panels. Note that the period shown for May only includes May 29 - 31; plots include only positions that were at most 0.5 h apart). Figure from Golder and ONA 2013.

3.3.11 Akolkolex Bay Use

Juvenile White Sturgeon were found in the Akolkolex Bay area more often in daytime than nighttime. The majority of the fish recorded near the mouth of the Akolkolex were categorized as fish that remained near the array, since the periods between tag locations were less than 0.5 h. A considerably lower number were categorized as fish that left or returned into the array area. The frequency of fish leaving the VPS array by the mouth of the Akolkolex ranged from 80 cases in springtime (52 daytime, 28 nighttime), and 75 cases in the fall (44 daytime, 31 nighttime). The frequency of return of fish into the array in the Akolkolex area was similar to the frequency of fish leaving the array (Golder and ONA 2013). Overall, the results indicate that juvenile White Sturgeon did not foray into the Akolkolex River bay very often, since the majority of fish remained within the VPS array. However, when fish did leave the array and enter the bay area, they were more likely to do so during daytime than nighttime.

3.4 Juvenile Sturgeon Capture Efforts to Estimate Growth and Survival

3.4.1 Capture Effort

Fishing effort increased for both gill nets and setlines over the ten years that fish sampling activities occurred (

Table 15). For the first four years of the study, the fishing effort was focused at locations where acoustic-tagged fish were detected and in areas considered to have a high probability of encountering a Sturgeon (e.g., the channel thalweg, sandy flats) and areas where tagged Sturgeon were previously captured. Both full overnight (n = 52) and short duration night time (n = 64) gill nets were used in 2010. During 2014 to 2018, a GRTS stratified sampling design was introduced to ensure random coverage in the Revelstoke Reach and the upper ALR to determine if juvenile Sturgeon were using other habitat types and locations. Effort was increased in these years with the objective of capturing sufficient numbers of juvenile Sturgeon to determine growth and survival metrics. Even with this increased level of effort, very few juvenile Sturgeon have been captured. Details on within-year gill netting and set lining activity are available in the CLBMON-21 annual report series. Details on 2018 fish sampling effort and results are located in Appendix A.

Table 15: Gill net and setline effort and number of juvenile White Sturgeon captured by each sample method and associated CPUE for the MCR from 2007 to 2018.

Study Year	Gill Net Effort			Set Line Effort			Total WSG Catch	No. Re-captured
	Net Units[a]	No. WSG Captured	CPUE (WSG/Net Unit)	Hook Hours[b]	No. WSG Captured	CPUE (WSG/100 Hook Hours)		
2007	2.1	0	0	0.0	-	-	0	-
2008	22.3	4	0	0.0	-	-	4	-
2009 [c]	36.3	2	0.1	1,085.0	0	0	2	-
2010 [c]	72.5	4	0.06	14,101.0	0	0	4	-
2011	No capture effort undertaken - acoustic tracking range testing							
2012	No capture effort undertaken - 2D acoustic array tracking							
2013	8.5	0	0.000	9,686.3	0	0.000	0	-
2014 [d]	20.7	8	0.289	34,533.8	3	0.009	11	-
2015	49.1	1	0.020	66,534.4	0	0.000	1	-
2016	82.4	0	0.000	96,142.3	8	0.008	8	-
2017	59.1	3	0.051	101,656.6	5	0.005	7	1
2018	25.1	0	0.000	44,379.7	2	0.005	2	-
Total	**353**	**22**	**1**	**368,119**	**18**	**0**	**39**	**1**

a Net units equal area of gill net fish divided by $100m^2$ time the soak time divided by 24 hours
b Hook hours equal the number of hooks fishing on the set line divided by the soak time
c For 2009 and first half of 2010,setline hook sizes used were 12 & 10. All other years, hooks were size 7 & 6.
d Detailed gill net catch effort not found; CPUE based on provided average soak times

During the initial years of the program, sampling was completed in the late summer and early fall. In Years 7 to 10 (2013 to 2016), sites were selected using the GRTS protocol and sampled over a three to four month period starting from the southern end of the study area and moving to the northern end over the study period. Year 10 (2016) also included setline sites in Beaton Arm. In Year 11 (2017), the sampling effort started at sites at the north end of the study area. Greenslide Creek down to Arrowhead were sampled in June to determine if juvenile Sturgeon were using this section of the Revelstoke Reach in late spring. The crew then moved south to the ALR Narrows (RKm 122) and sampled from south to north again, re-sampling the sites from Greenslide Creek to Arrowhead a second time in September (Appendix A). Most (79%) of juvenile White Sturgeon captures in the study area occurred in September (Table 16). In 2018, sites were sampled in the riverine section from Shelter Bay north to Greenslide Creek only.

Table 16: Summary of juvenile White Sturgeon captured by year and by gear type in the MCR from 2007 to 2018. Grayed area indicates occurrence of sampling and the value indicates the number of juvenile White Sturgeon captured that week.

Month	Week	2007	2008	2009		2010		2011*	2012*	2013		2014		2015		2016		2017		2018		Total Sturgeon Captured
		Gill	Gill	Gill	Set	Gill	Set	none	none	Gill	Set	Gill	Set	Gill	Set	Gill	Set	Gill	Set	Gill	Set	
June	Week 1																					0
	Week 2																					0
	Week 3																					
	Week 4																	1				1
July	Week 1																					
	Week 2																					0
	Week 3																					0
	Week 4																					0
August	Week 1																					0
	Week 2																					0
	Week 3											1										1
	Week 4			2										1					3		1	7
September	Week 1																					
	Week 2		2														4	2	2			10
	Week 3		2			1						2	1								1	7
	Week 4											2	1				4					7
October	Week 1					3						1	1									4
	Week 2											2	1									3
	TOTAL	0	4	2	0	4	0			0	0	8	4	1	0	0	8	3	5	0	2	40

* capture sessions were not conducted in 2011 and 2012

3.4.2 Juvenile White Sturgeon Captures

Over the twelve years of the program, no juvenile White Sturgeon were captured upstream of about RKm 214 (downstream of Begbie Creek; Table 17). Depending on the ALR elevation, the highest use area observed for juvenile White Sturgeon starts at approximately this RKm. The reservoir-river interface zone is typically around this area in September. The natural restriction of flow at RKm 201 likely creates its own backwater hydraulic effect in most years, the sediments in this location are fine and water depth of the thalweg is 5 to 10 m deep. The river section with the largest number of captures was from 0.7 km upstream of Blanket Creek (RKm 209.7) to 0.6 km downstream of Greenslide Creek (RKm 205.6). The second highest number of captures was from Tree Island (RKm 201.8) to 0.6 km u/s Walter Hardman Generating Station (RKm 197.6). A map of capture locations can be found in Appendix B.

Table 17: Summary of location of sample sites and numbers of juvenile White Sturgeon captured by gear type and year, and by river section in the MCR during 2007 to 2018.

River Section Description	U/S Rkm	D/S Rkm	2007	2008	2009		2010		2011	2012	2013		2014		2015		2016		2017		2018		Total Sturgeon captured
			Gill	Gill	Gill	Set	Gill	Set	none	none	Gill	Set	Gill	Set	Gill	Set	Gill	Set	Gill	Set	Gill	Set	
1 km d/s Hwy 1 bridge – Big Eddy	228.3	226.1	-	Y	Y	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-			**0**
1 km d/s Wells Cr. – 1 km d/s Hwy 1 bridge	226	220	-	Y	Y	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-			**0**
3.5 km d/s Begbie Creek – 1 km d/s Wells Creek	219.9	214.1	Y	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-			**0**
0.8 km d/s Greenslide Creek – 3.5 km d/s Begbie Creek	214	209.8	Y	Y (3)	Y	-	Y (1)	Y	-	-		-	Y	Y	Y	Y	Y	Y	Y	Y			**4**
0.7 km u/s Blanket Creek – 0.8 km d/s Greenslide Creek	209.7	205.6	Y	Y (1)	Y	Y	Y (2)	Y	-	-		-	Y(2)	Y (2)	Y	Y	Y	Y (4)	Y	Y	Y	Y(1)	**12**
0.6 km u/s Walter Hardman – 0.7 km u/s Blanket Creek	205.5	201.9	Y	Y	Y (1)	Y	Y	Y	-	-		-	Y	Y	Y	Y	Y	Y (2)	Y	Y (1)	Y	Y	**4**
Tree Island – 0.6 km u/s Walter Hardman	201.8	197.6	-	Y	Y	Y	Y	Y	-	-		-	Y(3)	Y	Y	Y	Y	Y (2)	Y	Y(3)	Y	Y	**8**
1 km u/s Crawford Creek – Tree Island	197.5	192.1	-	-	Y (1)	Y	Y	Y	-	-		-	Y(2)	Y (1)	Y	Y	Y	Y	Y(2)*	Y	Y	Y(1)	**7**
1.5 km d/s Wallis Creek – 1 km u/s Crawford Creek	192	186.6	-	Y	Y	Y	Y (1)	Y	-	-		-	Y (1)	Y	Y	Y	Y	Y	Y	Y	Y	Y	**2**
Arrowhead – 1.5 km d/s Wallis Creek	186.5	182.1	-	Y	Y	Y	Y	Y	-	-	Y	-	Y	Y	Y	Y	Y	Y	Y	Y			**0**
Beaton Arm			-	-	Y	-	-	-	-	-		-		Y	-	-	Y	Y	-	-			**0**
Beaton flats	182	179	-	-	Y	Y	Y	Y	-	-	Y	-	Y	Y	Y	Y	Y	Y	Y	Y			**0**
Arrow Lake to Nakusp	179	134	-	-	-	-	-	-	-	-	Y	Y	Y	Y	Y (1)	Y	Y	Y	Y	Y			**1**
Nakusp to u/s of Arrow Lake Narrows	133.9	119	-	-	-	-	-	-	-	-	Y@	Y	Y	Y	Y	Y	Y	Y	Y @ (1)	Y			**1**
Arrow Lake Narrows	118.9	107	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y			**0**
Total Sturgeon Captured			**-**	**4**	**2**	**0**	**4**	**0**	**-**	**-**	**0**	**0**	**8**	**3**	**1**	**0**	**0**	**8**	**3**	**5**	**0**	**2**	**40**

Y gear set during night hours
Y gear set during daylight hours
* includes one sturgeon recaptured in same session
@ gear had both day and overnight sets recorded

3.4.3 Gear Efficacy Testing

Gear efficacy testing was conducted following the 2016 juvenile release at Shelter Bay. Gill nets set in daytime for four hours did not capture any juvenile White Sturgeon. Three unplanned overnight gillnets sets captured 16 juvenile White Sturgeon with no mortalities. This suggested juvenile Sturgeon movements increased during nighttime hours, a conclusion that was supported by movement data collected using the fine-scale array (Section 4.4.1), as well as captures from other unplanned overnight gill net sets. Setlines did not capture any White Sturgeon during the gear efficacy testing. White Sturgeon captured during the gear efficacy testing were not used in other analyses.

3.4.4 Growth and Condition

Length and weight measurements and growth calculations of all Sturgeon captured during Years 1 to12 (2007-2018) are shown in Table 18 for fish captured in the same year of release, and in Table 19 for fish captured at least one year following release.

Almost half (45%) of all juvenile Sturgeon recaptured from 2007 to 2018 had been released the same year of recapture (Table 18). Mean length and weight of juveniles at large for their first summer varied depending on size at release. For fish released at 10 months old, mean length was 32.9 cm ± 5.1 cm and mean weight was 0.22 kg ± 0.1 kg. These fish had a mean of growth of 5 cm FL and 40 g in weight, equating to 19.0% and 20.3% growth on their release length and weight, respectively, over the summer months (mean days at large = 141 days).

For those year classes of fish that had been released after 22 months in the hatchery and captured within the same year of release, mean length was 42.2 cm ± 5.2 cm and mean weight was 0.47 kg ± 0.2 kg. On average, these larger fish grew 7.8 cm FL and 150 g in weight, or 26.7% and 75.1% of body length and weight, respectively, over the summer (mean days at large = 137 days; Table 19).

The smaller fish released at 10 months old averaged 41.6 cm FL and 510 g in weight when recaptured after one winter (1.39 years) at large (Table 19). This was similar to the 41.6 cm FL and 450 g size the larger 22-month-old fish attained in 0.38 years after their first summer at large (Table 18). Larger fish released at 22 months of age grew at a faster rate than 10-month-old fish in their first summer at large (Table 18).

Ten Sturgeon survived for at least two years at large (Table 19) ranging in age from 2.3 to 10.3 years at recapture. The largest fish was 81 cm FL and weighed 3.96 Kg. There have been no captures from the 2010 and 2016 year classes during the entire program.

Table 18: Juvenile White Sturgeon captured the same year after release (<365 days at large) from 2007-2018 in the middle Columbia River.

Capture ID	RKm	Year Class	Years at Large	Days at Large	Release Fork Length (cm)	Release Weight (kg)	Fork Length at Capture (cm)	Weight at Capture (kg)	Relative Weight (%)	Total Growth Length (cm)	Total Growth Weight (kg)	Percent Growth of Release Length (%)	Percent Growth of Release Weight (%)
2008-1	207.4	2007	0.37	134	21.0	0.07	25.1	0.08	88.7	4.1	0.01	19.5	20.9
2008-2	210.2	2007	0.38	137	31.0	0.23	35.6	0.22	79.3	4.6	0.00	14.8	-1.3
2009-1	192.5	2008	0.33	121	32.0	0.25	38.5	0.35	95.6	6.5	0.10	20.3	40.3
2010-3	206.4	2009	0.46	167	22.0	0.08	27.5	0.11	88.0	5.5	0.02	25.0	28.6
2014-6	207.7	2013	0.38	139	28.0	0.20	34.0	0.22	90.3	6.0	0.02	21.4	10.0
2014-7	208.5	2013	0.38	139	28.0	0.20	32.1	0.18	89.0	4.1	-0.02	14.6	-10.0
2014-8	207.5	2013	0.41	148	29.0	0.22	39.0	0.38	100.1	10.0	0.16	34.5	72.7
2014-9	208.0	2013	0.42	154	28.0	0.20	28.0	0.13	99.9	0.0	-0.07	0.0	-35.0
2014-10	206.0	2013	0.42	155	29.0	0.22	39.0	0.33	86.9	10.0	0.11	34.5	50.0
2015-1	177.8	2014	0.32	117	29.0	0.19	30.5	0.24	140.0	1.5	0.05	5.2	26.3
Average of 10 month old fish released			**0.39**	**141.1**	**27.7**	**0.19**	**32.9**	**0.22**	**95.8**	**5.2**	**0.04**	**19.0**	**20.3**
Standard Deviation					**3.5**	**0.1**	**5.1**	**0.1**	**16.8**	**3.2**	**0.1**	**11.1**	**31.1**
2016-1	205.5	2014	0.35	128	27.0	0.15	39.0	0.37	97.2	12.0	0.22	44.4	151.0
2016-4	195.5	2014	0.37	136	41.0	0.55	44.5	0.64	110.8	3.5	0.10	8.5	18.2
2016-5	205.5	2014	0.39	141	42.0	0.54	43.0	0.53	101.8	1.0	-0.01	2.4	-2.0
2016-6	205.5	2014	0.38	140	29.0	0.22	38.0	0.39	111.7	9.0	0.17	31.0	76.5
2016-7	201.5	2014	0.39	141	26.5	0.14	33.0	0.14	63.3	6.5	0.00	24.5	2.2
2016-8	202.6	2014	0.39	141	27.0	0.14	48.0	0.44	59.3	21.0	0.31	77.8	225.9
2017-3	192.8	2015	0.34	124	44.0	0.53	46.0	0.61	94.3	2.0	0.09	4.5	16.2
2018-2	207	2017	0.39	144	38.0	0.31	45.7	0.66	104.2	7.70	0.35	20.3	112.9
Average of 22 month old fish released			**0.37**	**136.9**	**34.3**	**0.32**	**42.2**	**0.47**	**92.8**	**7.8**	**0.15**	**26.7**	**75.1**
Standard Deviation					**8.1**	**0.2**	**5.2**	**0.2**	**21.5**	**7.0**	**0.1**		

Table 19: Juvenile White Sturgeon captured over one year after release (>365 days at large) from 2007-2018 in the middle Columbia River.

