Columbia River Project Water Use Plan
Columbia White Sturgeon Management Plan

Mid Columbia River Juvenile Sturgeon Detection and Habitat Program and Tracking of Existing Sonic Tagged Sturgeon

Implementation Year 6

Reference: CLBMON-21

Juvenile White Sturgeon Monitoring: 2012 Investigations

Study Period: 2012

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June 27, 2013

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CLBMON-21: MIDDLE COLUMBIA RIVER

Juvenile White Sturgeon Monitoring: 2012 Investigations

Submitted to:
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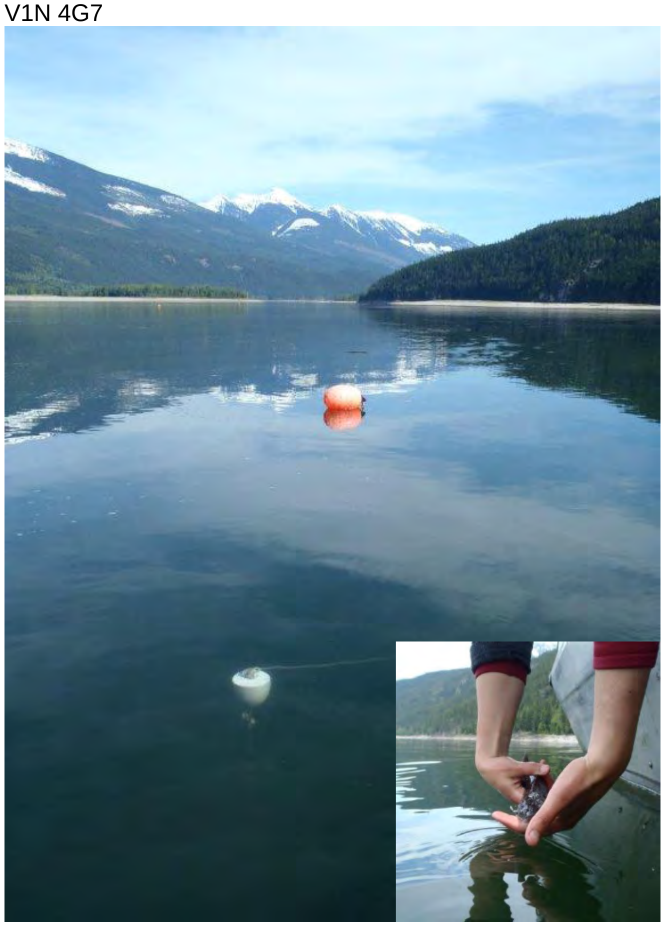

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REPORT

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Cover Photo: Upstream view of the Middle Columbia River from the downstream portion of the VPS array. The red buoy is attached to a VR2W receiver and the white bullet float on the foreground is attached to a reference tag. Insert on lower right shows the release of an acoustic-tagged juvenile White Sturgeon into the VPS Array. May, 2012

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EXECUTIVE SUMMARY

The White Sturgeon *(Acipenser transmontanus)* in the Middle Columbia River (MCR), within the Arrow Lakes Reservoir (ALR) between Hugh L. Keenleyside Dam (HLK) and Revelstoke Dam, are part of an endangered population segment isolated upstream of HLK. Hatchery reared juvenile White Sturgeon have been released annually since 2007 into the MCR to determine habitat use, growth, and survival. Previous studies have identified post release dispersal and habitat use at a large scale (5 km intervals) using juveniles tagged with acoustic transmitters. However, finer scale data pertaining to relationships between fish movements and seasonal changes in ALR water surface elevation are lacking and required for management decisions.

Finer scale movements (<10 m) and the associated relationships to environmental parameters have been recently described for several fish species using positioning systems that rely on arrays of acoustic receivers. The objective of this study was to deploy a Vemco Positioning System (VPS) to monitor and describe the fine-scale movements (<10 m) and associated habitat use by released juvenile White Sturgeon in the MCR. An array of 29 acoustic receivers was established within a 3 km length of the MCR between the mouth of the Akolkolex River and the Walter Hardman Generating Station. Fifty juvenile White Sturgeon were tagged with acoustic transmitters and released within the VPS array on May 15, 2012. Simultaneous detections on multiple receivers were used to determine the positions of individual fish using signal triangulation algorithms. The estimated positions were used to determine the type of habitat (thalweg, floodplain, shallows) used, relocation distance, and swimming speed. The resulting dataset was analysed for relationships between fish movement distances, speed, and habitat association, and time of day, season, ALR elevation and status (filling, full, emptying, stable).

Out of the 50 juveniles released in the VPS area in mid-May, 25 moved out of the study area in the first two weeks of the study, 13 fish were recorded in the area throughout the summer, and only 5 were recorded in the fall. Overall, juvenile White Sturgeon were found to heavily utilize the thalweg throughout the study period (May 15 – October 30, 2012). A shift from thalweg-only positions to some use of floodplain and shallow habitats occurred in late June. Throughout the summer, all three habitat types were used, although the thalweg was the most frequently used habitat. In October, the fish shifted back to almost exclusive use of the thalweg. In the spring, the majority of the estimated daily movement was less than 2 km, and most of the fish remained in the thalweg. In the summer, fish movement increased, with daily movements up to 5 km; similar numbers of fish were recorded in the thalweg and the floodplain area, and many were recorded in the shallows. In the fall, the patterns of movement appeared to be similar to those in the spring. Movement speeds were similar between nighttime and daytime hours but changed seasonally, with highest rates estimated for the summer months (mean ± SD of 0.09 ± 0.48 m/s in the thalweg) compared to spring (0.04 ± 0.1 m/s) and fall months (0.02 ± 0.05 m/s).

Overall, results of this study suggest that juvenile White Sturgeon used a wider range of depths, and made more frequent, longer, and faster movements in the summer compared to spring and fall. Previously, the low capture rate of juveniles in the area was potentially attributed to a lack of movement. However, fine scale description of movements used in this study revealed that sturgeon moved hundreds of metres per day throughout the seasons, which indicated that lack of movement is not the cause for low capture rates. Reasons for these seasonal differences are unknown, but could relate to the level or status of ALR. ALR was filling during the spring, emptying in the fall, and transitioned from filling, to full (stable), to emptying during the summer.

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Table of Contents

1.0 BACKGROUND AND INTRODUCTION 1

1.1 Objectives 2

1.1.1 Management Questions 2

1.1.2 Management Hypotheses 3

1.1.3 2012 Study Objectives 3

2.0 METHODS 4

2.1 Study Area 4

2.2 Study Period 4

2.3 Physical Parameters and Habitat Data Collection 4

2.4 VPS 8

2.4.1 Set Up 8

2.4.2 Testing 8

2.4.3 Download and Maintenance 9

2.4.4 Juvenile Tagging 9

2.4.5 Data Analysis 10

3.0 RESULTS 16

3.1 Physical Parameters 16

3.1.1 Discharge, ALR Elevation, and Water Temperature 16

3.1.2 Habitat Measurements 19

3.2 Juvenile White Sturgeon Movements and Habitat Use 21

4.0 DISCUSSION 34

4.1.1 VPS effectiveness 35

4.1.2 Juvenile White Sturgeon Habitat Use 36

5.0 RECOMMENDATIONS FOR REFINEMENTS TO FUTURE CAPTURE PROGRAMS 39

6.0 LITERATURE CITED 40

7.0 CLOSURE 42

TABLES

Table 1: Summary of juvenile White Sturgeon releases, sample effort, and captures in the middle Columbia River from 2007 to 2012. 2

Table 2: Chronology of sampling activities for the 2012 middle Columbia River juvenile White Sturgeon monitoring program. 7

Table 3: Summary of drag and drop tests performed in the VPS area on 3 and 14 May, 2012. 9

Table 4: Descriptive statistics of length and weight of juvenile hatchery White Sturgeon released into the Middle Columbia River study area on May 15, 2012. 10

Table 5: 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. 23

FIGURES

Figure 1: Overview of the middle Columbia River juvenile White Sturgeon monitoring area (section enclosed within the red line). 5

Figure 2: VPS study area with receiver and reference tag locations, May 15 to October 30, 2012. Depth contours (0-2 m, 2-5 m, 5-10 m, >10 m) are shown on the map. Photo date is unknown but represents an ALR elevation of approximately 435 masl. 6

Figure 3: HPEm as a function of HPE for all synchronization and reference tags; points represent individual estimated positioning errors. A transparency value of 0.01 was imposed, hence at least 100 points must overlap to create a solid black point. The lines and equations of three regressions (90th, 95th, and 99th quantiles) are plotted (solid, dashed, and dotted lines, respectively). 12

Figure 4: Cumulative proportion of tag positions in relation to HPE (Horizontal Position Error). The cumulative proportions of tag positions at HPE = 5 and HPE = 7 are provided on the graph. 13

Figure 5: Minimum distance traveled between tag positions (m) by time of day, habitat classification (thalweg, floodplain, shallows), and week since the start of the study (1 to 4 on 2nd Y-axis). Point colour corresponds to daytime (orange) and nighttime (green). Note that day- and nigh-time periods overlap during the study, as sunrise and sunset times change during the spring, summer, and fall periods. 14

Figure 6: Spatial positions of juvenile White Sturgeon in the first four weeks of the study. Point colour corresponds to habitat classification (shallow, floodplain, thalweg) and each study week (1 to 4) is shown in a separate panel. The number of individuals and the tag positions in each week are provided on each panel. 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. 15

Figure 7: Mean daily discharge of the Columbia River at Revelstoke Dam, 2012 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2011. The white line represents average mean daily discharge value. The study period is indicated by the horizontal bar. 17

Figure 8: Mean daily water level elevation (in metres above sea level) for the Columbia River at Nakusp, 2012 (black line). The shaded area represents minimum and maximum mean daily water elevations recorded at Nakusp between 2001 and 2011. The white line represents average mean daily elevation value. The study period is indicated by the horizontal bar. 18

Figure 9: Mean daily water elevation (metres above sea level) of the Arrow Lakes Reservoir, and the resultant depths at the three habitat classifications (thalweg, floodplain, shallows). 18

Figure 10: Near-bottom water temperatures in the Middle Columbia River juvenile White Sturgeon study area from May 1 to November 1, 2012 (R25 and Ref 2 stations), and surface water temperatures at Station 6 of BC Hydro's Middle Columbia River Physical Habitat Monitoring Program, located approximately 17 km upstream of the study area. 19

Figure 11: 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. 20

Figure 12: Sensitivity analysis showing histograms of estimated swimming speeds (m/s) derived from the main dataset, restricted by three HPE cut-offs (HPE = 5, 6, and 7). Swim speeds that were frequently recorded are shown in the top panel (High counts) and swim speeds with only a few observations are shown in the bottom panels (Low counts). 21

Figure 13: 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). 22

Figure 14: Estimated minimum movement speeds (m/s) of juvenile White Sturgeon in the VPS array, plotted by time of day, season, and habitat classification (thalweg, floodplain or shallows). 23

Figure 15: Boxplots of 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. 24

Figure 16: Mapped locations of individual juvenile White Sturgeon that were only detected in the first two weeks of the study (May 15 – May 28, 2012). 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. 25

Figure 17: Mapped positions of juvenile White Sturgeon within the VPS array. Panels show the positions included using various HPE cutoff values. Point colour corresponds to season, and colour strength corresponds to use, with more solid colours representing heavier use. The thalweg and floodplain contours are shown as black and light-blue lines, respectively. The number of fish and positions in each season within each HPE stratum are provided in the facets. 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 after the first two weeks post release are shown. 26

Figure 18: Mapped positions of juvenile White Sturgeon within the VPS array, shown by season and individual tag number (WSG01-WSG50). Only tag locations starting from week three of the study are shown, as detailed in Section 2.4.5. 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. 27

Figure 19: Spatial distribution of juvenile White Sturgeon, by season and HPE cutoff values. Point colour corresponds to habitat classification (shallows, floodplain, or thalweg). Maps are based on Google Earth maps, taken Dec 31, 2001, when ALR elevation at Nakusp was approximately 423 m. 28

Figure 20: 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. 29

Figure 21: Histogram is 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. 30

Figure 22: Histograms of daily lengths of time spent by individual juvenile White Sturgeon within each habitat depth classification in each season. The number of fish recorded within each stratum is provided within the panel; plots include only positions that were at most 0.5 h apart. 31

Figure 23: 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). 32

Figure 24: Daily individual minimum distance traveled between tag locations (top) and minimum daily average movement speed (bottom) versus daily average discharge; point colour represents habitat classification (thalweg, floodplain, shallows). 33

Figure 25: Number of positions based on detections of juvenile White Sturgeon (N cases) at the three receivers near the Akolkolex River mouth by season. Different panels show detections for fish that remained within the telemetry array (recorded continuously on at least one of the three receivers) near the mouth of the Akolkolex River, left for more than 0.5 h, or returned to the array after at least 0.5 h of being undetected. 34

APPENDICES

APPENDIX A
Release Data

APPENDIX B
Physical Data

1.0 BACKGROUND AND INTRODUCTION

Since 1995, surveys to assess the status of White Sturgeon (*Acipenser transmontanus*) in the Middle Columbia River (MCR), within the Arrow Lakes Reservoir (ALR) between Hugh L. Keenleyside Dam (HLK) and Revelstoke Dam have indicated the presence of a remnant population segment [estimated at 52 individuals (95% C.I. = 37 to 92) in 2003] isolated upstream of HLK (Golder 2006). Although spawning has been confirmed for this population segment (at a location approximately 6 km downstream of Revelstoke Dam), evidence of successful recruitment to the juvenile stage has not been obtained (Golder 2011). The reasons for the apparent lack of recruitment in the MCR are unclear, but may be related to the presence and operational characteristics of dams on the mainstem Columbia River (Hildebrand et al. 1999).

White Sturgeon in the Canadian Columbia River were listed as Endangered under the Species At Risk Act (SARA) in 2006 (Environment Canada 2013). As part of the Water License Requirements Program, BC Hydro implemented the Mid-Columbia juvenile White Sturgeon release and monitoring program in 2007. The purpose was to determine the suitability of the MCR (defined as the Columbia River between Revelstoke Dam and the Beaton Flats area of ALR) as a second recovery area for White Sturgeon in the Upper Columbia River Basin and the development of either a self-sustaining population or a failsafe population (i.e., a second population supported by artificial supplementation to provide future broodstock in the event of a catastrophic failure of the primary population). A 10 year MCR White Sturgeon implementation plan was recommended by the Water Use Planning Consultative Committee to study juvenile White Sturgeon habitat availability and suitability in the MCR (BC Hydro 2007). This multi-year study originally included an adult White Sturgeon monitoring component, in addition to juvenile monitoring. The adult component was completed in 2007 (Year 1), after the last of the acoustic tags previously implanted in these fish had expired (Golder 2008). The juvenile component of the multi-year study is ongoing.

Since 2007, 43 178 hatchery reared juvenile White Sturgeon [approximately 10 months of age and marked with Passive Integrated Transponder (PIT) tags] have been released into the MCR below Revelstoke Dam (Golder 2012; Table 1). The releases have varied annually from 4206 to 9625 juveniles. Releases have also included 250 acoustic-tagged individuals (50 per year from 2007 to 2010, and 50 in 2012; Appendix A, Table A1). Since 2007, a Vemco remote telemetry receiver array has been deployed in the MCR to monitor large-scale post-release movements of the acoustic-tagged fish (Golder 2008). These studies provided data on 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 meso- or micro-habitat use

During the first four years of study (2007 to 2010), another objective of the annual monitoring programs was to obtain data on juvenile White Sturgeon survival, growth, habitat use, and diet (Golder 2008, 2009a, 2010, 2011). A key objective of these programs was the capture of juvenile sturgeon using gill nets and set lines (Table 1). However, in spite of annual increases in capture effort and continued hatchery releases that increased the potential population available for capture, only 10 juvenile White Sturgeon were captured during this period (Table 1). The low number of captures and the need for high-resolution movement data led to an alternate phased approach developed for the 2011 and 2012 studies. A Vemco VR2W Positioning System (VPS) approach was chosen as a means to provide information on fine scale movements that would assist in improving juvenile capture success while simultaneously providing information on the effects of flow and reservoir operations on movement patterns and habitat use.

Table 1: Summary of juvenile White Sturgeon releases, sample effort, and captures in the middle Columbia River from 2007 to 2012.

Study Year	No. Juvenile White Sturgeon Released	Cumulative Total Released	Gill Net Sampling[a]		Set Line Sampling	
			Effort (Net-units)	No. Captured	Effort (Hook-hours)	No. Captured
2007	4206	4206	2.1	0	0	0
2008	6534	10 740	22.3	4	0	0
2009	8168	18 908	36.3	2	1085	0
2010	9625	28 533	72.5	4	14 101	0
2011	8078	36 611	VPS feasibility study (range tests) – no capture effort			
2012	6567	43 178	Present study – no capture effort			
Total			**133.2**	**10**	**15 186**	**0**

[a] One net-unit = 100 m^2 of net sampled for 24 hours.

The VPS is an array of acoustic receivers deployed in a grid pattern. Configuration of the array and post-season processing allows triangulation of individual fish positions in order to provide high-resolution temporal and spatial movement patterns. Espinoza et al. (2011) observed that VPS positional accuracy was comparable to mobile tracking, but was less labour-intensive and ultimately less expensive and more efficient. The technique was successfully implemented in Lake Roosevelt, WA, where fine-scale movements (<5 m position accuracy) and habitat use of juvenile and adult White Sturgeon were recorded using a VPS array (McLellan et al. 2011).

The objective of the 2011 (Phase 1) study was to determine the feasibility of deploying a VPS system to monitor fine scale post-release movements of acoustic-tagged juvenile White Sturgeon in the MCR. Range testing was performed to determine the feasibility and optimal location for the VPS within the MCR. Results indicated that a VPS system would be feasible in the MCR and the most suitable location would be near the mouth of the Akolkolex River (Golder 2012; see Section 2.1).

The 2012 (Phase 2) study involved deploying the VPS to increase our understanding of fine-scale movements of juvenile White Sturgeon and expand our knowledge of habitat use and movements that could potentially lead to improved capture rates in future studies. Improved capture rates would, in turn, help to answer the management questions associated with this ongoing project.

This report describes work conducted for BC Hydro by the Okanagan Nation Alliance and Golder Associates in 2012 (Year 6) under the project CLBMON-21: Middle Columbia River Juvenile Sturgeon Detection and Habitat Use and Tracking of Existing Sonic-tagged Sturgeon.

1.1 Objectives

1.1.1 Management Questions

The management questions to be addressed through the multi-year monitoring program (as taken from the Terms of Reference; 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 MCR?

6) Can modifications be made to the operations of Revelstoke Dam and/or ALR to protect or enhance juvenile White Sturgeon habitat?

1.1.2 Management Hypotheses

The following management hypotheses (and sub-hypotheses, as taken from the Terms of Reference; BC Hydro 2007) were used to guide the first 5 years (2007 to 2011) of this study program:

H_1: The recruitment of White Sturgeon in ALR is limited by the quality and quantity of juvenile habitat below Revelstoke Dam.

- H_{1A}: Quality and quantity of White Sturgeon juvenile habitat in the MCR is directly related to discharge from the dam.
- H_{1B}: Quality and quantity of White Sturgeon juvenile habitat in the MCR is directly related to water elevation in ALR.
- H_{1C}: 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 ALR.

H_2: Quality and quantity of White Sturgeon juvenile habitat in the MCR can be significantly improved through changes in dam and reservoir operations.

H_{3A}: Juvenile White Sturgeon do not survive in the MCR in significant numbers from release as post-hatch larvae to year one.

H_{3B}: Juvenile White Sturgeon do not survive in the MCR in significant numbers from release as late sub-yearling stage to year 2+ or older.

1.1.3 2012 Study Objectives

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. The specific objectives were as follows:

1) 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.

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.

2.0 METHODS

2.1 Study Area

The overall MCR study area consisted of the section of the Columbia River from Revelstoke Dam downstream to the Beaton Flats area (Figure 1). This dynamic section of the Columbia River is approximately 55 km in length and varies in width from approximately 150 m at points below Revelstoke Dam to over 3 km in the Beaton Flats area. This area is influenced by discharge from Revelstoke Dam and water levels in ALR, a functioning storage reservoir, and typically experiences water level changes of up to 10 m twice annually (during filling in spring and drawdown in fall and winter) in the downstream portion. Physical conditions in the majority of the study area vary from lotic at low ALR levels (in late winter and early spring) to lentic at high ALR levels (in summer and early fall).