Capture ID	RKm	Capture Method	Year Class	Years at Large	Release Fork Length (cm)	Release Weight (kg)	Fork Length at Capture (cm)	Weight at Capture (kg)	Relative Weight (%)	Total Growth Length (cm)	Total Growth Weight (kg)	Growth/Year Length (cm)	Growth/Year Weight (kg)	Percent Growth of Release Length (%)	Percent Growth of Release Weight (%)
2014-1	196.2	gillnet	2012	1.28	30.0	0.22	41.0	0.43	96.38	11.0	0.21	8.6	0.16	36.7	95.5
2014-2	192.0	gillnet	2012	1.36	31.0	0.21	36.0	0.29	98.96	5.0	0.08	3.7	0.06	16.1	38.1
2014-3	195.4	gillnet	2012	1.37	29.0	0.18	44.5	-	-	15.5	-	11.3	-	53.4	-
2014-4	196.0	setline	2012	1.37	30.0	0.20	41.5	0.52	112.08	11.5	0.34	8.4	0.25	38.3	170.0
2014-5	200.1	gillnet	2012	1.37	28.0	0.17	36.8	0.30	95.36	8.8	0.13	6.4	0.09	31.4	76.5
2008-3	210.6	gillnet	2006	1.38	19.0	0.04	26.8	0.11	100.09	7.8	0.07	5.6	0.05	41.1	169.0
2008-4	210.8	gillnet	2006	1.38	18.0	0.04	25.3	0.08	80.02	7.3	0.03	5.3	0.02	40.6	74.4
2010-1	205.9	gillnet	2008	1.40	34.0	0.25	54.0	0.89	81.45	20.0	0.63	14.3	0.45	58.8	249.8
2014-11	199.5	gillnet	2012	1.42	29.0	0.18	46.5	0.63	94.01	17.5	0.45	12.3	0.31	60.3	250.0
2010-2	210.5	gillnet	2008	1.45	25.0	0.12	42.6	0.43	85.56	17.6	0.31	12.1	0.22	70.4	263.0
2010-4	190.7	gillnet	2008	1.46	41.0	0.39	62.3	1.42	82.50	21.3	1.03	14.6	0.70	52.0	263.0
Average of released 10 month old fish at large for 1 year				**1.39**	**28.5**	**0.18**	**41.57**	**0.51**	**92.64**	**13.0**	**0.33**	**9.3**	**0.23**	**45.4**	**164.9**
Standard Deviation					**6.4**	**0.1**	**10.7**	**0.4**	**10.2**	**5.6**	**0.3**	**3.8**	**0.2**		
2009-2	202.2	gillnet	2006	2.31	19.0	0.04	38.0	0.28	79.08	19.0	0.24	8.2	0.10	100.0	645.9
2016-2	207.5	setline	2013	2.36	29.0	0.22	40.5	0.38	88.62	11.5	0.16	4.9	0.07	39.7	73.5
2017-2	199.5	setline	2013	3.34	28.0	0.20	55.0	1.04	90.20	27.0	0.84	8.1	0.25	96.4	417.4
2017-4 [a]	192.8	gillnet	2013	3.34	-	-	55.0	1.04	90.20	-	-	-	-	-	-
2016-3	195.5	setline	2012	3.36	30.0	0.21	54.0	1.01	92.95	24.0	0.81	7.1	0.24	80.0	392.7
2017-5	193.0	setline	2012	4.30	28.0	0.17	54.5	1.43	127.75	26.5	1.26	6.2	0.29	94.6	761.4
2017-8	200.7	setline	2012	4.31	28.0	0.18	46.5	0.62	92.52	18.5	0.44	4.3	0.10	66.1	244.4
2017-7	205.8	setline	2012	4.34	28.0	0.17	46.0	0.78	120.53	18.0	0.61	4.1	0.14	64.3	369.9
2017-1	124.1	gillnet	2011	5.15	23.0	0.09	56.5	1.65	131.19	33.5	1.56	6.5	0.30	145.7	1796.6
2017-6 [b]	199.4	setline	2007	10.30	20.0	0.06	80.4	3.62	92.04	60.4	3.56	5.9	0.35	302.0	6035.6
2018-1	193.2	setline	2009	9.40	20.0	0.08	81.0	3.96	98.3	61.0	3.88	6.5	0.41	305.0	4850.0
Average of released 10 month old fish at large for over 2 years				**4.05**	**24.36**	**0.15**	**48.23**	**1.06**	**92.33**	**23.37**	**0.92**	**6.22**	**0.21**	**103.41**	**1090.24**
Standard Deviation					**4.3**	**0.1**	**14.1**	**1.2**	**17.6**	**17.3**	**1.3**	**1.4**	**0.1**		

a Recapture of 2017-2   b PIT tag reader malfunction, scute removal pattern was used, average 2007 release length and weight used

Relative weights for juvenile White Sturgeon captured in the MCR ranged from 59.3% to 140.0% (Tables 18 and 19; Figure 21). The mean relative weight for all the MCR juvenile Sturgeon captured between 2007 and 2018 is 95.8% +/- 16.7% which is higher than the 85.7% +/- 7.4% reported in the first four years of sampling (Golder 2011). Relative weights after one summer at large for the 10-month-old fish averaged 95.8% +/- 16.8%, but for the 22-month-old fish the average was 92.8% +/- 21.5%. Although based on a much smaller sample size, relative weights of White Sturgeon juveniles in the MCR were higher than the 80 and 85% (depending on the year class) recorded for juvenile White Sturgeon in the Keenleyside Reach (BC Hydro 2017). White Sturgeon recapture in Lake Roosevelt Reach from 2003 to 2009 had relative weights of 104 % ± 24 for fish released in Washington and 107% ± 11% for fish released in BC but captured in Washington (Howell and McLellan 2013).

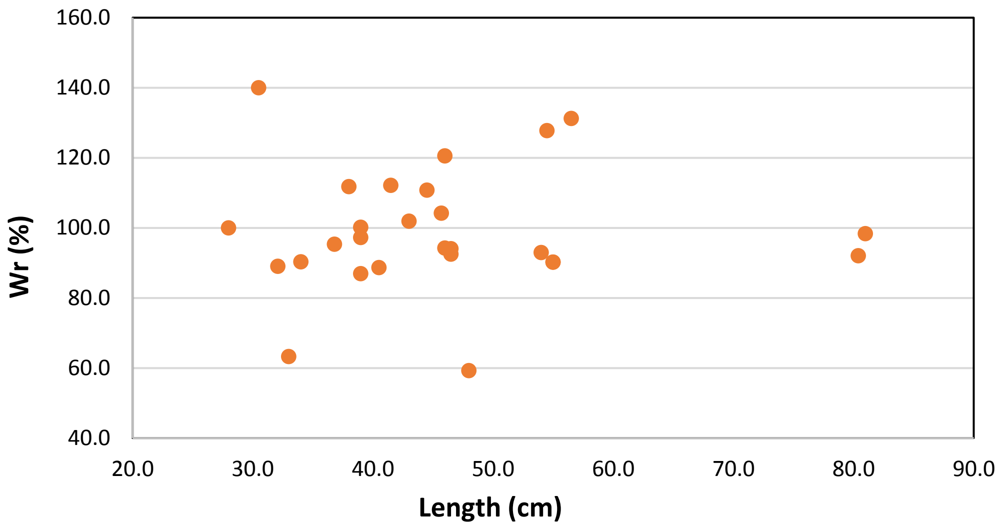

Figure 21: Plot of relative weight (Wr) for juvenile White Sturgeon captured in the MCR from 2007 to 2018 (n = 38).

The MCR juvenile White Sturgeon growth was best described using the equation (Figure 22):

$$W = 0.0213e^{0.07L}$$

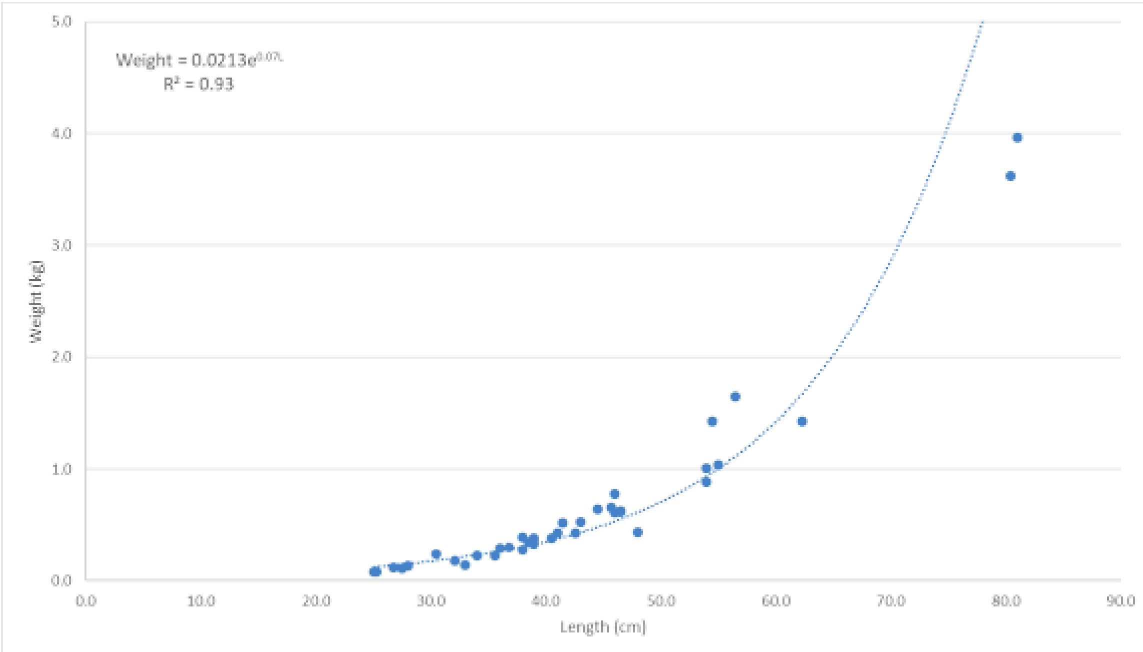

Figure 22: Length-weight regression of juvenile White Sturgeon captured in the MCR between 2007 and 2018 (n= 38).

3.4.5 Survival

Survival has not been estimated due to low recapture rates, which are attributed to a large study area and low capture efficiency. On average for all recaptured fish, total annual growth was 11.9 cm/year in length and 230 g/year in weight. This is comparable the juveniles released and recaptured in the Lower Columbia River juvenile sturgeon program. While most fish in the MCR have been captured in the same year they were released, one of the captured juveniles had survived to Age-10. Additional capture data are required to adequately address the survival question.

3.4.6 Diet

Stomach contents were analyzed to determine juvenile White Sturgeon prey utilization in the MCR. Stomach contents in juvenile White Sturgeon sampled have remained similar between years. Samples from 2010, and 2016-2018 were composed of:

- *Mysis relicta*, an introduced freshwater shrimp species;
- Chironomid midge larvae and,
- Unidentifiable fish (spinal column, flesh, and internal organs; skin and head not present).

White Sturgeon are difficult to gastric lavage for a complete stomach content analysis. Crossman *et.al*. (2016) compared gastric lavage to a complete stomach removal in the lower Columbia River in Canada and observed that on average, gastric lavage obtains 67% of the actual stomach contents. In 2017, the one recaptured juvenile White Sturgeon was gastric lavaged twice over a four-day period. Both samples contained large numbers of mysid shrimp, which indicated active feeding between capture events in September.

The decapod *Mysis relicta* was abundant in some sections of the middle Columbia River study area (Beaton Flats and downstream of Walter Hardman) during underwater video surveys in 2009 (Golder 2010b). Mysids are a key component of the diet of juvenile White Sturgeon downstream of HLK (Golder 2009b) and based on the stomach contents of lavaged fish in 2016-2018, are an important food source to MCR fish as well.

Substrate samples were taken at both sturgeon capture locations as well as representative habitat locations from 2016-2018. Order Diptera (Family Chironomidae) were the primary species identified in the samples (see Appendix D for full dataset). The average density of prey from all samples taken was low, only 0.014 individuals/sample.

3.4.7 Incidental Catch

Bycatch summaries for Years 1 to 11 of the program can be found in the CLBMON-21 annual report series. Data for Year 12 (2018) is provided in Appendix A. Generally, the most common bycatch species captured in gillnets were Mountain Whitefish, Peamouth Chub (*Mylocheilus caurinus*), Bull Trout, and Northern Pikeminnow (*Ptychocheilus oregonensis*).

Setline bycatch consisted mainly of Burbot; in past years, Burbot mortality on setlines was high due to the depth of setline sets and resultant swim bladder ruptures when the lines were retrieved. Fewer mortalities occurred when Burbot were captured in the shallower Revelstoke Reach. To reduce Burbot mortality, setlines in recent years were not set at depths greater than 25 m and were retrieved at a slow rate.

Boat electrofishing was conducted in the upper section of the MCR (from REV down to RKm 224) since 2001 for a different sampling program (CLBMON-16). A total of three White Sturgeon have been observed during that program; one juvenile (October 30, 2009 at Big Eddy; approx. 80 cm total length) and two adults (September 13, 2001 at the spawning area adjacent the Revelstoke golf course and October 25, 2018 near the rock groyne downstream of the City of Revelstoke boat launch) (ONA and Golder 2018; MCR Fish Indexing Database).

3.5 Adult White Sturgeon Movement

3.5.1 Mobile Tracking

Acoustic mobile tracking surveys using a Sonotronics receiver were conducted to monitor spawning movements of acoustic-tagged adult White Sturgeon into the Revelstoke spawning area from below Revelstoke Dam to Big Eddy (2007 MCR juvenile White Sturgeon study, five times between August 16 and September 4 2007; Golder 2008). No adult White Sturgeon were detected during these mobile tacking surveys or by the VR2W array receivers located in the vicinity of the Revelstoke spawning area (Big Eddy and upstream). During 2008, none of the adult tags were detected within the ALR or Revelstoke Reach during the mobile tracking session (Golder 2009).

3.5.2 VR2W Linear Array Detection

Five of the six adult White Sturgeon equipped with Vemco coded pingers were detected by the VR2W array (Golder 2008). The furthest upstream detection of an acoustic-tagged adult in

2007 was at RKm 195.0 in August, but this fish subsequently moved back downstream to RKm 180 (Beaton Flats; Table 20). The acoustic-tagged adults did not display typical spawning movements and as such, the movements detected were likely feeding related. The lack of detections from January to March 2008 was believed to be due to issues with the VR2W stations moving un-expectantly from their original locations in the Beaton Flats area, as well as the general lack of movement exhibited by Sturgeon during the winter months. Most of these fish were captured and tagged in lower ALR in 2002 and 2003. The fish that were not detected during the present study may have moved back downstream to that area.

Table 20: Locations and number acoustic-tagged adult White Sturgeon detected in the MCR, April to December 2007. Table from Golder 2008.

VR2W Station Locations [a] (RKm)	Number of Adult White Sturgeon Detected/Month								
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
195.0					1				
189.0		1	1	1	1	1			
184.0		1	2	1	3	1	2		
Beaton Flats/ Arm Area	3	3	2	1	2	3	4	3	3

[a] See Golder 2008 for receiver locations; the 5 VR2Ws in the Beaton Flats and mouth of Beaton Arm area were combined in this table.

4.0 Discussion

4.1 Management Questions

4.1.1 Where are the habitat locations utilized by juvenile Sturgeon in the Middle Columbia?

To date, the results of CLBMON-21 indicate that habitat preferences of juvenile White Sturgeon vary depending on the time of year and corresponding water levels as there were defined seasonal differences in meso-habitat use and movements within the MCR. In spring, juvenile White Sturgeon were detected almost exclusively in the thalweg. During summer months, juveniles were detected in all three meso-habitat areas (thalweg, floodplain, and shallows), although habitat use was primarily in the thalweg and floodplain habitats during summer. In the fall, the highest usage was again recorded in the thalweg, although limited use of the available floodplain also was observed.

The low use of non-thalweg areas in the fall by juvenile White Sturgeon may suggest other factors such as temperature may affect habitat use in that period. Hrenchuk *et al.* (2017) observed a seasonal spatial shift in distribution by acoustic-tagged Lake Sturgeon juveniles that vacated the reservoir-river transition zone as winter progressed, moving further downstream and occasionally laterally into backwatered shallows, potentially avoiding extreme ice conditions. After ice break-up, most individuals with active tags returned to the upstream end of the reservoir. These results also suggested factors other than habitat suitability can influence Lake Sturgeon juvenile movement and utilization patterns, similar to what we observed in White Sturgeon.