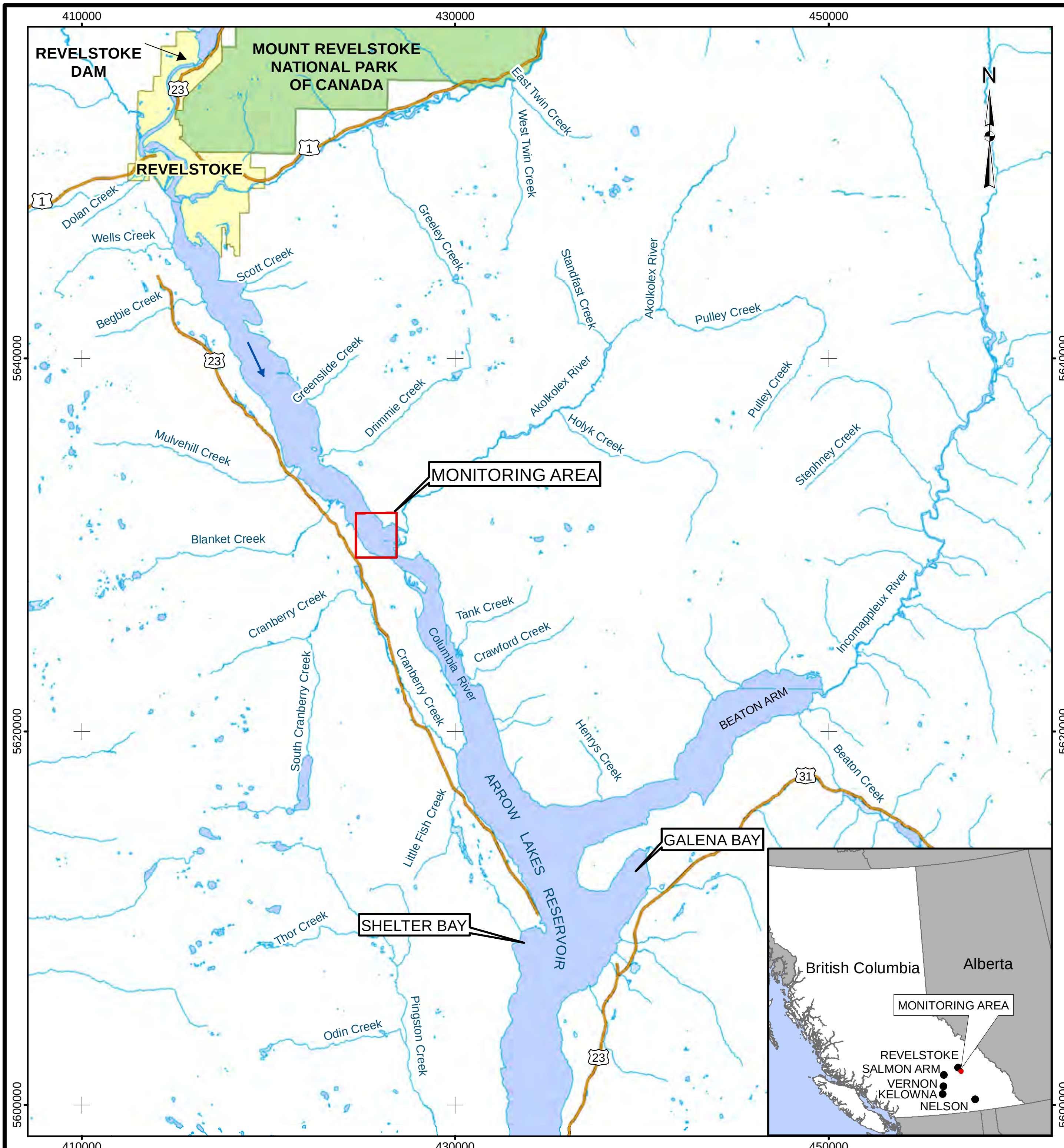
The VPS array was established within a 3 km length of the MCR between the mouth of the Akolkolex River and the Walter Hardman Generating Station (hereafter termed the study area; Figure 2). This area was chosen based on the results of the 2011 study (Golder 2012), as well as previous studies, which indicated high use of this area by acoustic-tagged hatchery juvenile White Sturgeon (Golder 2008, 2009a, 2010, 2011). The 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.

2.2 Study Period

The 26 receivers that comprised the initial VPS array were deployed on May 1 and 2, 2012; three additional receivers were added to the array on September 19, 2012 (Table 2). Acoustic-tagged juvenile White Sturgeon were released into the VPS area on May 15. The VPS study was conducted from May 15 to October 30, when all gear was removed from the river.

2.3 Physical Parameters and Habitat Data Collection

Physical parameters (e.g., depth and temperature) can influence acoustic signals and an important aspect of a VPS study is the reduction or elimination of factors that can affect acoustic signal output and reception. Large differences in depth can influence the time of signal arrival and therefore, skew positioning. Increased levels of turbidity (suspended sediments in the water) can cause signal attenuation (i.e., dampen acoustic signals).



LEGEND

- FLOW DIRECTION
- MAJOR ROAD
- WATERCOURSE
- CITY
- PROJECT LOCATION
- NATIONAL PARKS
- WATERBODY
- WETLAND

10 0 10

SCALE 1:300,000 KILOMETRES

REFERENCE

DRAFT

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DATUM: NAD83 PROJECTION: UTM ZONE 11

PROJECT

CLBMON-21:
MIDDLE COLUMBIA RIVER JUVENILE
WHITE STURGEON MONITORING PROGRAM

TITLE

OVERVIEW OF THE MIDDLE COLUMBIA RIVER JUVENILE WHITE STURGEON MONITORING AREA

Golder Associates

PROJECT		12-1492-0053	FILE No.	
DESIGN	MH	06 Mar. 2013	SCALE AS SHOWN	REV. 0
GIS	KLN	14 May 2013		
CHECK			FIGURE: 1	
REVIEW	LH	07 May 2013		

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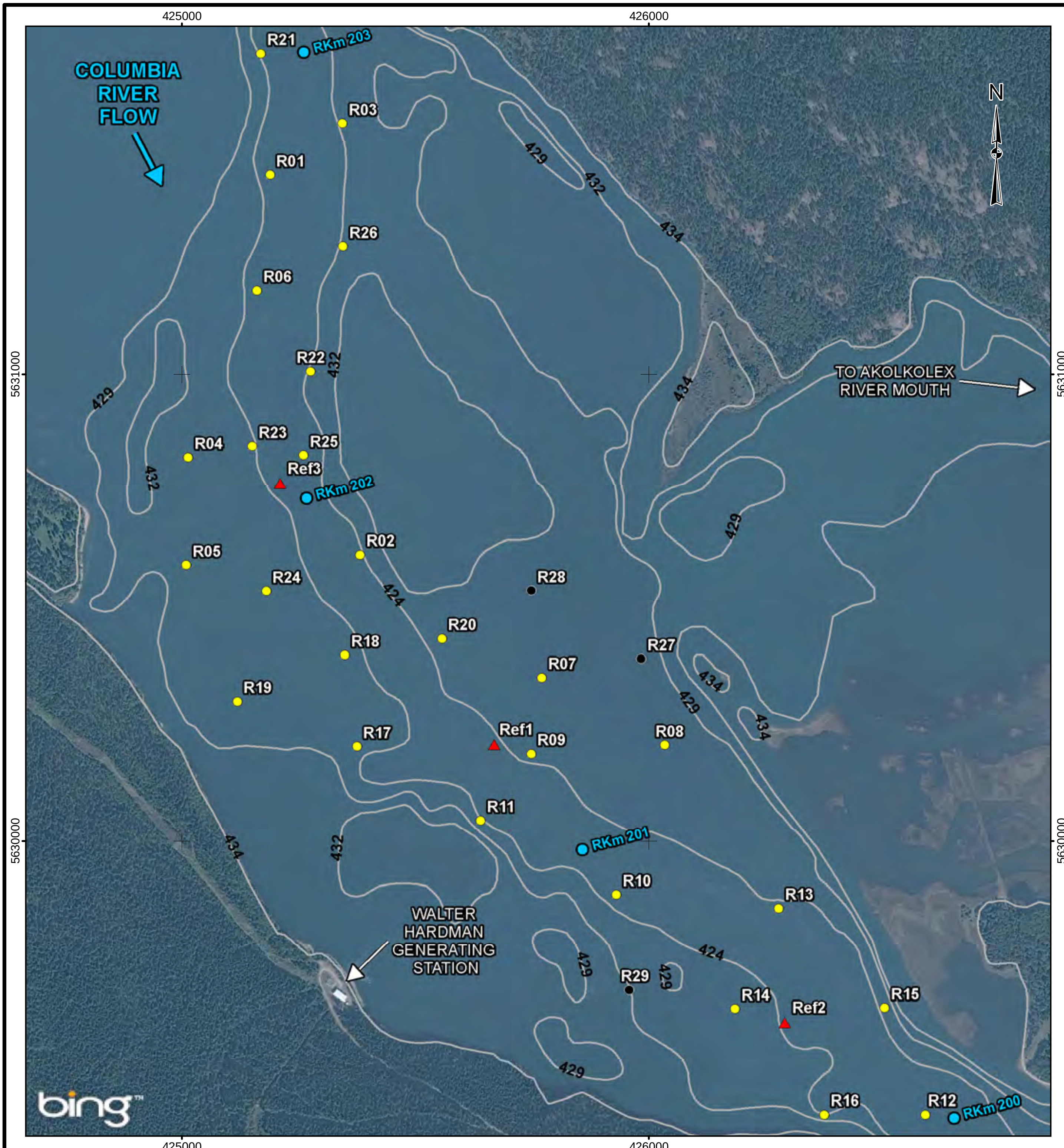

LEGEND

- RECEIVERS (R01 TO R26) INSTALLED MAY 03, 2012
- RECEIVERS (R27 TO R29) INSTALLED SEPTEMBER 18, 2012
- REFERENCE TAG LOCATION (REF1 TO REF3)
- RIVER KILOMETRE (RKm) MEASURED UPSTREAM FROM HUGH KEENLEYSIDE DAM
- ELEVATION CONTOURS (masl)

500 0 500

SCALE 1:12,000 METRES

REFERENCE

CONTOURS DIGITIZED FROM SCANNED NAVIGATIONAL MAP, CANADIAN HYDROGRAPHIC SERVICE CHART DATUM (CHART 3058, COLUMBIA RIVER, ARROWHEAD TO BLANKET CREEK, 1991). IMAGERY LAYER CREDITS: © 2010 DIGITALGLOBE IMAGE COURTESY OF USGS © 2010 GEOEYE © PROVINCE OF BRITISH COLUMBIA © 2013 MICROSOFT CORPORATION .
DATUM: NAD83 PROJECTION: UTM ZONE 11

PROJECT

CLBMON-21:
MIDDLE COLUMBIA RIVER JUVENILE
WHITE STURGEON MONITORING PROGRAM

TITLE

VPS STUDY AREA WITH RECEIVER AND REFERENCE TAG LOCATIONS, MAY 15 TO OCTOBER 30, 2012

Golder Associates

PROJECT		12-1492-0053	FILE No.	
DESIGN	MH	01 May 2013	SCALE AS SHOWN	REV. 0
GIS	KLN	23 May 2013	**FIGURE: 2**	
CHECK	SU	23 May 2013		
REVIEW	LH	23 May 2013		

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Table 2: Chronology of sampling activities for the 2012 middle Columbia River juvenile White Sturgeon monitoring program.

Date(s)	Activities
April 26	Field preparation
April 30	Field preparation, travel to Revelstoke
May 1-3	Deploy VPS, travel to Castlegar (May 3)
May 13	Field preparation, travel to Revelstoke
May 14	Drag and drop tests within VPS, download VPS
May 15	Release acoustic-tagged juvenile White Sturgeon (n = 50) into VPS area, travel to Castlegar
May 28	Field preparation, travel to Revelstoke
May 29-30	Depth measurements over previously exposed areas, download VPS, habitat measurements, travel to Castlegar
July 3	Field preparation, travel to Revelstoke
July 4-5	Download VPS, habitat measurements, travel to Castlegar
August 13	Field preparation, travel to Revelstoke
August 14-15	Download VPS, habitat measurements, travel to Castlegar
September 17	Field preparation, travel to Revelstoke
September 18-19	Download VPS, habitat measurements, added receivers 27, 28, and 29 to array on 19 September , travel to Castlegar
October 29	Field preparation, travel to Revelstoke
October 30-31	Download and remove VPS, travel to Castlegar, demobilization

Water temperature can influence water density that, in turn, can affect signal detection. Higher flow rates around acoustic receivers increase the amount of background noise, which can also interfere with detection of acoustic tag signals. There must be at least a 12 dB difference between the background noise and the acoustic signal for the signal to be detected (M. Holland, Vemco Ltd., Halifax, pers. comm., 2012). To assess the potential effect of these physical parameters on signal detection and positioning, the following data were recorded at four representative locations within the study area [i.e., at each River Kilometre (RKm); see Figure 2] during each VPS download:

- depth (determined by boat sounder to the nearest 0.1 m);
- turbidity (taken at the surface; Orbeco-Hellige Model 966 portable turbidimeter; accurate to 0.01 NTU in the lowest range);
- Secchi depth (measured to the nearest 0.1 m on the shaded side of the boat);
- current velocity (measured at the surface while at anchor using a Marsh-McBirney electromagnetic flowmeter accurate to ±2% of reading); and,
- location in Universal Transverse Mercator (UTM) coordinates (NAD 83 projection).

In addition, two temperature loggers (Tidbit v2 Water Temperature Logger, Onset Computer Corporation, Massachusetts, USA; accuracy of ± 0.2°C and range of -20°C to 30°C) were deployed within the VPS array to record hourly water temperatures. These temperature loggers were deployed approximately 1 to 2 m above the channel bottom, and were attached to receiver station R25 and reference tag station Ref2 (see Section 2.4.1 and Figure 2). Water temperature data were also obtained from Station 6 of the BC Hydro Physical Habitat Monitoring Program (CLBMON-15a; Golder in preparation), which was located at RKm 219.0, approximately

17 km upstream from the study area; these data were used to represent surface water temperature in the vicinity of the array during the study period. Hourly discharge (m^3/s) of the Columbia River at Revelstoke Dam and ALR water surface elevation data at Nakusp were obtained from BC Hydro Power Records.

2.4 VPS

2.4.1 Set Up

The acoustic receivers used during the present study were Vemco (model VR2W) single channel, submersible acoustic receivers that operate at a frequency of 69 kHz and are capable of identifying and decoding Vemco 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 communication key, Bluetooth® wireless technology, and a laptop running Vemco User Environment (VUE) software. Each VR2W has an operating life of approximately 15 months on a single battery. Time was synchronized among receivers during initialization, which matched the time on each receiver to that on the laptop.

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 (i.e., R01, R02, R03, R05, R07, R08, R11, R12, R18, R20-R23) 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 (Figure 2). 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).

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.

2.4.2 Testing

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 pinger) 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 pinger) 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% (Table 3), which is considered at or above the expected rate of positioning success (Vemco analyst, pers. comm.).

Table 3: Summary of drag and drop tests performed in the VPS area on 3 and 14 May, 2012.

Date	Test Type	Start Time	End Time	Duration (mins)	Possible Detections	Successful positions	Effectiveness (%)
May 3, 2012	Drag	12:15	13:01	46	110	63	57.3
May 3, 2012	Drop (mid-triangle)	13:15	13:31	16	38	23	60.5
May 3, 2012	Drop (edge of triangle)	13:32	13:45	13	31	17	54.8
May 14, 2012	Drag	11:34	12:48	74	178	138	77.5
May 3, 2012	Drag	12:15	13:01	46	110	63	57.3
All combined				**149**	**357**	**241**	**67.5**

2.4.3 Download and Maintenance

The VPS receivers were downloaded more frequently at the start of the study program in order to determine if the initial set up was optimal for fish positioning, and with less frequency as the study progressed (Table 2). When initially deployed, the receiver depth and UTM coordinates were recorded, and an extra 10 m of float line was added to each receiver station to account for rising ALR levels. Additional float line was added to certain stations during subsequent downloads as needed. During each download session, the UTM positions of each receiver were recorded prior to download, as well as after redeployment. The time of download and redeployment were also recorded. Receivers that had drifted were moved back to their original deployment locations, and any debris that had become entangled on float lines was removed.

2.4.4 Juvenile Tagging

Fifty juvenile White Sturgeon, implanted with an acoustic transmitter (Vemco V9 pingers, 30 second blanking interval, Amirix Systems, Bedford, Nova Scotia), were released into the study area on May 15, 2012. The juvenile White Sturgeon consisted of 10 fish from each of five maternal crosses that were reared at the Freshwater Fisheries Society of British Columbia's (FFSBC) hatchery near Wardner, BC. Tags were implanted in all fish at the Wardner Hatchery according to standard protocols approved by the Upper Columbia White Sturgeon Recovery Initiative (UCWSRI 2006). All fish were measured for weight (g) and fork length (mm) before release (see Table 4 for summary statistics, and Appendix A, Table A2 for individual fish measurements).

Half of the acoustic-tagged juvenile White Sturgeon were released in the upper third of the array at RKm 202.5 and the other half in the lower third at RKm 203.3 (Figure 2; see Appendix A, Table A2 for individual release information). Fish were transported to the release sites in transport tanks on-board a BC Hydro boat. An overall summary of release times, locations, and numbers for 2007-2012 study years is provided in Appendix A, Table A1.

Table 4: Descriptive statistics of length and weight of juvenile hatchery White Sturgeon released into the Middle Columbia River study area on May 15, 2012.

	Mean	SD	Min.	Max.	n
Fork Length (cm)	32	2	26	39	50
Weight (g)	250	53	146	403	50

2.4.5 Data Analysis

The VPS is based on the principle of range difference positioning (also known as time-difference-of-arrival (TDOA), hyperbolic positioning, and multilateration). 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 can be converted into a range difference, given knowledge of the signal propagation speed. In 2D positioning, each range difference defines a hyperbola on which the object may potentially be found. By using multiple hyperbolas, based on different pairs of receivers, the 2D position can be estimated.

In order to calculate the arrival time differences of signals at pairs of receivers, the detection time of a signal at a given receiver must be known. Since the clocks of two receivers may drift apart by as much as 3.5 seconds per day at 25°C, the VPS performs time synchronization between pairs of receivers. Time synchronization allows detection times expressed using one receiver's clock to be converted into a time using another receiver's clock. Only when detection times are expressed using a common time base, can they be used for range difference positioning.

Receiver clock time synchronization is accomplished using the stationary sync tag transmitters at known positions as a means to determine the skew between receiver clocks at sync tag detection times. The detection times of these sync tags, combined with knowledge of the distances from the sync tags to the receivers, are used to calculate the clock skew at the detection times. Once the clock skew is known, range difference positioning calculations are performed. An attempt is made to use arrival time data from every available combination of three detecting receivers to calculate a position for a particular transmission; successful positioning solutions are then combined into a final composite position, which consists of a weighted average of the individual three-receiver positions.

All of the juvenile White Sturgeon detection files (.vrl and .rld) downloaded from the receivers within the VPS array were sent to Vemco for initial analysis. Vemco estimated individual fish positions and calculated a horizontal position error (HPE) for each position. HPE estimates are based on an analysis of the error of calculated positions for sync and reference tags, calibrated to local environmental conditions; this information is used to provide a relative measure of the error potential of a calculated position (Espinoza et al. 2011). All statistical analyses were performed in R v. 2.15.3 (R Development Core Team, 2013), and plotting was performed using the package ggplot2 (Wickham 2009).

The accuracy of the HPE 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). We examined the relationship between HPE and HPEm values for sync and reference tags to describe error in the estimated positions of tagged fish. Plots of HPEm vs. HPE showed no strong relationship between the means of the variables (Figure 3). However, the regressions of the upper quantiles (90th, 95th, and 99th quantiles) of HPEm values on HPE were highly significant ($P < 0.001$ for all). Using the 90th, 95th, and 99th quantile regression equations (Figure 3) at HPE = 7, a total of 90, 95, and 99% of the empirical positioning error estimates were at or below 4.9, 6.8, and 13.1 m, respectively. All quantile regressions were performed using the package ‘quantreg’ (Koenker 2013) in R. While there was no ordinary least squares relationship between HPEm and HPE, the upper quantile regressions not only provided a means of relating between the two measures, but also allowed estimating the upper limit of error values. 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.

Subsequent processing of the telemetry positional dataset provided by Vemco included removing tag locations with HPE values that were considered unreliable for analysing fine-scale movements and habitat use. To determine an appropriate threshold value of HPE, above which tag locations would be omitted from the analysis, the cumulative proportion of tag locations was plotted against HPE values (to a maximum of 50 m) to illustrate the number of tag locations that would be omitted with various threshold HPE values (Figure 4).

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 of <10 m and the number of data points available for analysis. A sensitivity analysis was then conducted to determine the most appropriate cutoff value among these three candidates and its effect on the results. The sensitivity analysis included calculating fish relocation speeds under each of the three HPE scenarios. Previous studies reported swimming speeds of up to 2.5 m/s in adult White Sturgeon (Webber et al. 2007), and up to 0.5 m/s in juvenile Shortnose Sturgeon (Deslauriers 2011). Histograms of fish swimming speeds were used to visualize which cutoff value resulted in unrealistically high swimming speeds in comparison to previously reported swimming speeds for sturgeons, an indication of inaccurate positioning. Based on the results of the sensitivity analysis (see Section 3.2) 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.

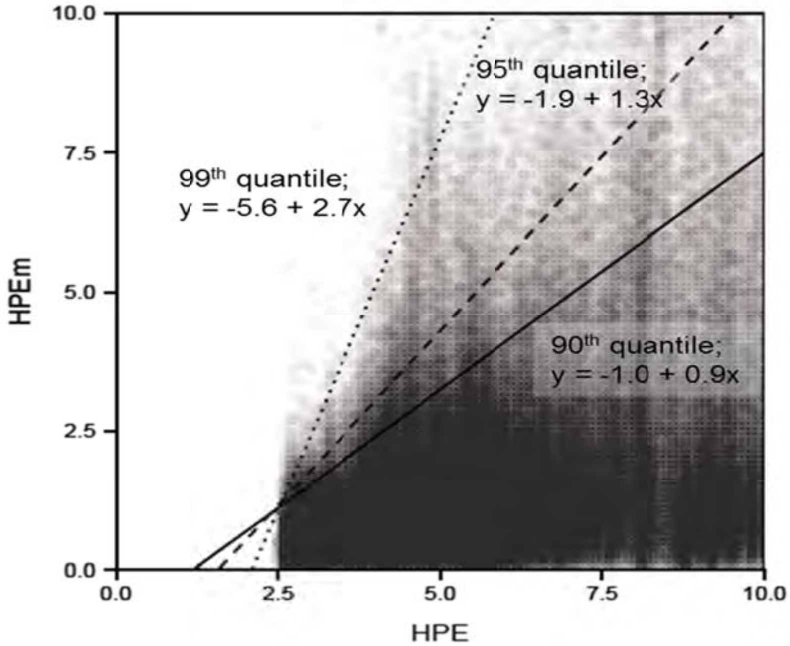

Figure 3: HPEm as a function of HPE for all synchronization and reference tags; points represent individual estimated positioning errors. A transparency value of 0.01 was imposed, hence at least 100 points must overlap to create a solid black point. The lines and equations of three regressions (90th, 95th, and 99th quantiles) are plotted (solid, dashed, and dotted lines, respectively).