Seasonal variation in the use of thalweg habitats has also been observed in juvenile White Sturgeon in the Lake Roosevelt Reservoir (McLellan *et al*. 2011, Howell and McLellan 2013). In that area, the probability of occupancy in the thalweg, based on models using VPS telemetry data, was high in the spring (86%) and winter (71%) and lower in the summer (33%). Although there are distinct seasonal trends in juvenile White Sturgeon habitat use patterns in the MCR, the small number of fish left in the study area by fall limited the strength of conclusions presented here.

The 2009 movement studies indicated the Beaton Flats area (RKm 180-182) had the highest use by tagged Sturgeon (by total tag days); this may suggest a decrease in available habitat upstream at ALR elevations of 434-436 masl. In contrast, juvenile Sturgeon showed increased use of areas near Mulvehill Creek (RKm 207) during the higher ALR elevations in summer and fall of 2008, when water elevations remained near 439 masl for an extended period. In 2007 and 2010, high use habitat was located between Blanket Creek (RKm 203.1) and Akolkolex River (RKm 200.0) when ALR elevations were approximately 436 to 438 masl. ALR elevations may help to identify high use locations that can direct future capture efforts.

The analysis of fish movement near the Akolkolex River mouth did provide some information on White Sturgeon use of shallow habitat in the MCR outside of the VPS array. Throughout all three seasons, the majority of estimated positions were classified as fish that remained within the VPS array near the Akolkolex River mouth. Use of the Akolkolex bay area was likely to be higher during daytime, since the daytime counts of fish that left the VPS array (presumably into the Akolkolex Bay area) were higher than nighttime counts of similar behaviour throughout all three seasons. Further analysis of the data would be needed to determine if the daytime movement was in the morning, mid-day or evening, as the juveniles potentially move into the shallows to feed.

4.1.2 What are the physical and hydraulic properties of this habitat that define its suitability as juvenile Sturgeon habitat?

Within the MCR, juvenile White Sturgeon appear to prefer calm (<0.5 m/s), deep (averAge-12.2 m) areas with fine substrates (clay and sand). While preference was for the deeper thalweg, use of floodplain and shallow habitats occurred in late June within the positional array. During the summer, all three habitats were used, although juvenile White Sturgeon spent the longest periods of time in the thalweg overall. In October, a shift from using the floodplains and shallows back to mainly using thalweg habitat occurred (Golder and ONA 2013). The timing of these movement patterns generally follows the spring increase and fall decrease in water surface elevations of ALR.

Several studies suggest that the assumption of juvenile White Sturgeon mostly occupying benthic habitats is reasonable. In a study in Lake Roosevelt reservoir, McLellan *et al.* (2011) found that depth measurements of tagged adult and juvenile White Sturgeon typically corresponds to the total depth at the location. Diet analyses of juvenile White Sturgeon in Lake Roosevelt showed a high proportion of benthic invertebrates, which also suggested benthic orientation of juveniles (Parsley *et al*. 2010). However, juvenile White Sturgeon in the ALR are known to forage on mysid shrimp that are known to make vertical diel migrations within the water column. The diel movement analysis conducted in 2009 (Golder 2010) indicates that juveniles are more active at night, which may indicate: 1) juvenile White Sturgeon may feed higher in the water column when foraging on mysids or 2) that mysid shrimp could have moved into shallower benthic areas during nighttime hours.

4.1.3 What is the quantity of available habitat meeting these conditions in the Middle Columbia?

All sturgeon captures have been between RKm 190.7-210.8 with the exception of one individual captured near Nakusp at RKm 124.1 and another captured near Shelter Bay at RKm 177.8. The dispersal analysis identified that juvenile White Sturgeon made rapid movements downstream to the riverine section of the river (RKm 207-212) following release at upstream sites (Big Eddy (RKm 228.3) and Moses Creek (RKm 233)) and upstream following release at Arrowhead (RKm 184). Available habitat in the preferred riverine section varies throughout the year depending on water elevations as a result of operations at REV and backwatering from the ALR. However, this section of river is generally deeper, has finer substrates and has available eddy habitat (slower water) compared to the upstream habitat (RKm 212 and up). The program to date has not quantified the availability of meso-habitat that is preferred by juvenile White Sturgeon in the MCR but given that juveniles are selecting calm (<0.5 m/s), deep (>10 m) areas with fine substrates within the MCR it is not expected that habitat is limiting.

4.1.4 How do hydraulic conditions resulting from dam and reservoir operations relate to habitat suitability for juvenile White Sturgeon in the mid-Columbia?

In general, habitat use for juvenile White Sturgeon is concentrated in the thalweg (< 10 m) of the riverine section in the MCR (RKm 190-212). Throughout the year, dam and reservoir operations alter the amount and type of habitat available in this section of river; when water elevations are high, the thalweg becomes deeper and other habitats including floodplain and shallows become available. When water elevations are low, the thalweg is the primary habitat available for juvenile Sturgeon. Juvenile Sturgeon movements and habitat use generally coincide with habitat availability; they increase as water levels increase, and become more concentrated during low water elevations.

Studies on juvenile White Sturgeon in other areas of the upper Columbia River Basin have shown a preference for depths greater than 10 m (Golder 2009, McLellan *et al.* 2011), which suggests depth is a factor in influencing seasonal habitat selection by juveniles in the MCR; additional habitat data would be required to test this hypothesis. The only observed trend in fish behaviour related to reservoir elevation (i.e., emptying, filling, full, or stable) was that distances traveled in the shallow habitat type were greater during the emptying phase of ALR than during the stable or filling reservoir phases (Golder and ONA 2013).

Juvenile Sturgeon also utilize the downstream section of the Revelstoke Reach study area in the vicinity of the river-reservoir transition zone where the effects of REV discharge fluctuations are attenuated by ALR elevations. Similarly, White Sturgeon juveniles are found at the transition zone in higher numbers in Lake Roosevelt Reach during sampling (Howell and McLellan 2013). Further work that summarizes key locations preferred by juvenile White

Sturgeon at different ALR elevations could help understand how to target habitat restoration projects in the future.

4.1.5 What are the survival rates of juvenile White Sturgeon in the Middle Columbia River?

Recapture rates of juveniles in the MCR have been low in all years of sampling (total captures = 40 of 61, 964 released fish; 2007-2018) with one of these fish recaptured in the same session, and none recaptured in subsequent sampling events. The lack of recaptures precludes estimating survival at this point.

Juvenile White Sturgeon CPUEs in the MCR ranged from 0.0 to 0.29 fish/net-hour for gill nets and 0.0 to 0.01 fish/hook-hour for setlines. These rates are very low compared to capture rates recorded for similar juvenile White Sturgeon monitoring programs elsewhere in the Columbia drainage. For example, efforts in the Columbia River below HLK monitoring program using setlines have recorded CPUE values of 0.84 and 1.12 in 2011 and 2012, respectively (BC Hydro 2015). In the Kootenay River and Kootenay Lake in 2015, one-hour daytime gill net sets produced a CPUE of 3.1 Sturgeon/net-hour (Stephenson and Evans 2016).

However, mean relative weight for all the MCR juvenile Sturgeon captured to date was 95.8% +/- 16.7%, which may indicate that growth is near normal for those individuals that were captured. This finding does not support a hypothesis that food resources are limiting growth and survival of juvenile Sturgeon in the MCR. The mean relative weights of juvenile Sturgeon in the Lower Columbia River (W_r = 80%; riverine habitat) were lower than in the MCR (W_r - 95%; reservoir habitat) (BC Hydro 2018). This is similar to findings reported by Millar and Beckman (1992) who reported that juveniles in the reservoir upstream of Bonneville Dam had higher mean growth for the first 7 year classes than juveniles captured in the riverine section below Bonneville Dam.

This program has not yet recaptured any of the juveniles released in the 2010 and 2016 brood years. The program has also not captured any fish that were released as either fed or unfed larval releases. Therefore, the effects of releasing early life-stage or larger juveniles on growth and survival cannot be determined at this time.

In order to address juvenile survival in this program, a substantial increase in captures and/or positive identification of mortality sources is needed. Increasing sampling effort and targeting areas of previous capture in all seasons should help to capture more juvenile White Sturgeon. Efforts to reduce bycatch mortality, especially for Bull Trout, have limited the duration of sets and sampling locations depending on time of year (see Golder 2010). However, setlines can be easily used in the riverine section between Shelter Bay and Greenslide Creek and are less likely to capture Bull Trout.

4.1.6 Can modifications be made to the operations of Revelstoke Dam and/or Arrow Lakes Reservoir to protect or enhance juvenile White Sturgeon habitat?

Based on captures and movements of acoustic-tagged individuals, juvenile White Sturgeon prefer the section of the MCR between Greenslide Creek (RKm 212) to Shelter Bay (RKm 177) and downstream. During very low ALR levels, this section of river can experience substantial daily fluctuations in water levels and velocities resulting from REV operations. However, based on the results to date in this program, juvenile White Sturgeon that reside in this area utilize deep, slow moving habitats associated with the thalweg of the Columbia River. These deep-water habitats are less prone to effects of REV discharge variations. Therefore, at present, there are no specific modifications to REV operations that could protect or enhance juvenile habitats.

Juvenile White Sturgeon in the Snake River downstream of Hells Canyon Dam in Idaho were studied for changes in oxygen respiration and movement over the range of discharge flows (Geist *et al*. 2005). The overall trend was for swim speeds and oxygen consumption to be less during lower, stable flows, but the differences between seasons were related to temperature and daylight factors. Higher flows from load shaping were shown to restrict juvenile Sturgeon movement but did not increase oxygen consumption, likely due to morphological and behaviour adaptions of living in high flow habitats

Macro-habitats with similar depth, velocity, and substrate characteristics as that selected by the 39 juvenile White Sturgeon captured during this study program, is abundant in the ALR throughout the year and in the MCR during periods of high ALR levels. The results of the first four years of study (2007 to 2010) indicate that juvenile White Sturgeon rarely use the upstream portion of the study area, where Revelstoke Dam and ALR operations have the greatest influence on habitat availability and suitability. Depths and velocities in the river/reservoir transition zone, where many juveniles have been detected, would be influenced to a lesser degree, however this influence would decrease with increased downstream distance from Revelstoke Dam.

5.0 Recommendations

The following recommendations are a result of the technical forum held for the Mid-Columbia White Sturgeon Management Plan in December 2018 (BC Hydro 2018b)::

- The primary uncertainty remaining in this program is survival of fish released from the conservation aquaculture program. As well, larger sizes at release have been tested over the course of the program, with the largest release sizes only occurring in recent years. Additional sampling is required to assess survival and evaluate the effects of size at release on survival.
    - Direct capture remains critical with a focus on Beaton Flats and pilot sampling of deeper habitats (>30m). Consultation required with FLNRO on bycatch mortalities
    - Consider telemetry if efforts to directly capture juveniles are not successful. Could provide additional distribution data for older larger sturgeon if encountered and the recommendation is that application of telemetry in the future is focused on recaptured fish that have survived for several years following release.
    - Review eDNA experimental work done by UVic/UBC/BC Hydro to determine if it could be a tool in the future to help guide direct sampling efforts.
- Further assess food availability and distribution for juvenile White Sturgeon in all habitat types and throughout the year in the riverine section of the MCR.
    - Deploy rock baskets to sample invertebrate prey types and density
    - Conduct plankton tows to determine seasonal and diel plankton (primarily mysids) availability

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Appendix A - 2018 Sample Data

Gillnets

Set #	Site	Location			Weather	Set Date	Set Time	Water Temp (°C)	Pull Date	Pull Time	Water Temp (°C) Day 2	Water Depth (m)		Orientation to Flow	Location in water Column	Soak Time (Time)	Soak Time (Hours)	Total # WSG	Gillnet Area (m^2)	Gillnet Hours	Comments
		Zone	Easting	Northing								Min	Max								
1	G2018-01	11	421198	5637464	cloudy / smoky	18-08-28	11:15	10.2	18-08-28	14:05	11.2	4.8	6.5	perpendicular	lower	2:50	2.83	0	217.4	615.2	234
2	G2018-81	11	421264	4536990	cloudy	18-08-28	11:25	10.2	18-08-28	14:20	11.4	4.5	11.1	perpendicular	lower	2:55	2.92	0	89.2	260.5	96
3	G2018-05	11	421339	5636868	cloudy	18-08-28	11:40	10.2	18-08-28	14:12	11.2	3.3	5.0	perpendicular	lower	2:32	2.53	0	186.9	472.9	average area
4	G2018-49	11	421445	5636436	cloudy	18-08-28	11:48	10.9	18-08-28	14:28	11.1	7.9	8.8	perpendicular	lower	2:40	2.66	0	239.7	637.6	255
5	G2018-17	11	421495	5636096	cloudy	18-08-28	11:58	11.4	18-08-28	14:41	11.0	7.3	8.8	perpendicular	lower	2:43	2.72	0	239.7	652.0	258
6	G2018-93	11	421614	5635903	cloud sun smoke	18-08-29	10:48	11.2	18-08-29	14:30	10.9	7.4	7.6	perpendicular	lower	3:42	3.7	0	239.7	886.9	258
7	G2018-69	11	421219	5635008	cloud sun smoke	18-08-29	11:13	11.2	18-08-29	14:50	10.8	9.0	11.3	perpendicular	lower	3:37	3.7	0	217.4	804.4	235
8	G2018-21	11	421149	5634807	cloud sun smoke	18-08-29	11:20	11.3	18-08-29	15:27	10.7	11.3	12.5	perpendicular	lower	4:07	4.12	0	135.2	557.0	slayer
9	G2018-37	11	421472	5634416	cloud sun smoke	18-08-29	11:33	11.3	18-08-29	15:45	10.5	7.4	8.3	parallel	lower	4:12	4.2	0	278.7	1170.5	300
10	G2018-89	11	422128	5634194	overcast	18-08-30	11:05	10.3	18-08-30	14:27	10.4	9.5	12.1	parallel	lower	3:22	3.36	0	278.7	936.4	300
11	G2018-53	11	422010	5633929	overcast	18-08-30	11:15	10.4	18-08-30	14:36	10.6	3.7	4.5	perpendicular	lower	3:21	3.35	0	59.5	199.3	64
12	G2018-85	11	422567	5633885	overcast	18-08-30	11:25	10.2	18-08-30	14:50	10.4	6.0	7.2	perpendicular	lower	3:25	3.42	0	217.4	743.5	235
13	G2018-09	11	422937	5633480	overcast	18-08-30	11:34	10.3	18-08-30	15:00	10.5	8.9	15.6	perpendicular	lower	3:26	3.43	0	135.2	463.7	96
14	G2018-13	11	423118	5633389	overcast	18-08-30	11:43	10.2	18-08-30	15:09	10.5	3.8	13.8	perpendicular	lower	3:26	3.43	0	239.7	822.2	258
15	G2018-57	11	423865	5633142	cloudy	18-08-31	11:28	10.7	18-08-31	15:15	10.7	4.6	5.9	perpendicular	lower	3:47	3.78	0	239.7	906.1	258
16	G2018-25	11	424158	5633240	cloudy	18-08-31	11:35	10.8	18-08-31	15:54	10.8	3.0	5.4	perpendicular	lower	4:19	4.32	0	135.2	584.1	96
17	G2018-73	11	424177	5632343	cloudy	18-08-31	11:45	10.6	18-08-31	15:34	10.7	4.3	5.7	parallel	lower	3:49	3.82	0	217.4	830.5	235
18	G2018-41	11	424576	5632549	sun cloud smoke	18-09-01	10:11	10.8	18-09-01	13:17	11.1	7.0	8.1	perpendicular	lower	3:06	3.1	0	217.4	673.9	235
19	G2018-45	11	424893	5632522	sun cloud smoke	18-09-01	10:18	10.7	18-09-01	13:34	11.2	11.5	11.9	perpendicular	lower	3:16	3.26	0	135.2	440.8	96
20	G2018-29	11	424758	5632121	sun cloud smoke	18-09-01	10:26	10.8	18-09-01	13:35	11.2	5.4	6.1	perpendicular	lower	3:09	3.15	0	239.7	755.1	258
21	G2018-65	11	424919	5631808	sun cloud smoke	18-09-01	10:32	10.8	18-09-01	13:43	11.0	4.5	4.5	perpendicular	lower	3:11	3.18	0	59.5	189.2	64
22	G2018-20	11	425079	5631602	sun cloud smoke	18-09-01	10:43	10.9	18-09-01	13:56	10.9	5.0	13.8	perpendicular	lower	3:13	3.22	0	239.7	771.8	258
23	G2018-36	11	424927	5631227	sunny	18-09-02	10:17	11.1	18-09-02	13:00	11.4	4.9	7.9	perpendicular	lower	2:43	2.72	0	278.7	758.1	300
24	G2018-96	11	425059	5631087	sunny	18-09-02	10:22	11.1	18-09-02	13:05	11.5	7.5	9.8	perpendicular	lower	2:43	2.72	0	59.5	161.8	64
25	G2018-52	11	424987	5630728	sunny	18-09-02	10:31	11.1	18-09-02	13:15	11.5	9.5	11.8	parallel	lower	2:44	2.73	0	217.4	593.5	235
26	G2018-72	11	425799	5630276	sunny	18-09-02	10:40	11.0	18-09-02	13:22	11.4	9.7	10.1	perpendicular	lower	2:42	2.7	0	135.2	365.0	96
27	G2018-08	11	426147	5630103	sunny	18-09-02	10:50	11.1	18-09-02	13:35	11.3	8.3	11.0	perpendicular	lower	2:45	2.75	0	217.4	597.9	235
28	G2018-24	11	426190	5629943	sun cloudy wind	18-09-03	10:15	11.1	18-09-03	13:24	12.1	7.8	10.8	perpendicular	lower	3:09	3.15	0	217.4	684.8	235
29	G2018-84	11	426429	5629711	sun cloudy wind	18-09-03	10:24	11.1	18-09-03	13:35	11.6	13.8	14.2	perpendicular	lower	3:11	3.18	0	135.2	429.9	96
30	G2018-60	11	426640	5629528	sun cloudy wind	18-09-03	10:31	11.7	18-09-03	13:54	12.8	16.1	13.2	perpendicular	lower	3:23	3.38	0	278.7	942.0	300
31	G2018-64	11	426806	5629098	sun cloudy wind	18-09-03	10:36	11.1	18-09-03	14:00	11.7	13.8	14.6	oblique	lower	3:24	3.4	0	59.5	202.3	64
32	G2018-100	11	427059	5629362	cloudy	18-09-03	10:43	11.1	18-09-03	14:10	12.0	6.3	10.4	perpendicular	lower	3:27	3.45	0	239.7	827.0	258
33	G2018-48	11	427425	5629238	cloudy	18-09-11	10:44	10.9	18-09-11	14:22	11.1	7.1	7.5	parallel	lower	3:38	3.63	0	59.5	216.0	64