In addition to data filtration using HPE values, data were also filtered according to the amount of time elapsed between tag locations. If a fish moved out of the VPS array and then returned, its minimum distance traveled and swimming speed estimates would be biased, as they would not include relocations outside of the array. To reduce the risk of such bias, we excluded all data points that were 0.5 h or more from the previous tag location. In this study, the great majority of data points had short time intervals between estimated positions (50^{th}, 75^{th}, 90^{th}, and 95^{th} quantiles equal to 2.8, 5.0, 8.7, and 12.8 mins, respectively), which suggested that in most cases, the source of error associated with the selected time interval was likely negligible.

The initial movements of fish released from a hatchery rearing environment may not represent “normal” behaviour in that the fish requires time to adapt to its new environment. To examine this possibility, we plotted the distances traveled in the first four weeks from release, binned by week (Figure 5). In addition, we plotted the spatial positions of the fish in these first weeks, to visually detect patterns in movements (Figure 6). Since during the first two weeks the fish exhibited higher use of the shallows than in the subsequent period (Figure 5, Figure 6), the first two weeks of VPS data were removed from all subsequent analyses.

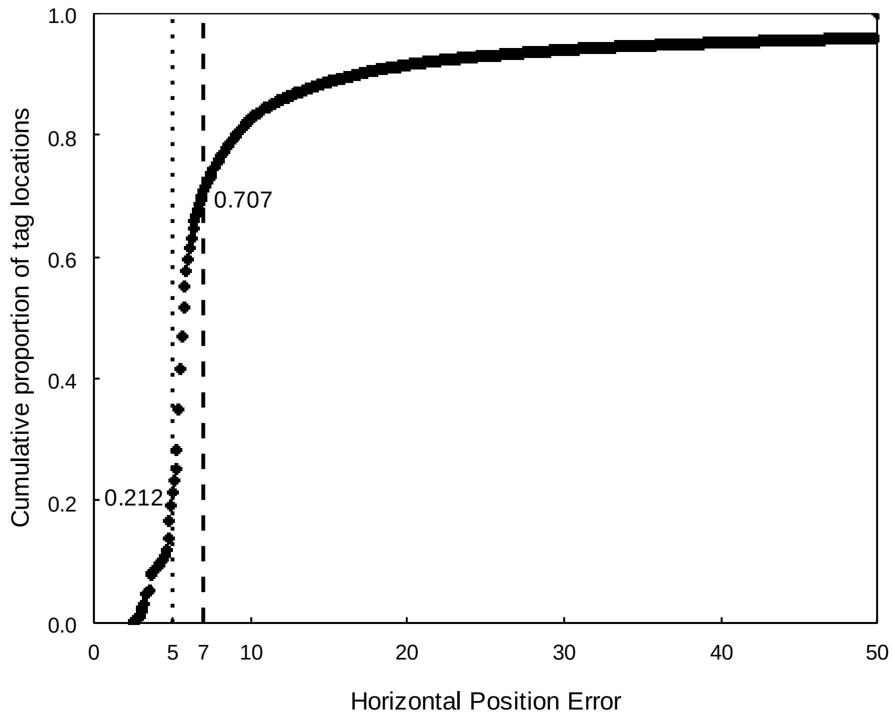

Figure 4: Cumulative proportion of tag positions in relation to HPE (Horizontal Position Error). The cumulative proportions of tag positions at HPE = 5 and HPE = 7 are provided on the graph.

Data obtained from telemetry studies are inherently pseudo replicated due to two factors: 1) the studies are based on (usually) a limited number of observed individuals, and 2) temporal autocorrelation is likely when observation times are short. Namely, a fish is likely to perform a type of activity, such as swimming at a given speed, for a time longer than the sampling unit, resulting in auto correlated sampling points. In-depth analysis, involving modeling and statistical inference, would be required to address this pseudo replication by treating individuals as random factors and utilising a temporal autocorrelation structure. While this study would benefit from such in-depth approaches, the analyses used were mainly descriptive, due to the addressed questions, and time and budget constraints.

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

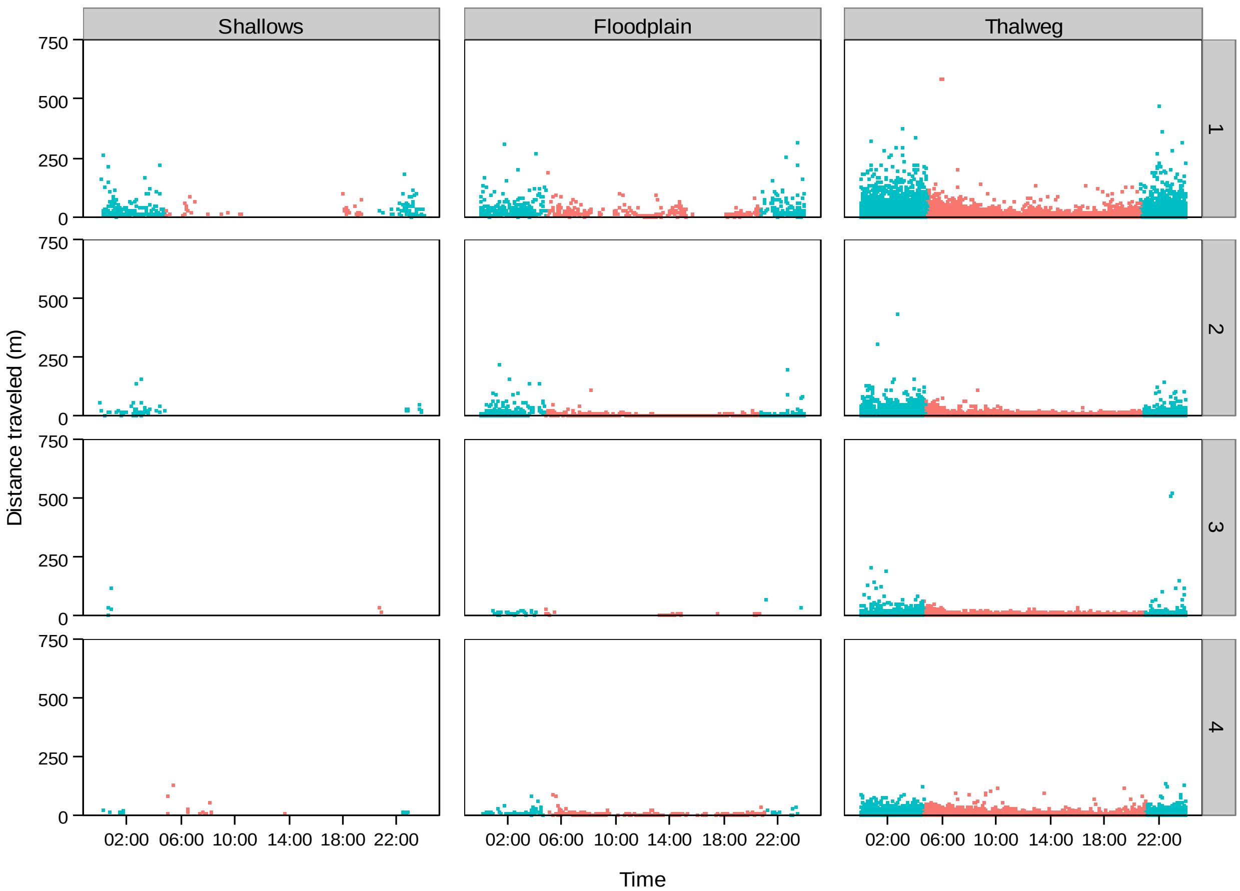

Figure 5: Minimum distance traveled between tag positions (m) by time of day, habitat classification (thalweg, floodplain, shallows), and week since the start of the study (1 to 4 on 2nd Y-axis). Point colour corresponds to daytime (orange) and nighttime (green). Note that day- and nigh-time periods overlap during the study, as sunrise and sunset times change during the spring, summer, and fall periods.

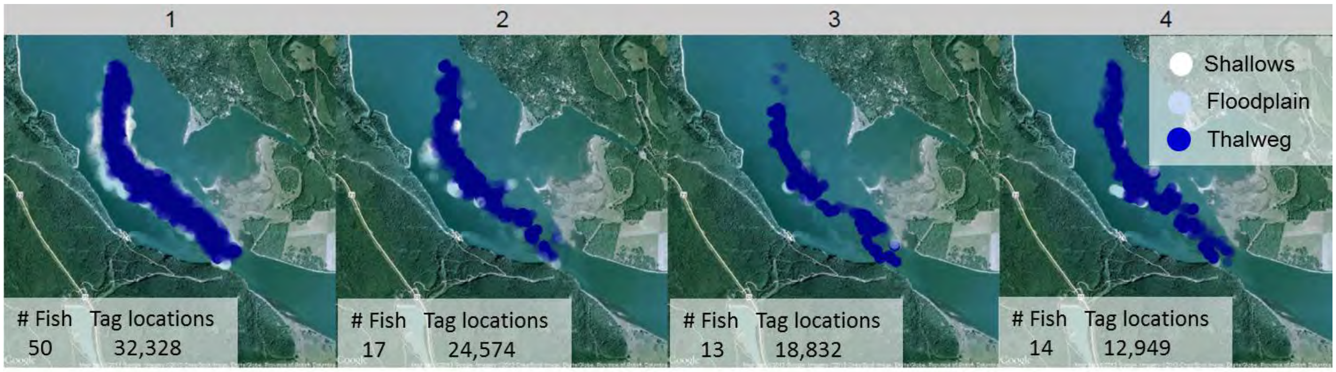

Figure 6: Spatial positions of juvenile White Sturgeon in the first four weeks of the study. Point colour corresponds to habitat classification (shallow, floodplain, thalweg) and each study week (1 to 4) is shown in a separate panel. The number of individuals and the tag positions in each week are provided on each panel. 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.

- 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 represent 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 ALR, 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; Figure 2) 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 (presumable 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.

3.0 RESULTS

3.1 Physical Parameters

3.1.1 Discharge, ALR Elevation, and Water Temperature

In 2012, mean daily discharge from Revelstoke Dam was above average for most of the year, and often approached or exceeded the maximum value observed since 2001 (Figure 7). Above-average snow pack loads and precipitation (Province of British Columbia River Forecast Centre 2013) contributed to the record high water discharges in the Columbia River in 2012. Discharge was exceptionally high during late July and early August when the spillway at REV was used for the first time since 1997. Discharge at Revelstoke Dam exhibited diel fluctuations that are typical of a facility that generates power based on demand (Figure 7). However, at the location of the VPS (approximately 35 km downstream from Revelstoke Dam), the effects of daily discharge variations from Revelstoke Dam were substantiality reduced because of the downstream attenuation and the moderating influence of the reservoir.

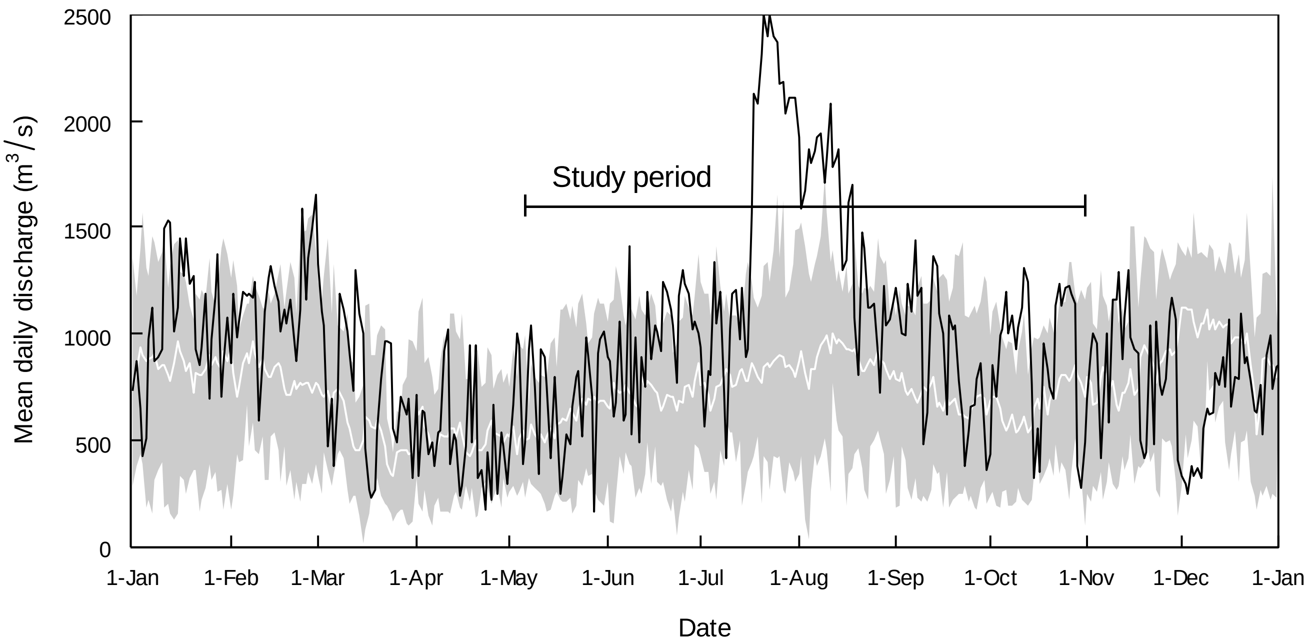

Figure 7: Mean daily discharge of the Columbia River at Revelstoke Dam, 2012 (black line). The shaded area represents minimum and maximum mean daily discharge values recorded at the dam from 2001 to 2011. The white line represents average mean daily discharge value. The study period is indicated by the horizontal bar.

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 8). In terms of reservoir operations, ALR was filling from May 15 to July 4, full from July 5 to 31, emptying from August 1 to September 27, and then stable until October 30. ALR elevation (measured at Nakusp) was low (430.34 to 433.74 masl) from May 15 to June 4, moderate (433.75 to 437.13 masl) from June 5 to June 18 and from August 29 to October 30, and high (437.14 to 440.53 masl) from June 19 to August 28 (Figure 8). This general pattern was similar to that observed in past study years (2007 to 2010) except that during 2012, peak reservoir level was higher than in previous study years. 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 9). Maximum depths in the floodplain area over the same period were typically from 5 to10 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).

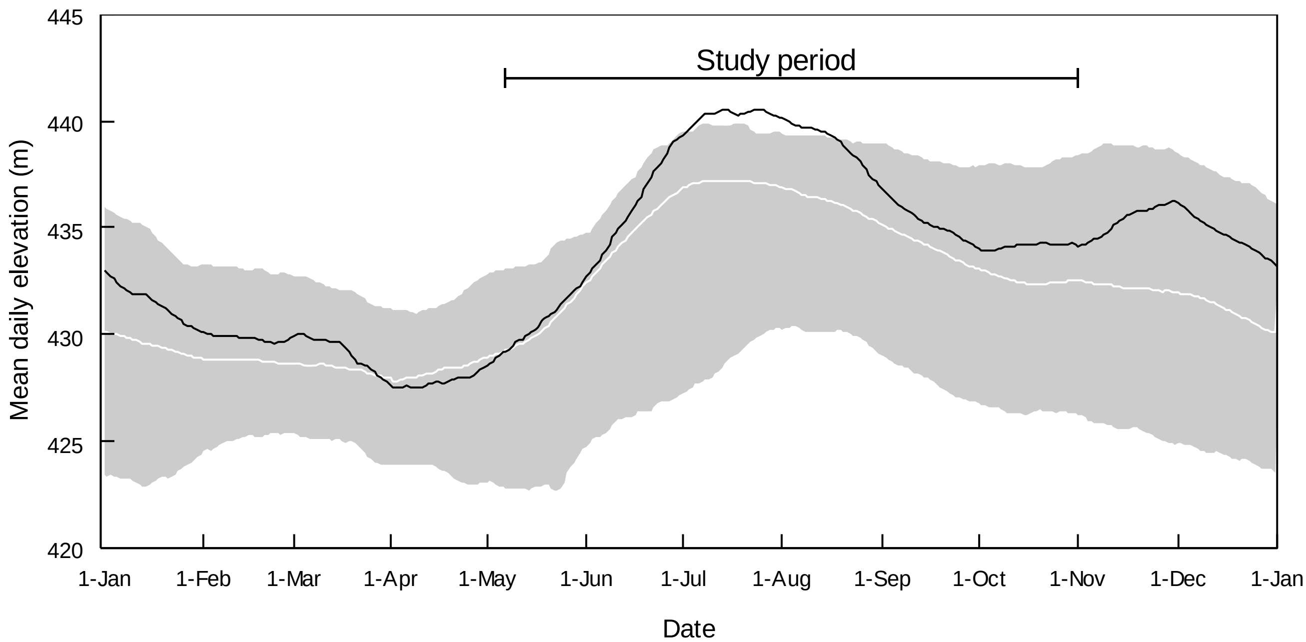

Figure 8: Mean daily water level elevation (in metres above sea level) for the Columbia River at Nakusp, 2012 (black line). The shaded area represents minimum and maximum mean daily water elevations recorded at Nakusp between 2001 and 2011. The white line represents average mean daily elevation value. The study period is indicated by the horizontal bar.

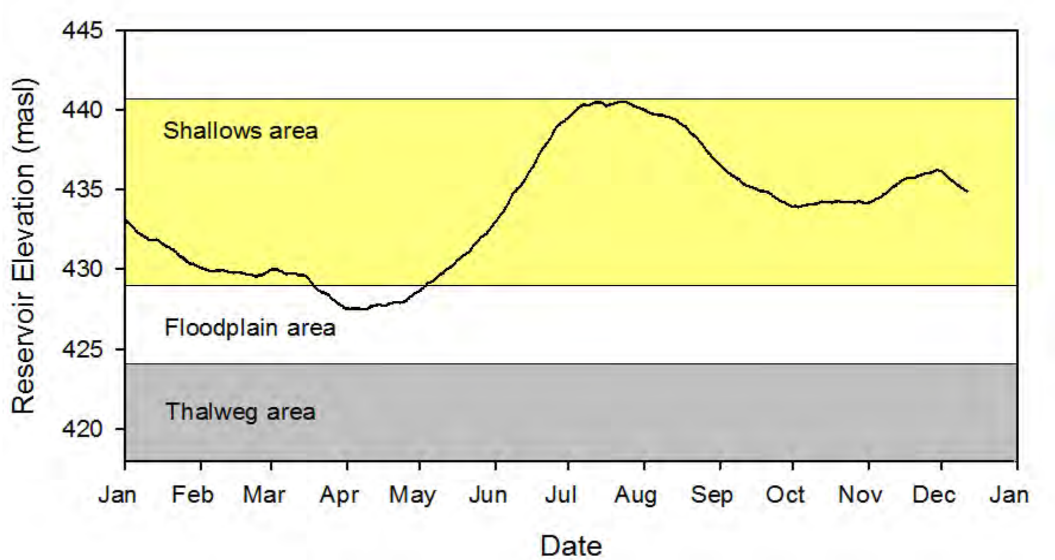

Figure 9: Mean daily water elevation (metres above sea level) of the Arrow Lakes Reservoir, and the resultant depths at the three habitat classifications (thalweg, floodplain, shallows).

From mid-May to mid-August 2012, near-bottom water temperatures in the study area increased (with some fluctuations) from 4.9°C to 13.0°C (Figure 10). Water temperature remained between 10.5°C and 12.8°C from mid-August to early October. Water temperature then gradually decreased to 8.1°C at the completion of the study on October 30. Near-bottom temperatures in the study area ranged from 4.2°C to 12.2°C from mid-May to mid-August, and decreased to 8.2°C on October 31, 2012 (Figure 10). Surface water temperatures, measured approximately 17 km upstream, were very similar to near-bottom temperatures, which suggests the water column in the study area remained well mixed over the spring to fall period and did not develop a thermocline.

3.1.2 Habitat Measurements

Physical habitat measurements taken at four representative locations within the study area during the VPS downloading sessions are summarized in Appendix B, Table B1. 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 the August site visit (Figure 11). Mean turbidity was typically low (≤3 NTU) at all sites except during the July sampling session (6 NTU; Figure 11). 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.