Set #	Site	Location			Weather	Set Date	Set Time	Water Temp (°C)	Pull Date	Pull Time	Water Temp (°C) Day 2	Water Depth (m)		Orientation to Flow	Location in water Column	Soak Time (Time)	Soak Time (Hours)	Total # WSG	Gillnet Area (m²)	Gillnet Hours	Comments
		Zone	Easting	Northing								Min	Max								
34	G2018-80	11	427663	5629209	cloud	18-09-11	10:53	11.0	18-09-11	14:40	11.2	9.3	11.2	parallel	lower	3:47	3.78	0	278.7	1053.5	300
35	G2018-16	11	427829	5628617	cloudy	18-09-11	11:05	11.1	18-09-11	14:47	11.1	4.1	4.2	perpendicular	lower	3:42	3.7	0	135.2	500.2	96
36	G2018-68	11	428151	5628840	cloudy	18-09-11	11:15	11.0	18-09-11	14:58	11.1	5.1	5.4	parallel	lower	3:43	3.72	0	217.4	808.7	235
37	G2018-32	11	428032	5629412	cloudy	18-09-11	11:26	11.1	18-09-13	13:10	12.0	7.6	9.0	parallel	lower	1:44	1.73	0	239.7	414.7	258
38	G2018-76	11	428740	5628140	cloudy	18-09-12	10:18	10.7	18-09-12	14:24	11.2	7.5	8.1	perpendicular	lower	4:06	4.1	0	239.7	982.8	258
39	G2018-44	11	428836	5462804	cloudy	18-09-12	10:25	11.3	18-09-12	14:30	11.2	7.6	8.0	perpendicular	lower	4:05	4.08	0	135.2	551.6	96
40	G2018-40	11	429026	5627446	cloudy	18-09-12	10:35	10.8	18-09-12	14:46	11.3	14.0	15.1	perpendicular	lower	4:11	4.18	0	278.7	1165.0	300
41	G2018-56	11	428926	5627275	cloudy	18-09-12	10:41	10.8	18-09-12	14:55	11.6	13.2	13.7	perpendicular	lower	4:14	4.23	0	59.5	251.7	64
42	G2018-88	11	429128	5626882	cloudy	18-09-12	10:51	10.8	18-09-12	15:06	11.5	8.9	11.1	perpendicular	lower	4:15	4.25	0	217.4	924.0	235
43	G2018-12	11	429292	5626613	rainy	18-09-13	10:36	10.7	18-09-13	14:02	10.7	6.9	10.9		lower	3:26	3.43	0	217.4	745.7	235
44	G2018-92	11	429364	5626103	rainy	18-09-13	10:44	10.7	18-09-13	14:10	10.8	11.8	12.3		lower	3:26	3.43	0	59.5	204.1	64
45	G2018-28	11	429087	5626082	rainy	18-09-13	10:51	10.8	18-09-13	14:20	10.9	3.8	4.3	parallel	lower	3:29	3.48	0	239.7	834.2	258
46	G2018-27	11	429185	5625692	rainy	18-09-13	10:58	10.7	18-09-13	14:32	10.9	9.8	10.6	parallel	lower	3:34	3.56	0	135.2	481.3	96
47	G2018-75	11	429617	5625092	rainy	18-09-13	11:08	10.7	18-09-13	14:44	10.8	3.3	5.3	perpendicular	lower	3:36	3.6	0	278.7	1003.3	300
48	G2018-43	11	429165	5625029	cloudy	18-09-14	10:23	10.3	18-09-14	13:55	10.2	3.3	9.5	perpendicular	lower	3:32	3.53	0	278.7	983.8	300
49	G2018-15	11	429071	5624699	cloudy	18-09-14	10:36	10.3	18-09-14	14:04	10.2	1.4	1.6	parallel	lower	3:28	3.46	0	135.2	467.8	96
50	G2018-59	11	429497	5624374	cloudy	18-09-14	10:45	10.4	18-09-14	14:20	10.4	2.9	3.7	oblique	lower	3:35	3.58	0	217.4	778.3	235
51	G2018-67	11	429924	5624380	cloudy	18-09-14	10:55	10.4	18-09-14	14:37	10.4	4.3	4.7	perpendicular	lower	3:42	3.7	0	59.5	220.2	64
52	G2018-31	11	429747	5623868	cloudy	18-09-14	11:05	10.4	18-09-14	14:52	10.3	4.3	5.6	oblique	lower	3:47	3.78	0	239.7	906.1	258
53	G2018-47	11	429765	5623499	cloudy	18-09-15	10:05	10.1	18-09-15	13:35	10.2	4.9	8.0	perpendicular	lower	3:30	3.5	0	239.7	839.0	258
54	G2018-79	11	429889	5623244	cloudy	18-09-15	10:12	10.1	18-09-15	14:00	10.2	10.6	11.0	perpendicular	lower	3:48	3.8	0	59.5	226.1	64
55	G2018-99	11	429941	5622691	cloudy	18-09-15	10:22	10.1	18-09-15	14:14	10.2	14.2	15.0	parallel	lower	3:52	3.86	0	217.4	839.2	235
56	G2018-63	11	430262	5622662	cloudy	18-09-15	10:30	10.1	18-09-15	14:20	10.3	8.4	10.7	perpendicular	lower	3:50	3.83	0	135.2	517.8	96
57	G2018-04	11	430633	5622398	cloudy	18-09-16	9:47	11.0	18-09-16	14:02	11.3	3.7	8.0	perpendicular	lower	4:15	4.25	0	217.4	924.0	235
58	G2018-55	11	430683	5622034	cloudy	18-09-16	9:52	11.1	18-09-16	14:15	11.4	14.3	15.6	perpendicular	lower	4:23	4.38	0	135.2	592.2	96
59	G2018-39	11	430609	5621669	cloudy	18-09-16	10:00	11.1	18-09-16	14:25	11.4	11.2	12.3	perpendicular	lower	4:25	4.42	0	239.7	1059.5	258
60	G2018-70	11	430950	5621080	cloudy	18-09-16	10:07	11.1	18-09-16	14:32	11.4	11.5	12.0		lower	4:25	4.42	0	59.5	263.0	64
61	G2018-87	11	431518	5620744	overcast	18-09-17	10:20	11.3	18-09-17	13:35	11.5	4.4	13.2	perpendicular	lower	3:15	3.25	0	239.7	779.0	258
62	G2018-11	11	431256	5620389	overcast	18-09-17	10:30	11.4	18-09-17	13:47	11.5	5.2	12.7	oblique	lower	3:17	3.28	0	278.7	914.1	300
63	G2018-91	11	431676	5620585	overcast	18-09-17	10:40	11.5	18-09-17	13:58	11.5	3.8	4.2	perpendicular	lower	3:18	3.3	0	217.4	717.4	235
64	G2018-07	11	431446	5620175	overcast	18-09-17	10:47	11.4	18-09-17	14:06	11.4	13.2	13.5	perpendicular	lower	3:19	3.32	0	59.5	197.5	64
65	G2018-23	11	431378	5619807	overcast	18-09-24	11:05	10.5	18-09-24	14:35	12.3	2.4	4.5	perpendicular	lower	3:30	3.5	0	186.9	654.2	average area
66	G2018-83	11	431550	5618452	overcast	18-09-24	11:21	10.5	18-09-24	14:47	11.5	1.9	3.2	perpendicular	lower	3:26	3.43	0	186.9	641.1	average area

Set #	Site	Location			Weather	Set Date	Set Time	Water Temp (°C)	Pull Date	Pull Time	Water Temp (°C) Day 2	Water Depth (m)		Orientation to Flow	Location in water Column	Soak Time (Time)	Soak Time (Hours)	Total # WSG	Gillnet Area (m²)	Gillnet Hours	Comments
		Zone	Easting	Northing								Min	Max								
67	G2018-35	11	431387	5619109	overcast	18-09-24	11:32	10.6	18-09-24	14:47	10.3	3.1	3.5	perpendicular	lower	3:15	3.25	0	59.5	193.4	64
68	G2018-51	11	431559	5618824	overcast	18-09-25	9:49	10.5	18-09-25	13:49	10.6	4.1	4.4	perpendicular	lower	4:00	4	0	186.9	747.6	average area
69	G2018-95	11	431600	5618565	overcast	18-09-25	10:01	10.5	18-09-25	14:06	10.7	5.2	6.0	perpendicular	lower	4:05	4.08	0	186.9	762.6	average area
70	G2018-77	11	431630	5618253	overcast	18-09-25	10:10	10.6	18-09-25	14:18	10.8	6.7	7.0	perpendicular	lower	4:08	4.13	0	186.9	771.9	average area
71	G2018-97	11	431729	5617581	overcast	18-09-25	10:17	10.7	18-09-25	14:31	10.8	6.6	7.1	perpendicular	lower	4:14	4.23	0	59.5	251.7	64
72	G2018-61	11	431912	5617324	overcast	18-09-26	9:45	10.5	18-08-26	14:00	10.7	5.6	9.3	perpendicular	lower	4:15	4.25	0	186.9	794.3	average area
73	G2018-02	11	432019	5617038	overcast	18-09-26	9:53	10.4	18-08-26	14:17	10.5	5.9	6.1	perpendicular	lower	4:24	4.4	0	217.4	956.6	234
74	G2018-18	11	432051	5616936	overcast	18-09-26	10:01	10.4	18-09-26	14:28	10.5	5.9	7.1	perpendicular	lower	4:27	4.45	0	186.9	831.7	average area
75	G2018-94	11	432225	5616726	overcast	18-09-26	10:12	10.3	18-09-26	14:35	10.4	9.7	10.0	perpendicular	lower	4:23	4.38	0	59.5	260.6	64
76	G2018-34	11	432508	5616368	overcast	18-09-27	10:07	10.3	18-09-27	13:52	11.0	7.1	9.3	perpendicular	lower	3:45	3.75	0	186.9	700.9	average area
77	G2018-38	11	432617	5616214	overcast	18-09-27	10:17	10.3	18-09-27	14:02	10.7	7.4	9.2	perpendicular	lower	3:45	3.75	0	186.9	700.9	average area
78	G2018-70	11	432659	5616011	overcast	18-09-27	10:24	10.3	18-09-27	14:15	11.0	7.8	9.9	perpendicular	lower	3:51	3.85	0	186.9	719.6	average area
79	G2018-22	11	433108	5615647	overcast	18-09-27	10:31	11.1	18-09-27	14:25	11.1	8.8	9.4	perpendicular	lower	3:54	3.9	0	59.5	232.1	little blue
80	G2018-86	11	433596	5614936	sunny/windy	18-09-28	10:02	11.7	18-09-28	14:02	12.3	10.5	10.7		lower	4:00	4	0	239.7	958.8	258
81	G2018-54	11	433619	5614769	sunny/windy	18-09-28	10:20	11.6	18-09-28	14:13	12.4	10.4	10.5	parallel	lower	3:53	3.88	0	186.9	725.2	average area
82	G2018-90	11	433795	4634654	sunny/windy	18-09-28	10:28	11.4	18-09-28	14:26	10.5	10.2	10.5	parallel	lower	3:58	3.96	0	186.9	740.1	average area
83	G2018-10	11	433872	5614330	sunny/windy	18-09-28	10:35	11.3	18-08-28	14:38	12.5	10.3	11	parallel	lower	4:03	4.05	0	186.9	756.9	average area
84	G2018-03	11	434026	5614370	overcast/windy	18-09-29	9:46	11.5	18-09-29	13:15	11.8	10.6	11.7	parallel	lower	3:29	3.48	0	186.9	650.4	average area
85	G2018-19	11	434220	5614104	overcast/windy	18-09-29	9:53	11.4	18-09-29	13:31	11.5	10.1	11.5	parallel	lower	3:38	3.63	0	239.7	870.1	258
86	G2018-98	11	434483	5613702	overcast/windy	18-09-29	10:01	11.1	18-09-29	13:41	11.3	10.9	11.4	oblique	lower	3:40	3.63	0	186.9	678.4	average area
87	G2018-30	11	434525	5613421	overcast/windy	18-09-29	10:08	11.1	18-09-29	13:51	11.3	11.1	13.1	parallel	lower	3:43	3.72	0	186.9	695.3	average area
88	G2018-62	11	434609	5613393	overcast/windy	18-09-29	10:15	11.0	18-09-29	13:59	11.2	14.4	14.6	parallel	lower	3:44	3.73	0	186.9	697.1	average area
89	G2018-46	11	434708	5612749	overcast/windy	18-09-30	10:08	10.3	18-09-30	14:03	10.8	20.0	30.0	parallel	lower	3:55	3.92	0	186.9	732.6	average area
90	G2018-78	11	434483	5612346	overcast/windy	18-09-30	10:21	10.8	18-09-30	14:20	10.9	24.1	35.5	parallel	lower	3:59	3.98	0	186.9	743.9	average area
91	G2018-42	11	434258	5612124	overcast/windy	18-09-30	10:28	10.9	18-09-30	14:52	10.9	18.6	21.2	parallel	lower	4:24	4.4	0	239.7	1054.7	258
92	G2018-26	11	434249	5611943	overcast/windy	18-09-30	10:32	10.9	18-09-30	14:38	10.9	20.1	20.4	parallel	lower	4:06	4.1	0	59.5	244.0	little blue