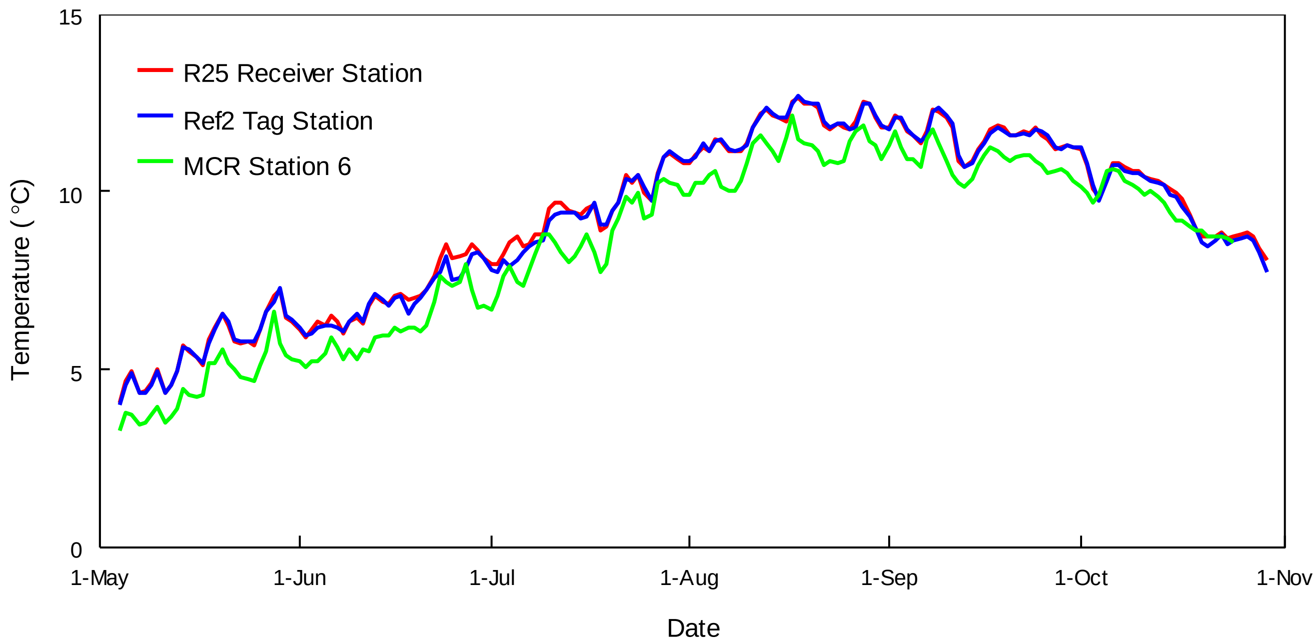

Figure 10: Near-bottom water temperatures in the Middle Columbia River juvenile White Sturgeon study area from May 1 to November 1, 2012 (R25 and Ref 2 stations), and surface water temperatures at Station 6 of BC Hydro's Middle Columbia River Physical Habitat Monitoring Program, located approximately 17 km upstream of the study area.

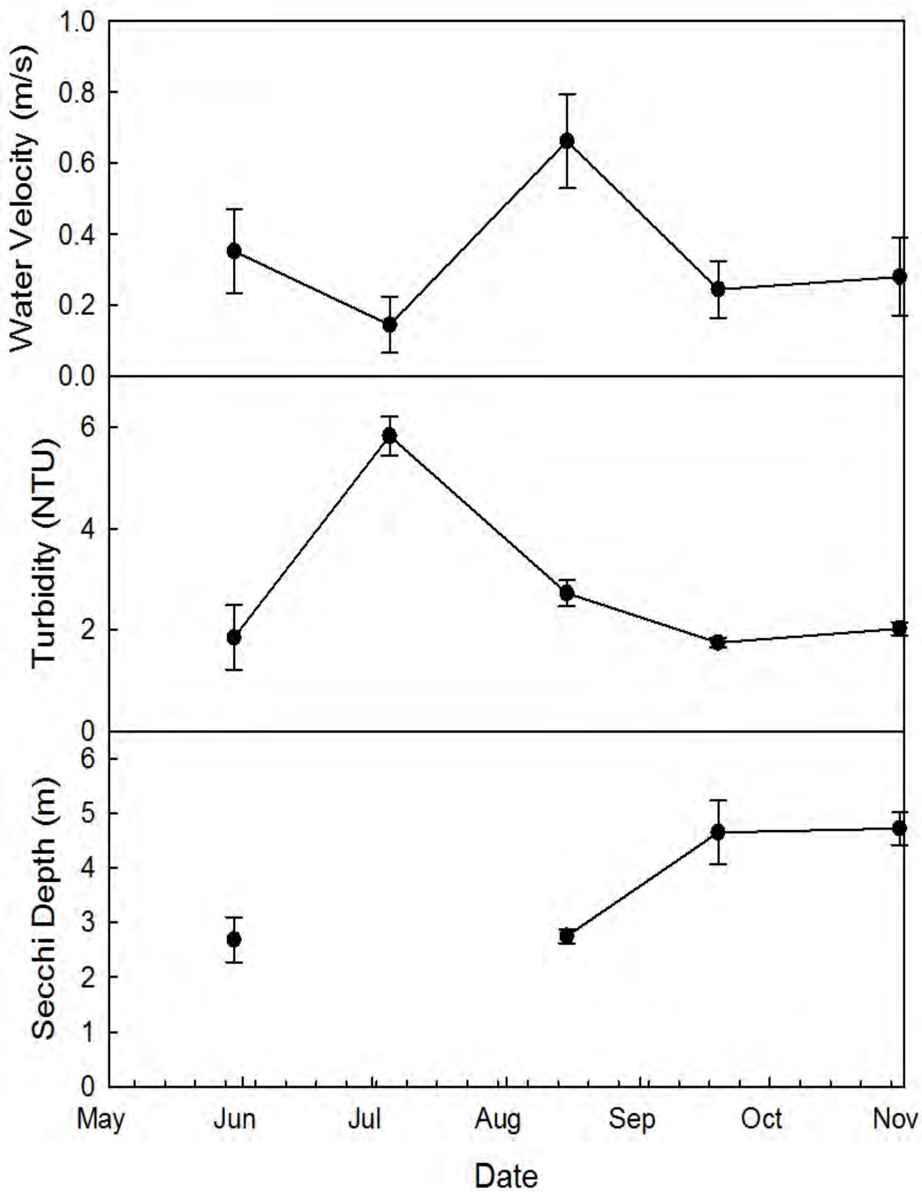

Figure 11: Physical habitat variables measured at four locations within the Middle Columbia River VPS study area at approximately monthly intervals between May 30 and October 30, 2012. Black dots represent the mean values and horizontal bars are standard deviations.

3.2 Juvenile White Sturgeon Movements and Habitat Use

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. 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 (Figure 12). 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 2.4.5), 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.

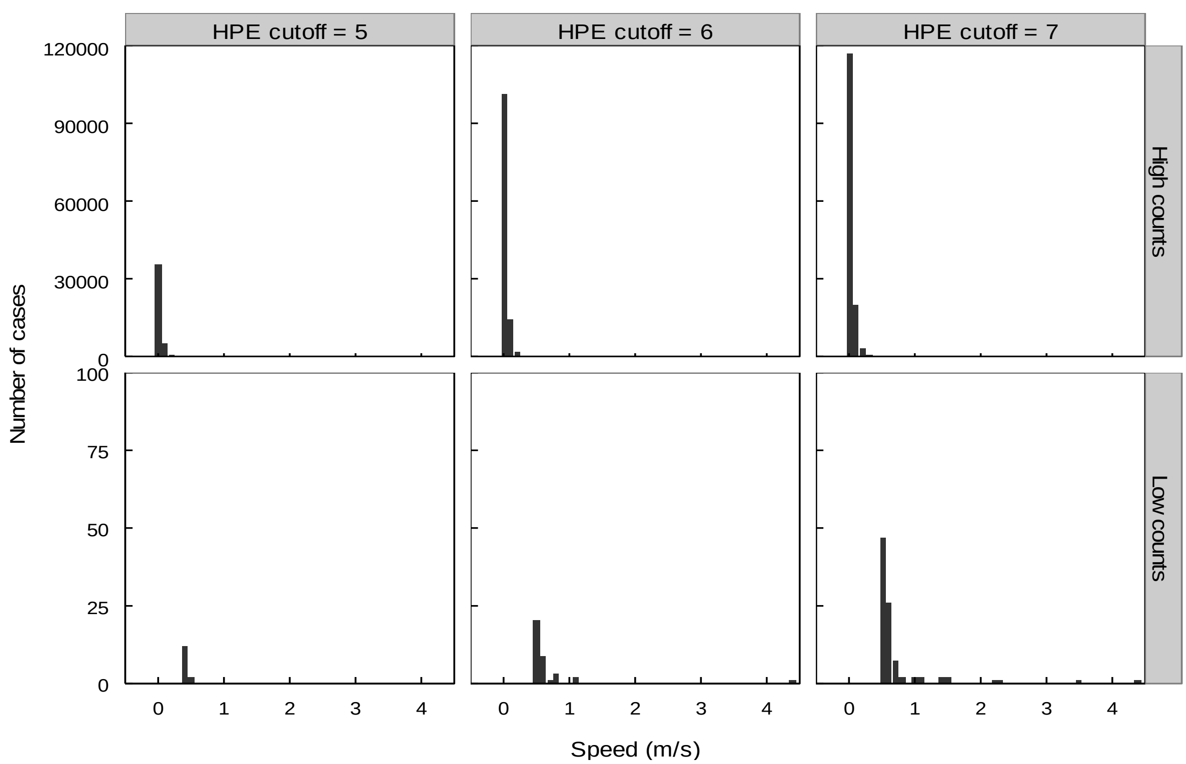

Figure 12: Sensitivity analysis showing histograms of estimated swimming speeds (m/s) derived from the main dataset, restricted by three HPE cut-offs (HPE = 5, 6, and 7). Swim speeds that were frequently recorded are shown in the top panel (High counts) and swim speeds with only a few observations are shown in the bottom panels (Low counts).

Tag locations by time of day, season, and habitat depth classification (Figure 13) 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).

Minimum movement speeds changed seasonally, with highest rates estimated in the summer, in comparison to spring and fall months (Figure 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 (see Table 4 for breakdown by season and habitat type). 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).