Setlines

Set #	Site	Location			Weather	Set Date	Set Time	Water Temp (°C)	Pull Date	Pull Time	Water Temp (°C) Day 2	Water Depth (m)		Orientation to Flow	Location in water column	Soak Time (Hours)		# Hooks	Effort (# Hooks * Soak Time)	Retrieved Hooks*				WSG Catch
		Zone	Easting	Northing								Min	Max							B	BL	F	L	
1	S2018-85	11	420865	5634572	sun cloud smoke	18-08-27	14:06	10.8	18-08-30	12:19	11.8	9.1	13.0	perpendicular	lower	22:13	22.22	20	479		20			0
2	S2018-17	11	421266	5637650	cloudy	18-08-28	13:16	11.1	18-08-29	11:47	11.1	5.1	5.3	perpendicular	lower	22:31	22.52	20	479	4	16			0
3	S2018-01	11	421186	5637565	cloudy	18-08-28	13:25	11.1	18-08-29	11:56	11.0	5.3	5.8		lower	22:31	22.52	20	479	1	19			0
4	S2018-05	11	421324	5636766	cloudy	18-08-28	13:33	11	18-08-29	12:08	11.0	4.7	10.0	perpendicular	lower	22:35	22.58	20	479		20			0
5	S2018-81	11	421413	5636574	cloudy	18-08-28	13:43	11.1	18-08-29	12:16	10.8	6.7	8.6	perpendicular	lower	22:33	22.55	20	479		20			0
6	S2018-93	11	421554	5635804	cloudy	18-08-28	13:54	11.6	18-08-29	12:26	10.7	7.6	7.9	perpendicular	lower	22:32	22.53	20	479	1	19			0
7	S2018-49	11	421709	5635601	sun cloud smoke	18-08-29	13:35	11.2	18-08-30	12:00	11.7	8.5	9.5	oblique	lower	22:25	22.42	20	479	6	14			0
8	S2018-33	11	421434	5635443	sun cloud smoke	18-08-29	13:46	10.7	18-08-30	12:06	11.4	10.0	10.3	parallel	lower	22:20	22.33	20	479		20			0
9	S2018-53	11	420997	5634969	sun cloud smoke	18-08-29	13:55	10.6	18-08-30	12:12	11.8	9.1	10.0	oblique	lower	22:17	22.28	20	479		20			0
10	S2018-37	11	421816	5634299	sun cloud smoke	18-08-29	14:15		18-08-30	12:31	10.4	13.6	16.1	parallel	lower	22:16	22.26	20	479		20			0
11	S2018-69	11	422135	5634048	overcast	18-08-30	13:29	10.5	18-08-31	11:57	10.4	12.7	13.3	parallel	lower	22:28	22.46	20	479		20			0
12	S2018-09	11	422611	5633663	overcast	18-08-30	13:41	10.5	18-08-31	12:10	10.5	14.6	16.3	parallel	lower	22:29	22.43	20	479		19	1		1
13	S2018-25	11	422754	5633455	overcast	18-08-30	13:50	10.8	18-08-31	12:55	10.6	11.6	16.0	parallel	lower	23:05	23.08	20	479	1	17		1	0
14	S2018-89	11	422942	5633257	overcast	18-08-30	14:03	10.8	18-08-31	13:04	10.8	6.0	8.2	parallel	lower	23:01	23.02	20	479		20			0
15	S2018-21	11	423321	5633111	overcast	18-08-30	14:12	10.7	18-08-31	13:14	10.7	15.3	16.0	parallel	lower	23:02	23.03	20	479		20			0
16	S2018-73	11	423016	5633368	cloudy	18-08-31	14:24	10.6	18-09-01	10:54	11.1	14.6	15.3	parallel	lower	20:30	20.5	20	477	19	1			0
17	S2018-41	11	423438	5633105	cloudy	18-08-31	14:33	10.6	18-09-01	11:02	11.1	11.0	12.1	parallel	lower	20:29	20.48	20	477		20			0
18	S2018-57	11	423885	5632799	cloudy	18-08-31	14:48	10.6	18-09-01	11:12	11.2	13.3	14.7	parallel	lower	20:24	20.4	19	453		19			0
19	S2018-57	11	423885	5632799	cloudy	18-08-31	14:48	10.6	18-09-01	11:12	11.2	13.3	14.7	parallel	lower	20:24	20.4	19	453		19			0
20	S2018-13	11	424171	5632563	cloudy	18-08-31	14:57	10.5	18-09-01	11:21	11.1	11.1	12.0	parallel	lower	20:24	20.4	20	477		20			0
21	S2018-65	11	424424	5632343	cloudy	18-08-31	15:06	10.6	18-09-01	11:30	11.1	9.5	15.8		lower	20:24	20.4	17	405		17			0
22	S2018-65	11	424866	5632798	sun cloud smoke	18-09-01	12:22	10.9	18-09-02	10:59	11.4	12.0	14.5	oblique	lower	22:37	22.62	20	479	3	17			0
23	S2018-29	11	425024	5632550	sun cloud smoke	18-09-01	12:33	11.2	18-09-02	11:07	11.5	10.9	12.0	oblique	lower	22:34	22.56	20	479		20			0
24	S2018-45	11	425102	5632324	sun cloud smoke	18-09-01	12:41	10.7	18-09-02	11:16	11.6	16.4	19.0	parallel	lower	22:35	22.58	20	479		20			0
25	S2018-30	11	425249	5631757	sun cloud smoke	18-09-01	12:51	11.3	18-09-02	11:34	11.3	13.6	13.9	perpendicular	lower	22:43	22.72	20	479		20			0
26	S2018-42	11	425437	5631563	sun cloud smoke	18-09-01	13:02	10.9	18-09-02	11:32	11.4	6.8	7.4	oblique	lower	22:30	22.5	20	479	16	3		1	0
27	S2018-26	11	425210	5630899	sunny	18-09-02	12:18	11.5	18-09-13	10:56	11.7	13.2	13.8	parallel	lower	22:38	22.63	20	479	20				0
28	S2018-90	11	425338	5630504	sunny	18-09-02	12:25	11.3	18-09-03	11:06	11.5	12.2	13.1	parallel	lower	22:41	22.68	20	479	18	2			0
29	S2018-10	11	425510	5630230	sunny	18-09-02	12:33	11.5	18-09-03	11:18	11.3	13.3	14.1	parallel	lower	22:45	22.75	20	479	7	13			0
30	S2018-74	11	425676	5630159	sunny	18-09-02	12:41	11.6	18-09-03	11:30	11.6	12.0	13.7	parallel	lower	22:49	22.81	20	479	16	4			0
31	S2018-58	11	426003	5629887	sunny	18-09-02	12:50	11.5	18-09-03	11:40	12.0	13.9	15.0	parallel	lower	22:50	22.83	20	479	18	2			0
32	S2018-14	11	426412	5629625	cloudy	18-09-11	13:33	11.4	18-09-12	11:05	11.0	11.8	12.3	parallel	lower	21:32	21.53	10	239		10			0
33	S2018-66	11	426416	5629360	SUN/CLOUD	18-09-11	13:47	11.1	19-09-12	11:25	10.9	7.2	7.5	oblique	lower	21:38	21.63	20	478		20			0
34	S2018-97	11	426657	5629515	SUN/CLOUD	18-09-11	13:59	11.0	18-09-12	11:35	10.9	6.5	17.4	oblique	lower	21:36	21.6	20	478		20			0

Set #	Site	Location			Weather	Set Date	Set Time	Water Temp (°C)	Pull Date	Pull Time	Water Temp (°C) Day 2	Water Depth (m)		Orientation to Flow	Location in water column	Soak Time (Hours)		# Hooks	Effort (# Hooks * Soak Time)	Retrieved Hooks*				WSG Catch
		Zone	Easting	Northing								Min	Max							B	BL	F	L	
35	S2018-02	11	427110	5629312	SUN/CLOUD	18-09-11	14:08	10.7	18-09-12	11:50	10.6	6.5	7.6	oblique	lower	21:42	21.7	20	478		20			0
36	S2018-18	11	427230	5629123	SUN/CLOUD	18-09-11	14:17	10.9	18-09-12	11:58	10.7	12.5	13.2	parallel	lower	21:41	21.68	20	478		20			0
37	S2018-94	11	427379	5629080	cloudy	18-09-12	13:32	10.9	18-09-13	11:24	10.5	12.7	13.6	parallel	lower	21:52	21.42	20	478		20			0
38	S2018-61	11	428190	5629134	cloudy	18-09-12	13:42	11.1	18-09-13	11:31	10.7	12.1	13.0	parallel	lower	21:49	21.82	20	478		20			0
39	S2018-77	11	427737	5628894	cloudy	18-09-12	13:53	11.3	18-09-13	11:51	10.5	9.0	12.2		lower	21:58	21.96	20	478		20			0
40	S2018-34	11	428012	5628717	cloudy	18-09-12	14:01	11.0	18-09-13	12:03	10.7	10.2	11.0	perpendicular	lower	22:02	22.03	20	478		20			0
41	S2018-86	11	428418	5628451	cloudy	18-09-12	14:10	11.1	18-09-13	12:15	10.6	10.1	12.6	parallel	lower	22:05	22.08	20	478		20			0
42	S2018-77A	11	428501	5629127	rain/cloud	18-09-13	13:12	10.8	18-09-14	11:27	10.2	13.3	21.2	perpendicular	lower	22:15	22.25	20	479		20			0
43	S2018-34A	11	428850	5628766	rain	18-09-13	13:22	10.7	18-09-14	11:43	10.2	16.5	19.4	parallel	lower	22:21	22.35	20	479		20			0
44	S2018-86A	11	428809	5628172	rain	18-09-13	13:31	10.7	18-09-14	11:52	10.1	6.2	10.1	oblique	lower	22:21	22.35	20	479		20			0
45	S2018-54	11	428926	5627859	rain	18-09-13	13:39	10.7	18-09-14	12:05	10.3	9.3	11.5	oblique	lower	22:26	22.43	20	479		20			0
46	S2018-22	11	428881	5627256	rain	18-09-13	13:47	10.7	18-09-14	12:15	10.2	12.8	13.3		lower	22:28	22.46	20	479		20			0
47	S2018-38	11	428998	5626964	overcast	18-09-14	13:05	10.3	18-09-15	10:45	10.1	12.6	13.3	oblique	lower	21:40	21.68	20	478		20			0
48	S2018-70	11	428903	5626910	overcast	18-09-14	13:11	10.3	18-09-15	10:55	10.1	14.6	15.3	parallel	lower	21:44	21.73	20	478		20			0
49	S2018-06	11	429221	5626367	overcast	18-09-14	13:20	10.3	18-09-15	11:03	10.1	11.0	13.0	perpendicular	lower	21:43	21.72	20	478		20			0
50	S2018-19	11	429203	5624899	partly cloudy	18-09-14	13:20	10.3	18-09-15	11:50	11.6	14.1	15.4	parallel	lower	22:30	22.5	20	479		20			0
51	S2018-50	11	429324	5625983	overcast	18-09-14	13:28	10.3	18-09-15	11:14	10.1	14.3	15.0	perpendicular	lower	21:46	21.76	20	478		20			0
52	S2018-82	11	429399	5625803	overcast	18-09-14	13:35	10.3	18-09-15	11:24	10.1	14.2	16.5	oblique	lower	21:49	21.82	20	478		20			0
53	S2018-03	11	429373	5625448	partly cloudy	18-09-15	13:05	10.2	18-09-16	11:04	11.5	15.7	17.0	parallel	lower	21:59	21.98	20	478		19		1	0
54	S2018-98	11	429352	5625159	partly cloudy	18-09-15	13:11	10.2	18-09-16	11:20	11.4	14.5	15.7	parallel	lower	22:09	22.15	20	478		20			1
55	S2018-95	11	429255	5624673	partly cloudy	18-09-15	13:29	10.3	18-09-16	11:58	11.5	14.1	15.0	parallel	lower	22:29	22.48	20	479		20			0
56	S2018-35	11	429250	5624298	partly cloudy	18-09-15	13:35	10.3	18-09-16	12:10	11.4	15.0	15.9	parallel	lower	22:35	22.58	20	479		20			0
57	S2018-78	11	429406	5624286	partly cloudy	18-09-15	13:45	10.2	18-09-16	12:16	11.5	12.7	13.3	parallel	lower	22:31	22.52	20	479		20			0
58	S2018-62	11	429353	5624008	cloudy	18-09-16	13:10	11.3	18-09-17	11:00	11.3	12.7	13.8	oblique	lower	21:50	21.83	20	478		20			0
59	S2018-51	11	429570	5623413	cloudy	18-09-16	13:20	11.2	18-09-17	11:09	11.4	12.8	15.0	oblique	lower	21:49	21.82	20	478		20			0
60	S2018-07	11	429892	5623093	cloudy	18-09-16	13:27	11.3	18-09-17	11:16	11.4	11.4	12.2	oblique	lower	21:49	21.82	20	478		20			0
61	S2018-83	11	429820	5622822	cloudy	18-09-16	13:35	11.3	18-09-17	11:24	11.4	13.0	13.7	oblique	lower	21:49	21.82	20	478		20			0
62	S2018-23	11	430150	5622635	cloudy	18-09-16	13:42	11.3	18-09-17	11:35	11.4	14.8	15.4	oblique	lower	21:53	21.88	20	478		20			0
63	S2018-71	11	430310	5622182	cloudy	18-09-16	13:48	11.3	18-09-17	11:45	11.4	10.0	14.1	oblique	lower	21:57	21.95	18	430		18			0
64	S2018-51B	11	429421	5625527	overcast	18-09-17	12:31	11.4	18-09-18	9:44	11.0	3.8	16.2	perpendicular	lower	21:13	21.22	20	478		18	1	1	0
65	S2018-52B	11	429324	5625707	overcast	18-09-17	12:37	11.4	18-09-18	9:53	11.0	13.6	14.2	parallel	lower	21:16	21.26	20	478		20			0
66	S2018-53B	11	429240	5626103	overcast	18-09-17	12:44	11.4	18-09-18	10:06	11.0	15.0	16.2	perpendicular	lower	21:22	21.36	20	478	1	19			0
67	S2018-54B	11	428968	5626553	overcast	18-09-17	12:53	11.5	18-09-18	10:20	11.0	14.4	16.5	perpendicular	lower	21:27	21.45	20	478		12			0
68	S2018-55B	11	429128	5626996	overcast	18-09-17	13:00	11.5	18-09-18	13:30	11.0	10.9	12.3	perpendicular	lower	0:30	24.5	20	20		20			0

Set #	Site	Location			Weather	Set Date	Set Time	Water Temp (°C)	Pull Date	Pull Time	Water Temp (°C) Day 2	Water Depth (m)		Orientation to Flow	Location in water column	Soak Time (Hours)		# Hooks	Effort (# Hooks * Soak Time)	Retrieved Hooks*				WSG Catch
		Zone	Easting	Northing								Min	Max							B	BL	F	L	
69	S2018-56B	11	427365	5629032	overcast	18-09-17	13:10	11.2	18-09-18	10:45	11.0	13.5	15.0	perpendicular	lower	21:35	21.58	17	406		17			0
70	S2018-46	11	430578	5622069	overcast	18-09-24	13:22	11	18-09-25	10:29	10.2	14.9	15.2	perpendicular	lower	21:07	21.11	20	478		20			0
71	S2018-67	11	430633	5621924	overcast	18-09-24	13:36	10.9	18-09-25	10:46	10.2	14.0	15.1	perpendicular	lower	21:10	21.16	20	478	2	18			0
72	S2018-59	11	431041	5621639	overcast	18-09-24	13:48	11.0	18-09-25	11:01	10.2	8.9	16.0		lower	21:13	21.21	20	478		20			0
73	S2018-15	11	431067	5621249	overcast	18-09-24	13:58	10.7	18-09-25	12:24	10.3	13.8	15.1	perpendicular	lower	22:26	22.43	20	479	1	19			0
74	S2018-75	11	430999	5621117	overcast	18-09-24	14:12	10.8	18-09-25	11:24	10.4	11.8	13.2	perpendicular	lower	21:12	21.2	18	430		18	0		0
75	S2018-43	11	431399	5620203	overcast	18-09-25	12:50	10.7	18-09-26	10:22	10.2	5.0	12.7	perpendicular	lower	21:32	21.53	20	478		20			0
76	S2018-27	11	431402	5620438	overcast	18-09-25	12:59	10.6	18-09-26	10:38	10.3	12.3	14.2	perpendicular	lower	21:39	21.65	20	478		20			0
77	S2018-91	11	431463	5619908	overcast	18-09-25	13:15	10.7	18-09-26	10:55	10.3	1.2	7.2	oblique	lower	21:40	21.16	20	478		20			0
78	S2018-11	11	431499	5619614	overcast	18-09-25	13:23	11.9	18-09-26	10:59	10.8	1.2	2.5	perpendicular	lower	21:36	21.6	20	478		20			0
79	S2018-87	11	431542	5619555	overcast	18-09-25	13:33	11.2	18-09-26	11:10	10.3	1.0	2.2	perpendicular	lower	21:37	21.62	20	478		20			0
80	S2018-55	11	431598	5618752	overcast	18-09-25	13:43	10.6	18-09-26	11:29		3.2	4.6	perpendicular	lower	21:46	21.76	20	478		20			0
81	S2018-39	11	431534	5618408	overcast	18-09-26	12:45	10.7	18-09-27	10:38	10.5	6.1	6.9	perpendicular	lower	21:53	21.88	20	478		20			0
82	S2018-76	11	431360	5617782	overcast	18-09-26	12:59	11.1	18-09-27	10:49	10.6	6.9	7.3	perpendicular	lower	21:50	21.83	20	478		20			0
83	S2018-16	11	431719	5617752	overcast	18-09-26	13:11	10.8	18-09-27	10:55	10.7	5.9	6.5	perpendicular	lower	21:44	21.73	20	478	20				0
84	S2018-60	11	431746	5617530	overcast	18-09-26	13:23	10.7	18-09-27	11:03	10.6	5.6	8.9	perpendicular	lower	21:40	21.66	20	478		19		1	0
85	S2018-68	11	432075	5616886	overcast	18-09-26	13:34	10.5	18-09-27	11:23	10.7	6.4	9.8	perpendicular	lower	21:49	21.82	20	478		20			0
86	S2018-48	11	432156	5616670	overcast	18-09-26	13:41	10.7	18-09-27	11:33	10.7	6.7	9.8	perpendicular	lower	21:52	21.86	20	478		20			
87	S2018-72	11	432405	5616506	overcast	18-09-27	12:52	10.5	18-09-28	10:49	10.3	7.2	9.1	perpendicular	lower	21:57	21.95	20	478		20			0
88	S2018-32	11	432404	5616322	overcast	18-09-27	13:04	10.5	18-09-28	11:00	10.4	6.7	9.4	perpendicular	lower	21:56	21.93	20	478		19		1	0
89	S2018-40	11	432698	5616140	overcast	18-09-27	13:15	10.8	18-09-28	11:29	10.5	7.2	7.7	perpendicular	lower	22:14	22.23	20	479	1	15		4	0
90	S2018-56B	11	432841	5616127	overcast	18-09-27	13:24	10.7	18-09-28	11:40	11.8	7.9	8.2	perpendicular	lower	22:16	22.26	20	479	1	19			0
91	S2018-88	11	433181	5615466	overcast	18-09-27	13:35	11.7	18-09-28	11:50	11.3	8.9	10.5	perpendicular	lower	22:15	22.25	20	479	1	19			0
92	S2018-44	11	433567	5615184	overcast	18-09-27	13:45	12.3	18-09-28	12:05	11.2	9.9	10.5	perpendicular	lower	22:20	22.33	20	479	13	7			0
93	S2018-12	11	433489	5615015	sun/wind	18-09-28	13:10	12.2	18-09-27	10:30	11.2	10.0	10.6		lower	21:20	21.33	20	478		20			0
94	S2018-28	11	433615	5614828	sun/wind	18-09-28	13:20	12.2	18-09-29	10:36	11.5	10.5	10.7		lower	21:16	21.26	20	478		19		1	0
95	S2018-92	11	433781	5614467	sun/wind	18-09-28	13:30	12.1	18-09-29	10:45	11.5	10.4	11.0		lower	21:15	21.25	20	478		19		1	0
96	S2018-47	11	434116	5614091	sun/wind	18-09-28	13:39	12.1	18-09-29	10:57	11.5	11.8	12.6	perpendicular	lower	21:18	21.3	20	478	1	19			0
97	S2018-31	11	434280	5613872	sun/wind	18-09-28	13:50	12.0	18-09-26	11:06	11.3	10.9	11.1		lower	21:16	21.26	20	478		20			0
98	S2018-24	11	434570	5613782	breezy	18-09-29	12:14	11.2	18-09-30	10:46	10.1	10.8	11.5	perpendicular	lower	22:32	22.53	20	479		19		1	0
99	S2018-84	11	434695	5613418	brezy	18-09-29	12:23	11.2	18-09-30	11:03	10.1	14.0	15.2	oblique	lower	22:40	22.66	20	479		20			0
100	S2018-08	11	434499	5613255	breezy	18-09-29	12:31	11.3	18-09-30	11:20	10.1	14.1	15.2	oblique	lower	22:49	22.82	20	479		20			0
101	S2018-52	11	434555	5612714	breezy	18-09-29	12:49	11.2	18-09-30	11:41	10.4	28.7	30.4	perpendicular	lower	22:52	22.86	20	479		20			0
102	S2018-99	11	434457	5612490	breezy	18-09-29	13:04	11.2	18-09-30	11:51	10.4	17.6	33.7		lower	22:47	22.78	20	479		20			0

Bycatch – Gillnets

Date	Site	Set	Spp.	Life Stage	Quantity	Live	Dead	Mortality Rate %	Fork Length
18-08-28	5	G2018-17	KO	A	1	1			233
18-08-28	1	G2018-01	MW	A	1	1			293
18-08-29	7	G2018-69	KO	A	7	7			220, 235, 230, 225, 237, 275, 235, 240
18-08-29	8	G2018-21	MW	A	1	1			210
18-08-29	9	G2018-37	KO	A	3	3			225, 250, 230
18-08-30	14	G2018-13	KO	A	1	1			off net
18-08-30	12	G2018-85	KO	A	1	1			225
18-08-30	13	G2018-09	MW	A	1	1			235
18-08-30	10	G2018-89	KO	A	2	2			230, 234
18-08-31	16	G2018-25	KO	A	1	1			250
18-09-01	22	G2018-20	KO	A	5	5			225, 225, 215, 230, 220
18-09-01	22	G2018-20	MW	A	2	2			270, 260
18-09-01	20	G2018-29	KO	A	5	5			220, 230, 225, 220, 230
18-09-02	27	G2018-08	KO	A	12	11	1	8.33	230, 227, 231, 237, 224, 241, 224, 235, 224, 245, 216, 219
18-09-02	23	G2018-36	MW	A	2	2			264, 265
18-09-03	32	G2018-100	KO	A	10	10			224, 236, 224, 206, 230, 226, 224, 220, 250, 226
18-09-03	32	G2018-100	MW	A	2	2			274, 254
18-09-03	32	G2018-100	KO	A	6	6			224, 221, 225, 225, 245, 220
18-09-03	32	G2018-100	BT	A	1	1			escaped
18-09-03	30	G2018-60	BT	A	2	2			472, 404
18-09-03	30	G2018-60	KO	A	6	5	1	16.67	225, 220, 232, 228, 234, 224
18-09-03	30	G2018-60	BB	A	1	1			670
18-09-03	30	G2018-60	PCC	A	1	1			-
18-09-03	31	G2018-64	NSC	J	1	1			242
18-09-03	29	G2018-84	NSC	J	1	1			233
18-09-03	29	G2018-84	PCC	A	1	1			212
18-09-03	29	G2018-84	KO	A	1	1			226
18-09-03	28	G2018-24	KO	A	6	6			226, 234, 230, 226, 225, 215
18-09-11	37	G2018-32	KO	A	1	1			220
18-09-11	37	G2018-32	PCC	A	1	1			220

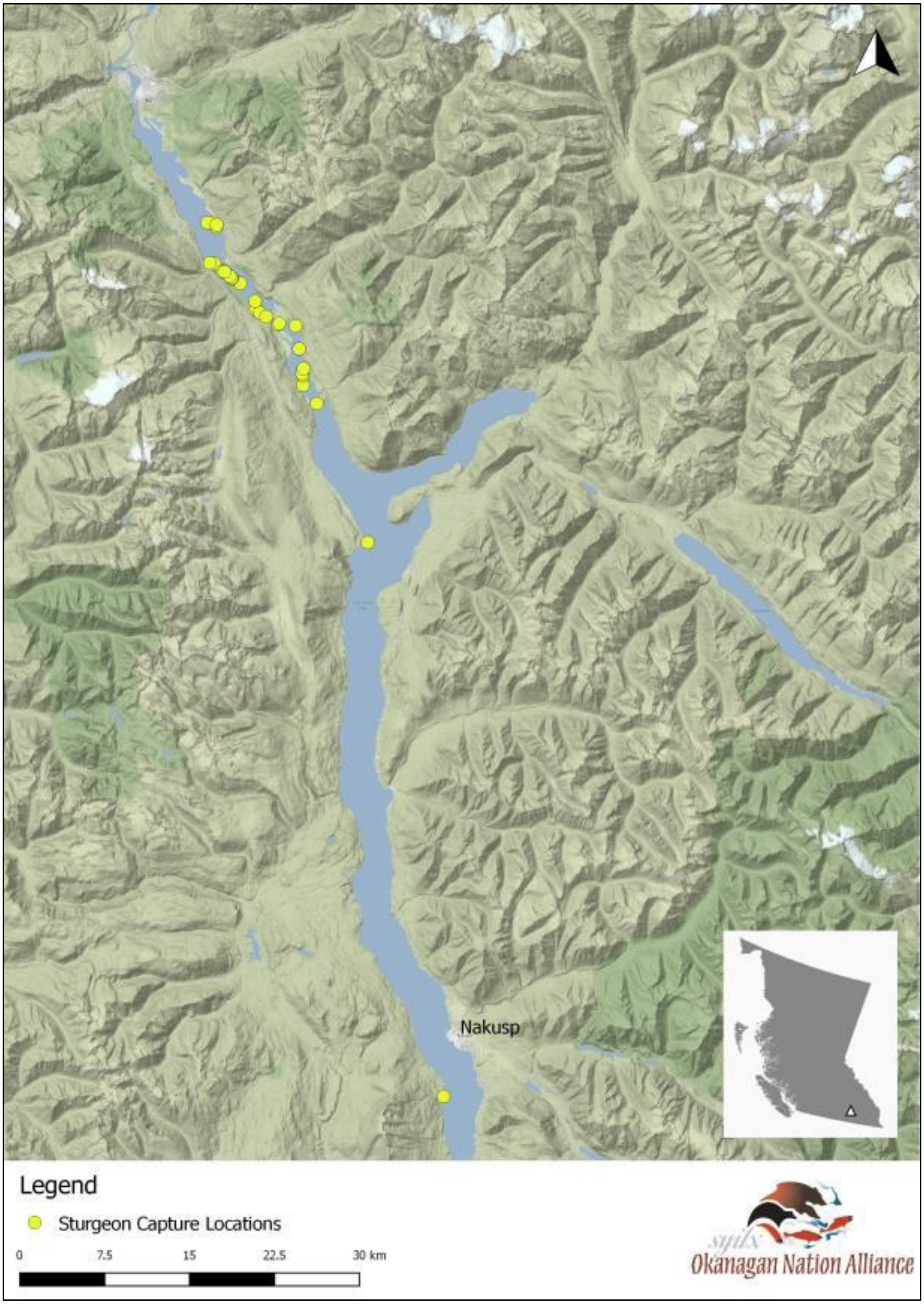
18-09-11	34	G2018-80	NSC	A	4	4			280, 270, 235, 225
18-09-11	34	G2018-80	BT	A	1	1			off net
18-09-11	34	G2018-80	KO	A	4	4			230, 220, 220, 225
18-09-11	34	G2018-80	MW	A	1	1			290
18-09-11	36	G2018-68	MW	A	1	1			280
18-09-12	42	G2018-88	MW	A	1	1			280
18-09-12	42	G2018-88	PCC	A	2	2			220, 235
18-09-12	41	G2018-56	PCC	A	5	4	1	20.00	205, 249, 220, 229, 235
18-09-12	41	G2018-56	MW	A	1	1			escaped net
18-09-12	40	G2018-40	BT	A	1	1			303
18-09-12	40	G2018-40	LW	A	1		1	100.00	281
18-09-12	40	G2018-40	PCC	A	9	9			229, 245, 255, 264, 234, 239, 236, 233, 243
18-09-12	40	G2018-40	MW	A	1		1	100.00	266
18-09-12	40	G2018-40	KO	A	1	1			229
18-09-12	39	G2018-44	MW	A	1	1			245
18-09-12	38	G2018-76	BT	A	1	1			278
18-09-13	43	G2018-12	LW	A	1	1			275
18-09-13	43	G2018-12	NSC	A	1	1			280
18-09-13	43	G2018-12	KO	A	2	2			226, 2224
18-09-13	43	G2018-12	MW	A	1	1			255
18-09-13	44	G2018-92	PCC	A	4	4			220, 230, 228, 226
18-09-13	47	G2018-75	MW	A	1	1			240
18-09-13	47	G2018-75	KO	A	2	2			226. 220
18-09-14	50	G2018-59	MW	A	1	1			225
18-09-14	50	G2018-59	Carp	A	1		1	100.00	4 lbs 7 oz, 475 mm (stomach empty)
18-09-14	48	G2018-43	KO	A	2	2			225, 235
18-09-14	48	G2018-43	MW	A	1	1			226
18-09-15	55	G2018-99	PCC	A	1	1			226
18-09-15	55	G2018-99	LW	A	1	1			255
18-09-15	53	G2018-47	MW	A	1	1			289
18-09-16	57	G2018-04	MW	A	2		2	100.00	244, 270
18-09-16	57	G2018-04	PCC	A	1	1			out of net
18-09-16	58	G2018-55	PCC	A	7	3	4	57.14	225, 226, 212, 220, 215, 235, 238, 202

18-09-16	58	G2018-55	KO	A	1	1			230
18-09-16	59	G2018-39	KO	A	2	2			230, 235
18-09-16	59	G2018-39	MW	A	5	2	3	60.00	260, 280, 258, 254
18-09-16	59	G2018-39	LW	A	1		1	100.00	265
18-09-17	61	G2018-87	BT	A	1	1			320
18-09-17	62	G2018-11	MW	A	1	1			270
18-09-17	62	G2018-11	KO	A	2	2			230, 225
18-09-17	63	G2018-91	MW	A	1	1			230
18-09-24	66	G2018-83	LW	A	1	1			280
18-09-24	65	G2018-23	KO	A	3	3			225, 210, 225
18-09-25	28	G2018-24	MW	A	1	1			270
18-09-25	68	G2018-51	BT	A	3	3			700, 690, lost
18-09-25	68	G2018-51	NSC	A	1	1			725?
18-09-25	68	G2018-51	MW	A	1	1			730?
18-09-25	69	G2018-95	BT	A	1	1			670
18-09-26	72	G2018-61	LSU	A	1	1			250
18-09-26	73	G2018-02	LW	A	2	2			270, 280
18-09-26	73	G2018-02	NSC	A	1	1			out of net
18-09-28	81	G2018-54	MW	A	1	1			350
18-09-29	85	G2018-19	MW	A	1	1			275
18-09-29	84	G2018-03	NSC	A	1	1			255
Total					**183**	**167**	**16**		

Bycatch – Setlines

Pull Date	Site	Set	Species	Life Stage	Quantity	Live	Dead	Mortality Rate (%)	Fork Length
18-08-29	7	S2018-49	BB	A	1	1			680
18-09-02	25	S2018-30	BB	A	1		1	100	473
18-09-03	29	S2018-10	BB	A	1	1			570
18-09-14	42	S2018-77A	BB	A	1	1			624
18-09-14	43	S2018-34A	BB	A	1	1			770
18-09-16	56	S2018-35	BB	A	1	1			555
18-09-25	70	S2018-46	BB	A	1	1			720
18-09-25	71	S2018-67	BB	A	2	2			560, 520
18-09-25	72	S2018-59	BB	A	1		1	100	350
18-09-25	73	S2018-15	BB	A	1	1			570
18-09-26	75	S2018-43	BB	A	1	1			580
18-09-26	97	S2018-31	BB	A	2	2			380, 610
18-09-27	92	S2018-44	BB	A	1	1			660
18-09-28	87	S2018-72	BB	A	1	1			610
18-09-29	95	S2018-92	BB	A	1	1			640
18-09-29	99	S2018-84	BB	A	3	3			500, 560, 480
18-09-30	102	S2018-99	BB	A	5	4	1	20	560, 750, 530, 495, 510
18-09-30	100	S2018-08	BB	A	4	4			540, 515, 620, 550
18-09-30	101	S2018-52	BB	A	7	4	3		540, 560, 560, 570, 500, 495, 570
18-09-15	47	S2018-38	CSU	A	1	1			450
18-09-16	57	S2018-78	CSU	A	1	1			424
18-08-30	8	S2018-33	NSC	A	1	1			330
18-09-03	29	S2018-10	NSC	A	1	1			540
18-09-16	56	S2018-35	NSC	A	1	1			335
18-09-17	68	S2018-55B	NSC	A	1	1			505
Total					**42**	**36**	**6**		

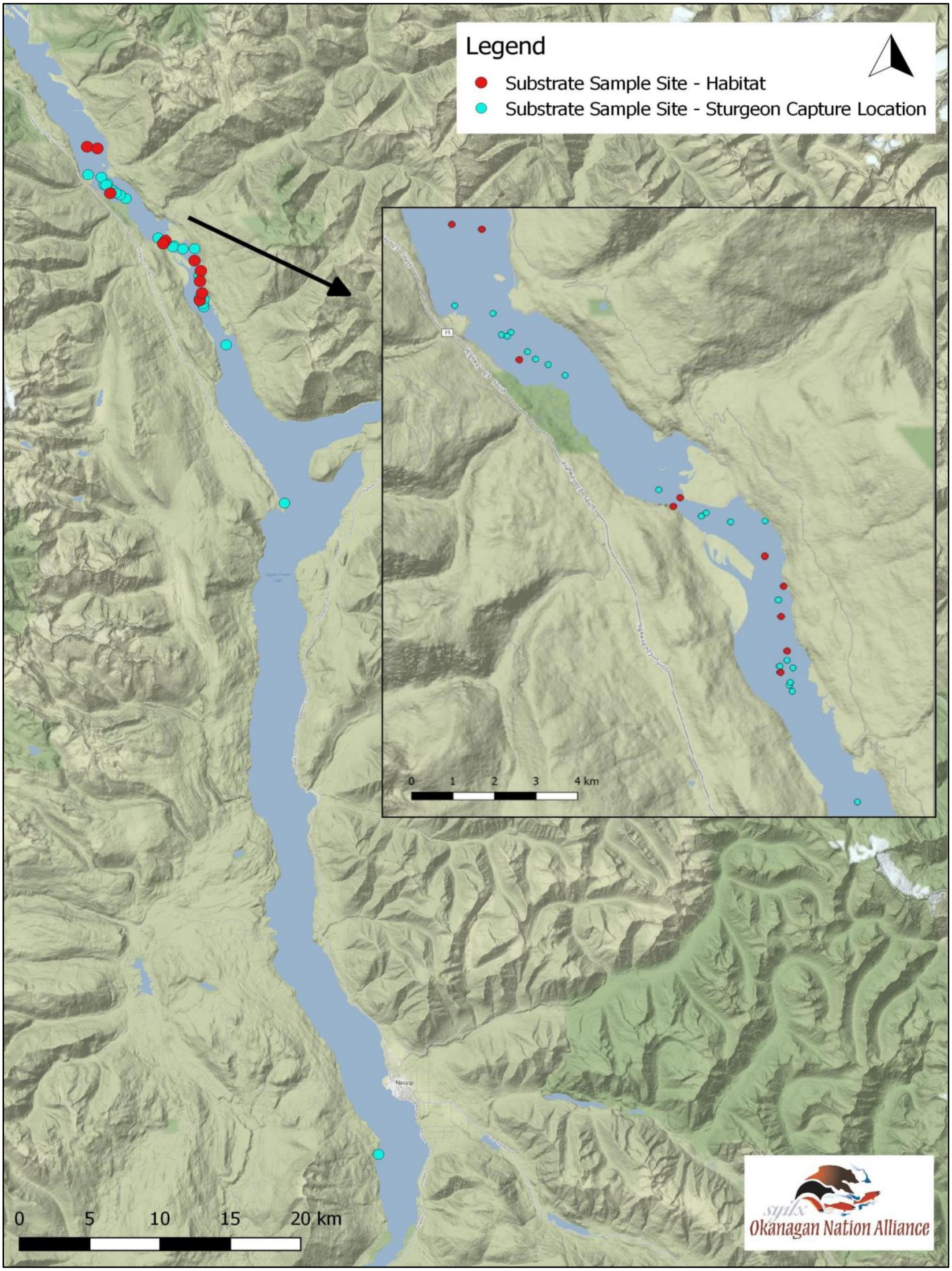
Appendix B - Location Map of Juvenile White Sturgeon Captures


Nakusp
Legend
Sturgeon Capture Locations
0
7.5
15
22.5
30 km
syilx
Okanagan Nation Alliance

Appendix C - Summary of Habitat Conditions Measured at Sturgeon Capture Locations

Year	RKm	Easting	Northing	Method	Time of Capture	Date of Capture	Water Temp (°C)	Average Water Depth (m)	Secchi Depth (m)	Mean Velocity	Substrate	Turbidity	Contents in Substrate Sample
2008-1	207.4	421775	5634402	gillnet	13:59	9/9/2008	-	18.3					
2008-2	210.2	421969	5637569	gillnet	0:13	9/12/2008	-	10.1					
2008-3	210.6	421587	5637901	gillnet	0:35	9/17/2008	-	10.9					
2008-4	210.8	421207	5637953	gillnet	1:38	9/17/2008	-	11.8					
2009-1	192.5	429332	5623717	gillnet	0:45	8/21/2009	-	16.4					
2009-2	202.2	425317	5630393	gillnet	1:34	8/22/2009	-	11.1					
2010-1	205.9	422784	5633545	gillnet	7:45	9/15/2010	10.5	14.3	3.5	0.28	fines/SG	-	
2010-2	210.5	422011	5637761	gillnet	20:56	10/4/2010	10.5	7.7		0.2	fines	4.2	
2010-3	206.4	422586	5633716	gillnet	20:00	10/6/2010	10	13.4		0.17	fines	2.9	
2010-4	190.7	430510	5622110	gillnet	10:50	10/8/2010	10.5	13.1	3.95	0.18	fines/some OD	2.4	
2014-1	196.2	429077	5627451	gillnet	-	8/18/2014	-	-			Sand		None
2014-2	192.0	429456	5623734	gillnet	-	9/19/2014	-	-			Sand		Biting Midge
2014-3	195.4	429219	5626818	gillnet	-	9/20/2014	-	-			Clay (sand)		Biting Midge
2014-4	196.0	429091	5627294	setline	-	9/21/2014	-	-			Sand		None
2014-5	200.1	426744	5629326	gillnet	-	9/22/2014	-	-			Pebbles (Sand)		None
2014-6	207.7	421621	5634952	gillnet	-	9/23/2014	-	-			Sand		None
2014-7	208.5	421948	5636021	setline	-	9/23/2014	-	-			Sand		6 Non-biting Midges
2014-8	207.5	421669	5634725	setline	-	10/2/2014	-	-			Sand (Clay)		None
2014-9	208.0	422473	5633700	gillnet	14:05	10/8/2014	10	10.8			Sand (Pebble)		Non-Biting Midge and Larvae
2014-10	206.0	423988	5632651	setline	11:46	10/9/2014	10.1	8.9			Sand		Biting
2014-11	199.5	428745	5628885	gillnet	14:20	10/10/2014	10.3	11.7					
2015-1	177.8	434805	5609954	gillnet	14:36	9/1/2015	11.2	9			Clay		None
2016-1	205.5	423284	5633071	setline	11:35	9/12/2016	10.5	10.8			Sand		None
2016-2	207.5	421360	5634454	setline	11:30	9/13/2016	11	9.5			Pebbles (Sand)		Biting Midge
2016-3	195.5	429033	5626890	setline	11:50	9/18/2016	9.8	10			Sand		None
2016-4	195.5	429033	5626890	setline	11:50	9/18/2016	9.8	10					
2016-5	205.5	423245	5633120	setline	11:25	9/23/2016	10.6	8.3			Sand (Pebble)		None
2016-6	205.5	423245	5633120	setline	11:25	9/24/2016	10.6	8.3					
2016-7	201.5	425657	5630059	setline	12:45	9/25/2016	9.5	7					
2016-8	202.6	425251	5631080	setline	12:16	9/25/2016	9.5	6.3					
2017-1	124.1	440884	5561347	gillnet	11:30	6/29/2017	15.4	13.6			Clay (Sand)		None
2017-2	199.5	427213	5629031	setline	13:15	9/11/2017	10.1	15.5			Sand		1 Caddisfly
2017-3	192.8	429326	5624567	gillnet	13:47	9/7/2017	12.2	15.3			Sand (Clay)		None
2017-4	192.8	429326	5624567	gillnet	13:47	9/7/2017	12.2	15.3			Sand (Clay)		None
2017-5	193.0	429259	5624720	setline	10:50	8/26/2017	11.1	17			Sand (Pebbles)		None
2017-6	199.4	427333	5629112	setline	12:30	8/27/2017	11.7	15.8			Sand		None
2017-7	205.8	423093	5633263	setline	12:58	9/10/2017	10.6	15.2			Sand		None
2017-8	200.7	426200	5629716	setline	10:54	8/28/2017	11.5	13.7			Sand (Clay)		None
2018-1	193.2	429352	5625159	setline	12:10	9/16/2018	11.4	15.1	3		Coarse sand		1 Diptera
2018-2	207	422611	5633633	setline	11:20	8/31/2018	10.5	15.5			Medium sand		Nothing
Mean	**199.2**						**10.8**	**12.2**	**3.5**	**0.2**		**3.2**	

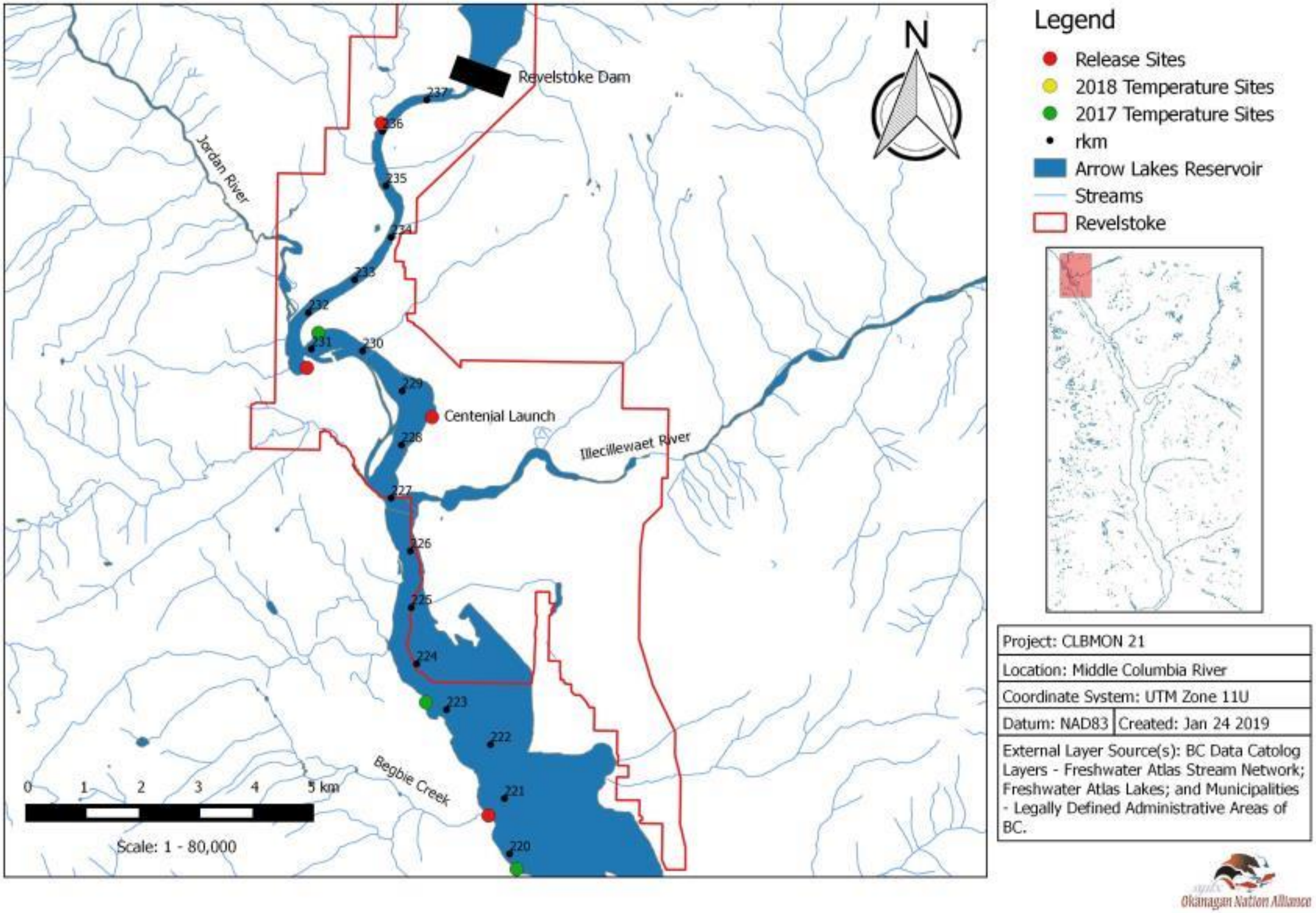
Appendix D – Map of Substrate Sample Locations and Data Summary


Legend
Substrate Sample Site - Habitat
Substrate Sample Site - Sturgeon Capture Location
0 1 2 3 4 km
0 5 10 15 20 km
Okanagan Nation Alliance

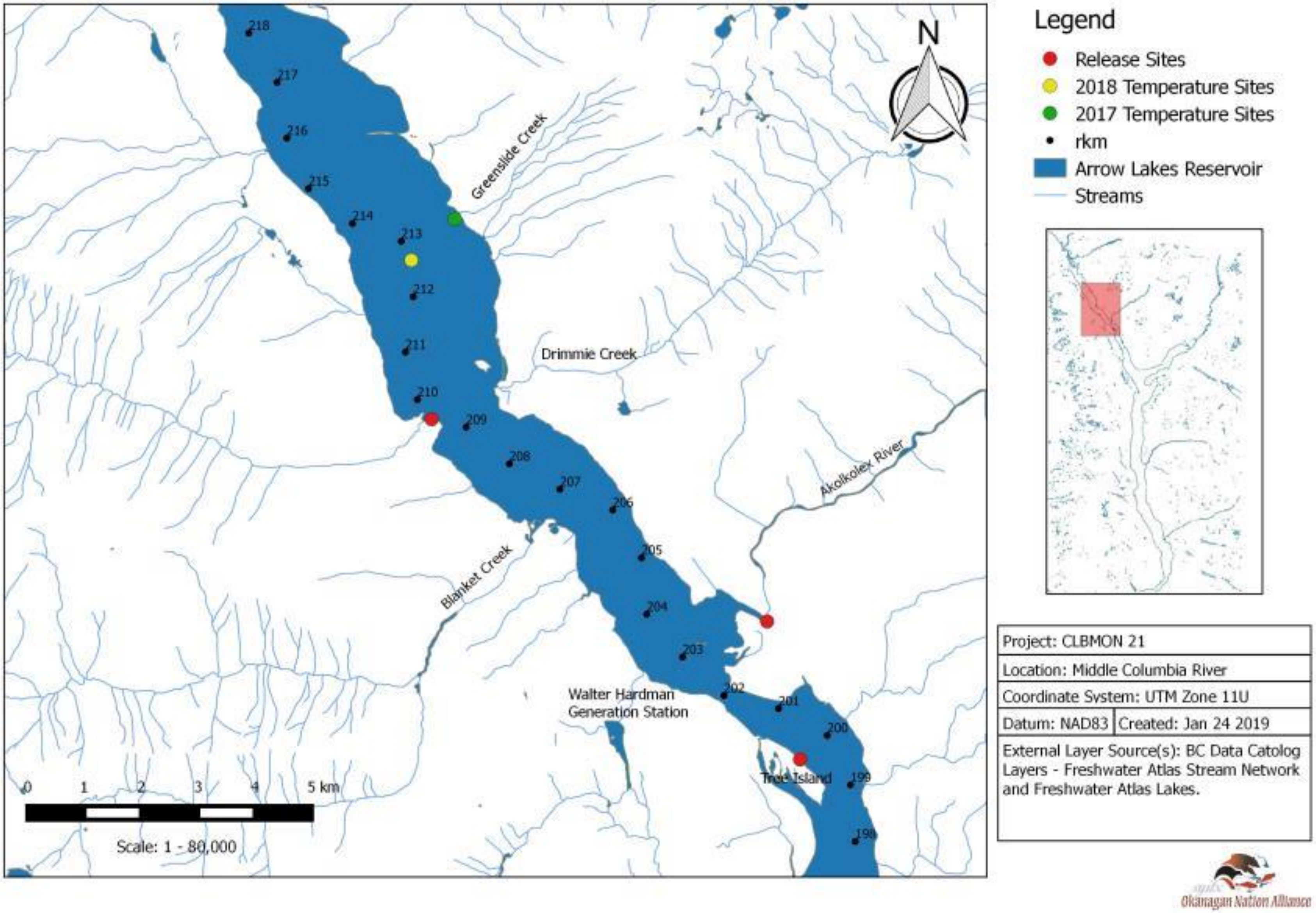
Collection Year	Site Name	Date of Analysis	Sample Type	Dominant Substrate	Secondary Substrate	Volume (cm3)	Screen Size	Contents	Order	Family	Lifestage	# Individuals	Density of Prey Type	Comments
2016	2014-5	12/20/2016	Sturgeon	Pebbles	Granule	na	500	none	-	-	-	-	0	small amount of detritus
2016	S020B	12/20/2016	Sturgeon	Pebbles	Granule	568.6	None - substrate large		Diptera	Chironomidae		1	0.002	kept for further analysis; note volume estimated
2016	2014-09	12/20/2016	Sturgeon	Granule	Pebble	568.6	105		Diptera	Chironomidae		1	0.002	kept for further analysis; note volume estimated
2016	2014-1	12/20/2016	Sturgeon	coarse sand	medium sand	na	105	none					0.000	some small vegetation
2016	2014-7	12/20/2016	Sturgeon	medium sand	fine sand	568.6	106		Diptera	Chironomidae		6	0.011	kept for further analysis; note volume estimated
2016	2014-2	12/20/2016	Sturgeon	coarse sand	medium sand	568.6	106		Diptera	Chironomidae		1	0.002	kept for further analysis; note volume estimated
2016	2014-10	1/4/2017	Sturgeon	fine sand	fine sand	433.2	106		Diptera	Chironomidae		3	0.007	kept for further analysis
2016	2014-3	1/4/2017	Sturgeon	clay	fine sand	667.9	106		Diptera	Chironomidae		1	0.001	2 pieces of driftwood in sample
2016	2014-8	1/4/2017	Sturgeon	fine sand	clay	731.0	106	none	-	-	-	-	0	lots of vegetative debris in sample
2016	2014-6	1/5/2017	Sturgeon	medium sand	fine sand	1083.0	106	none	-	-	-	-	0	sample was dry upon collection
2016	S8A	1/6/2017	Sturgeon	coarse sand	pebble	992.8	106	none	-	-	-	-	0	lots of driftwood in sample
2016	2014-4	1/6/2017	Sturgeon	coarse sand	medium sand	1137.2	106	none	-	-	-	-	0	not in ethanol
2016	S119A	1/6/2017	Sturgeon	coarse sand	medium sand	1159.6	106	none	-	-	-	-	0	not in ethanol
2016	S004B	1/12/2017	Sturgeon	coarse sand	medium sand	1210.4	106	none	-	-	-	-	0	some small rocks in sample
2016	2015-1	1/17/2017	Sturgeon	clay	clay	1046.9	106	none	-	-	-	-	0	wood in sample
2017	G038B		Sturgeon	clay	fine Sand	565.5	500	none	NA*	NA			0	Small amount of wood, some pebbles, not in ethanol
2017	106C		Sturgeon	medium Sand	clay	97.5	500	none	NA	NA			0	Took 3 ponar grabs and last one was the only successful one. There were two medium/large rocks in sample. Not in ethanol
2017	56C		Sturgeon	medium Sand	fine sand	780.0	500	none	NA	NA			0	some pebbles, not in ethanol
2017	76C		Sturgeon	medium Sand	pebbles	604.5	500	none	NA	NA			0	small amount of detritus and medium size rocks. Not in ethanol
2017	GA1		Sturgeon	medium Sand	clay	565.5	500	none	NA	NA			0	small amount of pebbles, not in ethanol
2017	52D		Sturgeon	coarse sand	granule	643.5	500	none	NA	NA			0	some detritus, not in ethanol
2017	20E		Sturgeon	medium Sand	fine sand	819.0	500	1 caddisfly casing	NA	NA			0	some bigger wood pieces, small amount of detritus , no ethanol.
2018	S2018-095	11/11/2018	Sturgeon	Coarse sand	Medium sand	595.7	500		Diptera	-	Pupa - wingpads visible	1	0.002	Little organic matter
2018	PS1	11/11/2018	Sturgeon	Silt	NA	126.4	500		Diptera	Chironomidae	Larva - no wing pads	24	0.190	6.8 m depth; very little organic matter
2018	PS1	11/11/2018	Habitat	Silt	NA	126.4	500		Roundworms*	-	-	3	0.024	*Roundworms are not aquatic insects are not described in the aquatic insects key available (see picture for details)
2018	PS2	11/23/2018	Habitat	Silt	NA	577.6	500		Diptera	Chironomidae	7 Larva 2 Pupa	9	0.016	6.7 m depth
2018	PS3	11/23/2018	Habitat	SIlt	NA	333.9	500		Diptera	Chironomidae	Larva	15	0.045	3.9 m depth

2018	PS3	11/23/2018	Habitat	SIlt	NA	333.9	500		Roundworms*	-	-	32	0.096	*Roundworms are not aquatic insects are not described in the aquatic insects key available (see picture for details)
2018	PS4	11/23/2018	Habitat	Medium sand	Coarse sand	379.1	500	1 Winged insect; not an aquatic insect	Diptera	Chironomidae	Larva	2	0.005	4.5 m depth; 2 m secchi; 11.1 °C; 11.17 %DO; 112.4 cond
2018	PS5	11/23/2018	Habitat	Cobble	Coarse gravel	208.4	500		Diptera	Chironomidae	Larva	1	0.005	7.0 m depth; 2.5 m secchi; 10.8 °C; 11.70 %DO; 110.4 cond
2018	PS5	11/23/2018	Habitat	Cobble	Coarse gravel	208.4	500		Diptera	-	Larva	1	0.005	More defined head / larger than previous seen
2018	PS6	11/23/2018	Habitat	Coarse gravel	Medium gravel	54.6	500	Nothing seen	-	-	-	0	0.000	7.6 m depth; 10.3 °C; 11.51 %DO; 105.6 cond
2018	PS7	11/23/2018	Habitat	Silt	NA	406.1	500		Diptera	Chironomidae	Larva	27	0.066	5.6 m depth; 10.1 °C; 11.19 %DO; 109.4 cond
2018	PS8	11/23/2018	Habitat	Coarse sand	Medium sand	694.9	500		Diptera	Chironomidae	Larva	1	0.001	13.4 m depth; 11.6 °C
2018	PS9	11/23/2018	Habitat	Wood	Medium sand	116.4	500		Diptera	Chironomidae	Larva	2	0.017	11.1 m depth; 11.5 °C; volume of wood measured
2018	PS10	11/23/2018	Habitat	SIlt	NA	541.5	500		Diptera	Chironomidae	Larva	12	0.022	4.8 m depth; 11.3 °C
2018	S2018985	11/23/2018	Habitat	Medium sand	Coarse sand	216.6	500	Nothing seen	-	-	-	-	0.000	14.7 m depth; 11.5 °C

Appendix E - Detailed maps of RKm, Release Sites and Temperature Stations



Revelstoke Dam
237
236
235
234
233
232
231
230
229
228
227
226
225
224
223
222
221
220
Jordan River
Centenial Launch
Illecillewaet River
Begbie Creek
N
0 1 2 3 4 5 km
Scale: 1 - 80,000
Legend
Release Sites
2018 Temperature Sites
2017 Temperature Sites
rkm
Arrow Lakes Reservoir
Streams
Revelstoke
Project: CLBMON 21
Location: Middle Columbia River
Coordinate System: UTM Zone 11U
Datum: NAD83
Created: Jan 24 2019
External Layer Source(s): BC Data Catolog Layers - Freshwater Atlas Stream Network; Freshwater Atlas Lakes; and Municipalities - Legally Defined Administrative Areas of BC.
Okanagan Nation Alliance


Legend
Release Sites
2018 Temperature Sites
2017 Temperature Sites
rkm
Arrow Lakes Reservoir
Streams
N
Greenslide Creek
Drimmie Creek
Akolkolex River
Blanket Creek
Walter Hardman Generation Station
Tree Island
218
217
216
215
214
213
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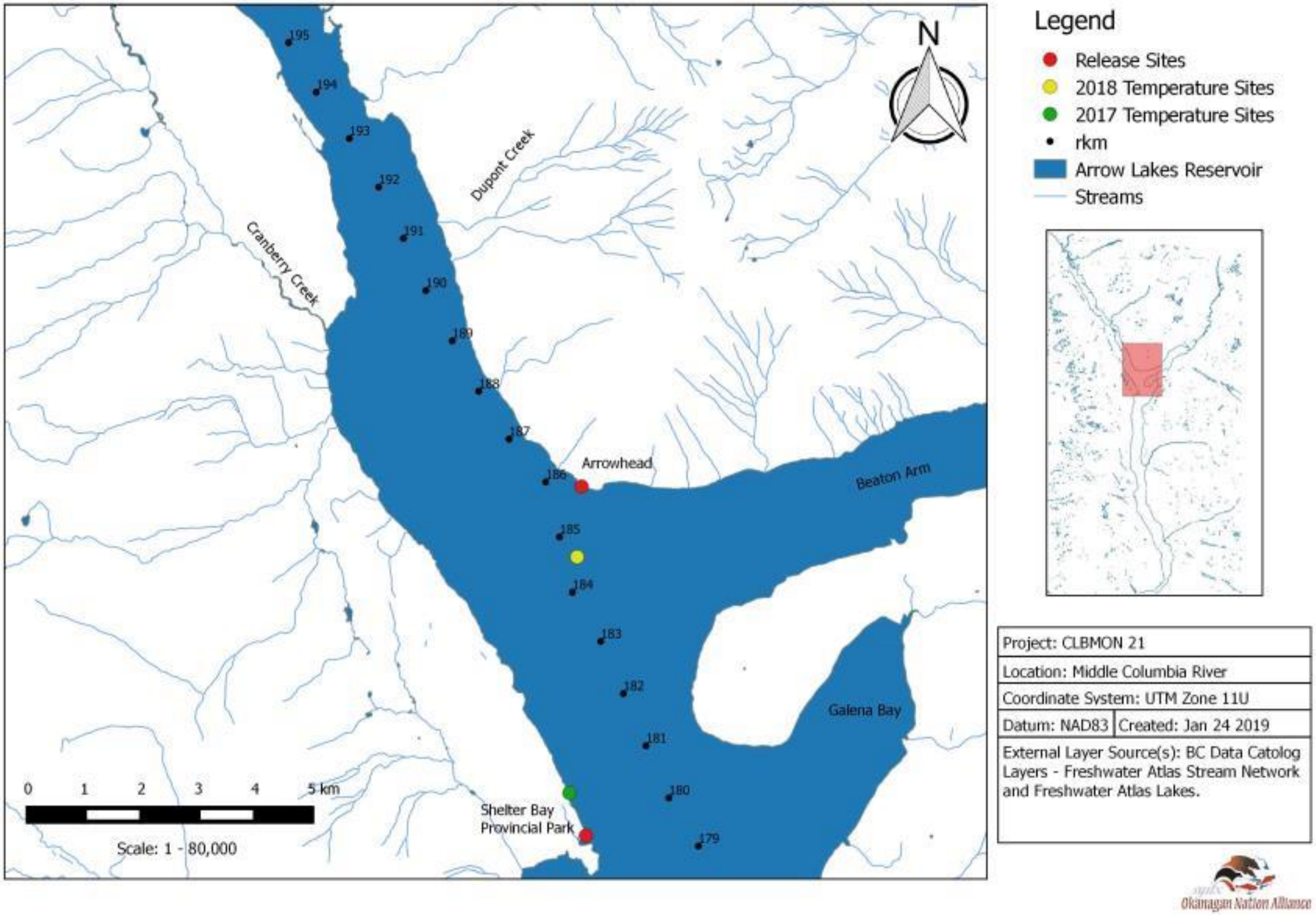
211
210
209
208
207
206
205
204
203
202
201
200
199
198
0 1 2 3 4 5 km
Scale: 1 - 80,000
Project: CLBMON 21
Location: Middle Columbia River
Coordinate System: UTM Zone 11U
Datum: NAD83
Created: Jan 24 2019
External Layer Source(s): BC Data Catalog Layers - Freshwater Atlas Stream Network and Freshwater Atlas Lakes.
Okanagan Nation Alliance


195
194
193
192
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189
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186
185
184
183
182
181
180
179
Dupont Creek
Cranberry Creek
Arrowhead
Beaton Arm
Galena Bay
Shelter Bay
Provincial Park
N
0 1 2 3 4 5 km
Scale: 1 - 80,000
Legend
Release Sites
2018 Temperature Sites
2017 Temperature Sites
rkm
Arrow Lakes Reservoir
Streams
Project: CLBMON 21
Location: Middle Columbia River
Coordinate System: UTM Zone 11U
Datum: NAD83
Created: Jan 24 2019
External Layer Source(s): BC Data Catolog Layers - Freshwater Atlas Stream Network and Freshwater Atlas Lakes.
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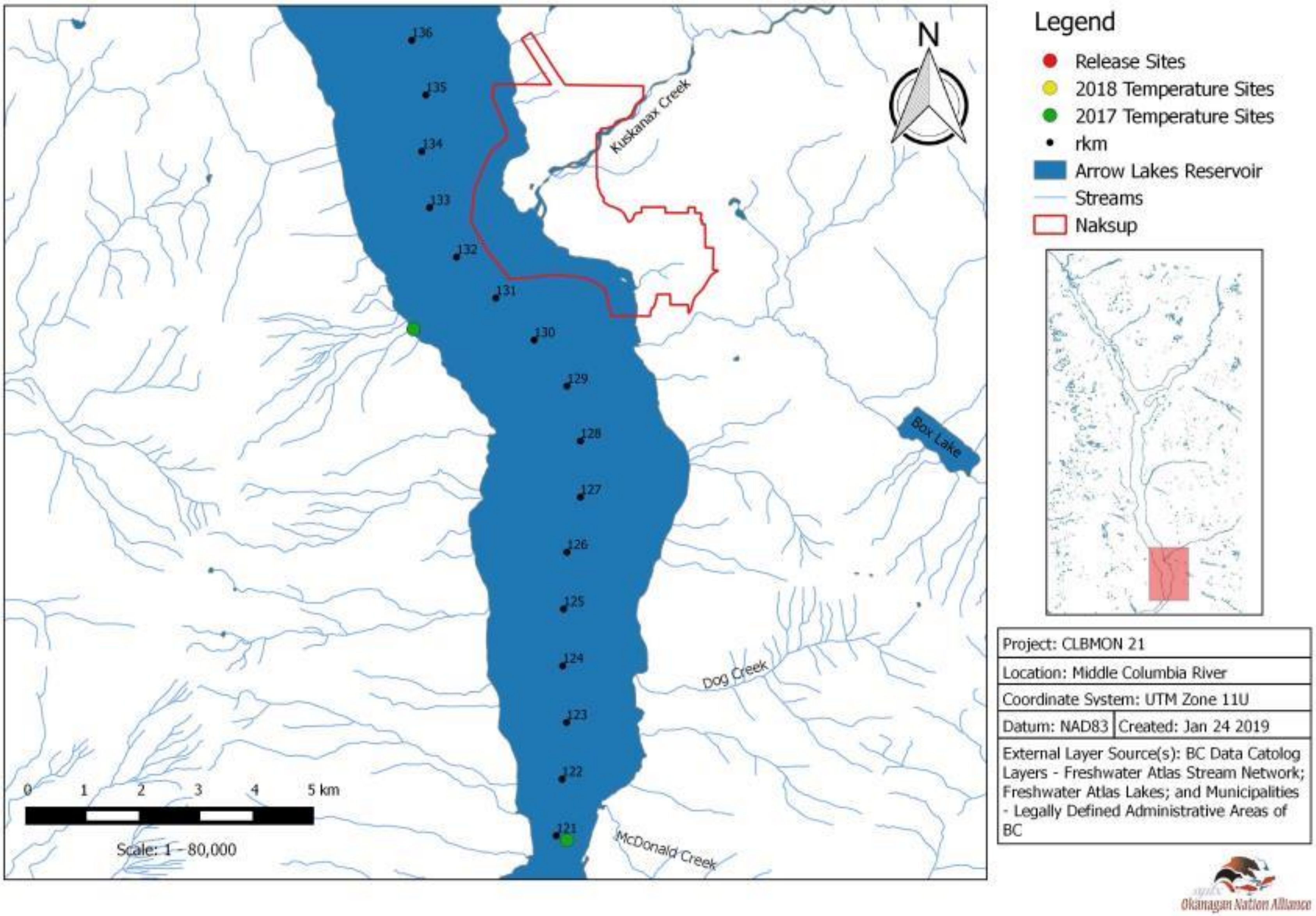
136
135
134
133
132
131
130
129
128
127
126
125
124
123
122
121
Kuskanax Creek
Box Lake
Dog Creek
McDonald Creek
N
0 1 2 3 4 5 km
Scale: 1 – 80,000
Legend
Release Sites
2018 Temperature Sites
2017 Temperature Sites
rkm
Arrow Lakes Reservoir
Streams
Naksup
Project: CLBMON 21
Location: Middle Columbia River
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