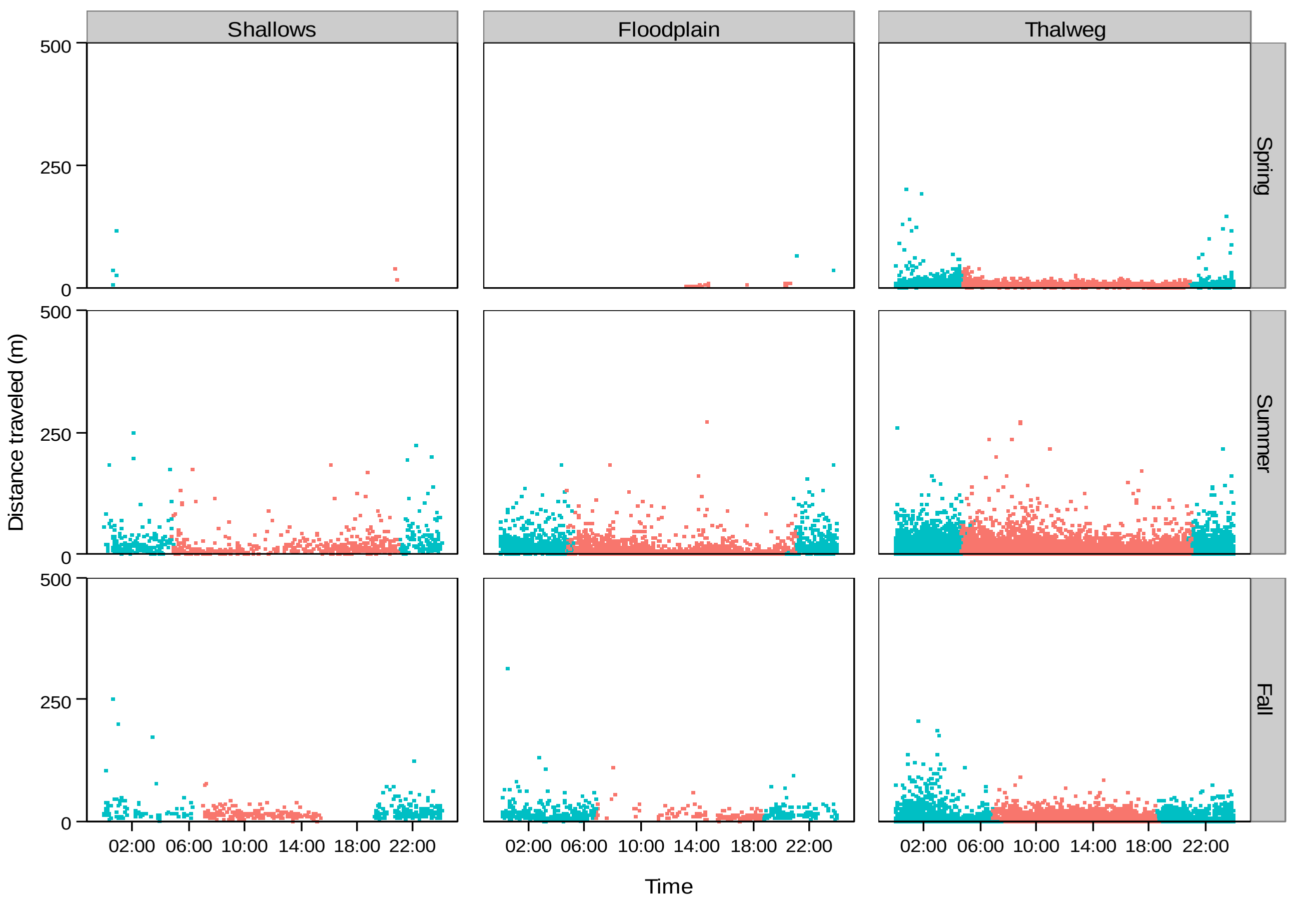

Figure 13: Minimum distance traveled between positions (m) of White Sturgeon juveniles in the VPS array, plotted by time of day, season, and habitat classification (thalweg, floodplain or shallows).

Juvenile White Sturgeon were observed to use shallow water under all ALR elevations (Figure 15). 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 (25th, 50th, and 75th quantiles of 0, 0.9, 2.1, and 4.9 m; Figure 15).

Table 5: 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	Summer	Fall
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

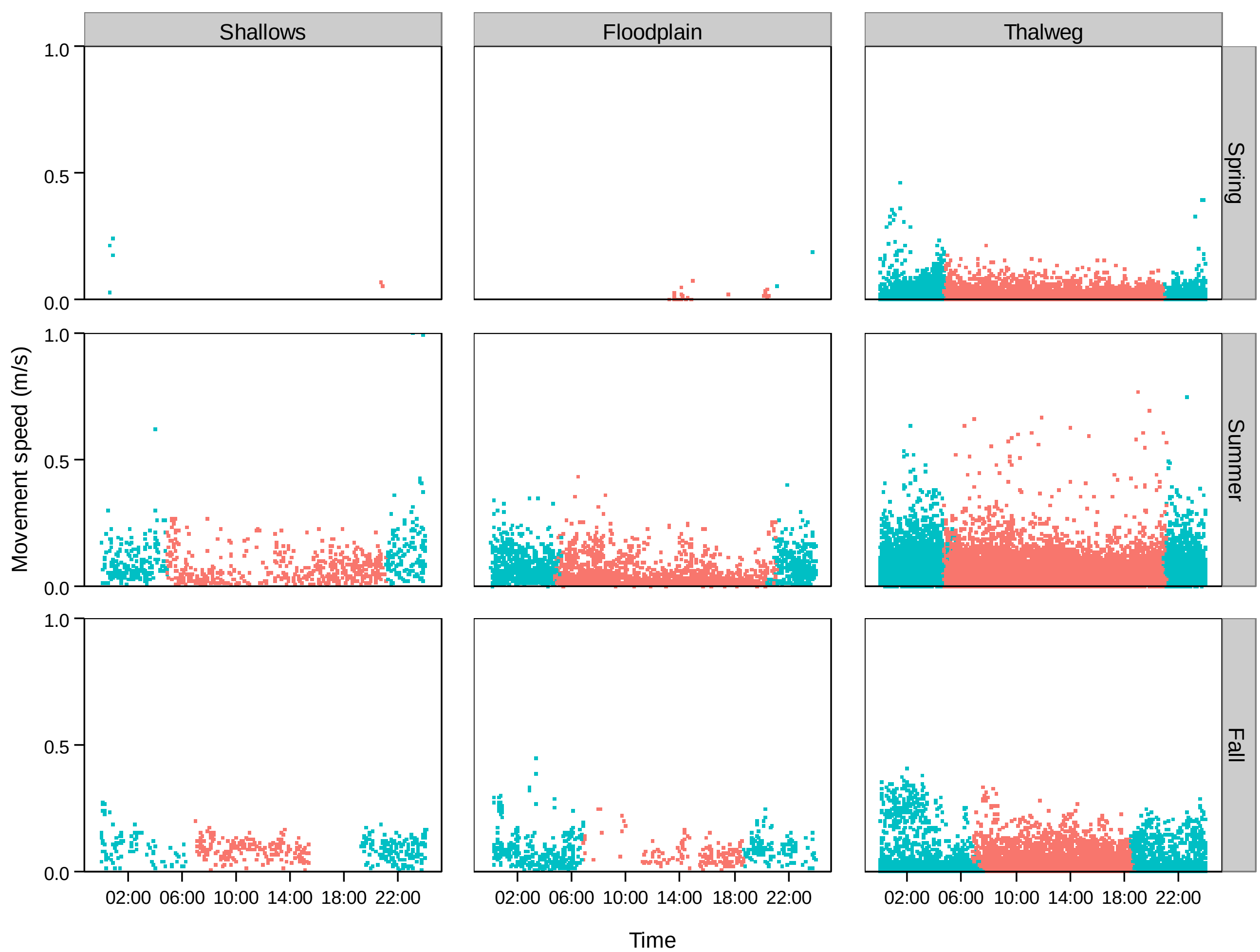

Figure 14: Estimated minimum movement speeds (m/s) of juvenile White Sturgeon in the VPS array, plotted by time of day, season, and habitat classification (thalweg, floodplain or shallows).

Half of the released 50 juveniles (*n* = 25 fish) were only recorded during the spring session and were absent from the study area in the summer and fall. Of the remaining 25 that stayed in 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 study period, juvenile White Sturgeon spent 0.03% to 25.3% of the time within the VPS array (mean ± SD = 4.8 ± 6.0%, median = 6.6%). These estimates are conservative, since they only take into account data of HPE ≤ 7. Under no HPE restriction, time spent in the array ranged between 0.03% and 31.2% (mean ± SD = 6.1 ± 7.3%, median = 2.3%).

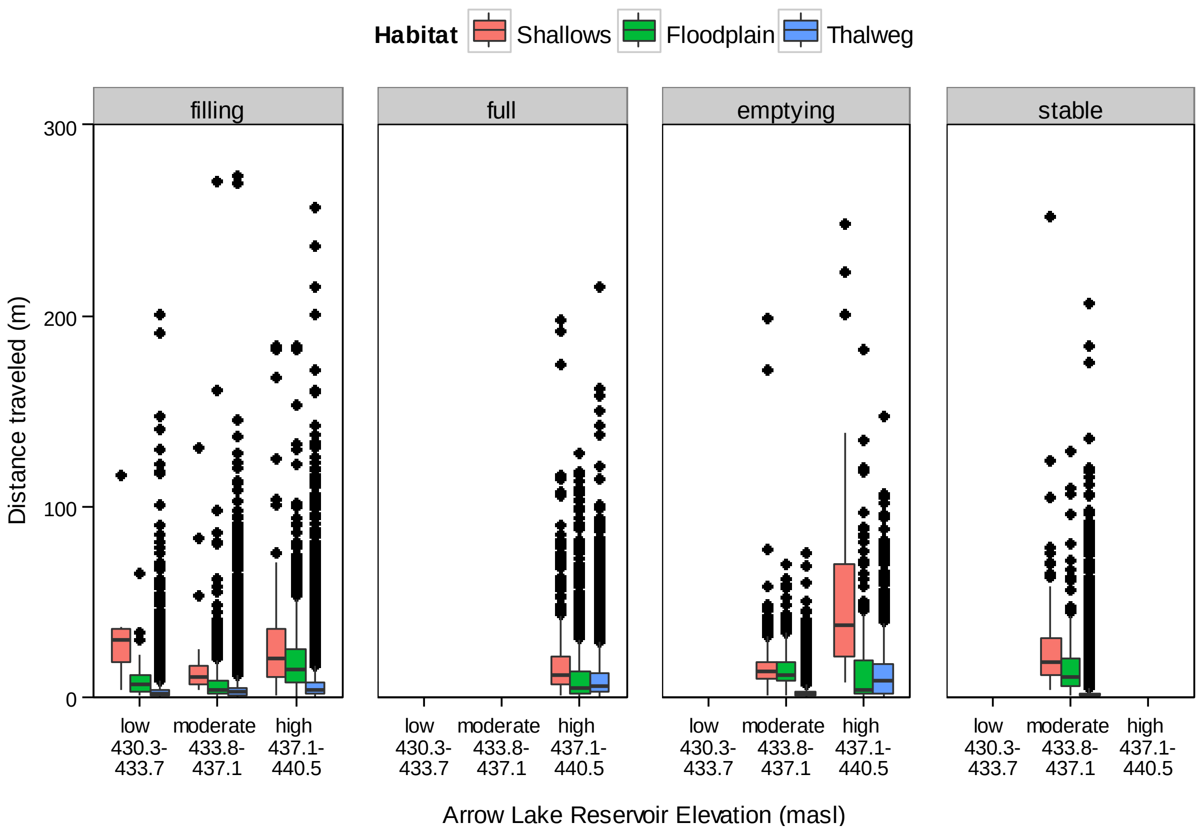

Figure 15: Boxplots of minimum distance traveled between tag positions (m), separated by habitat classification (thalweg, floodplain or shallows), ALR elevation (low, moderate, and high), and ALR status (filling, full, emptying, and stable). Each box represents the 25th and 75th quantiles (bottom and top lines, respectively), and the median (middle, bold line); whiskers extend to 1.5 times the interquartile distance; outliers are shown as individual points.

The fish that left the VPS array after the first two weeks of the study showed high individual variability in movement patterns and habitat use (Figure 16). Some were only located a few times prior to leaving the study area (e.g., WSG35, WSG47, WSG49). Those that stayed longer either stayed only in the thalweg (WSG33, WSG40) or utilised the floodplain (WSG10, WSG31). The length of their presence within the VPS array ranged from one day (WSG49) to 14 days (WSG35, WSG12; mean presence period of 5.3 days, median of 4.0 days). In total, six sturgeon left the array in the upstream direction within the first two weeks; three of the fish were released in the downstream location (RKm 202.5), and three were released in the upstream location (RKm 203.3). Out of the 19 sturgeon that left the array in the downstream direction, 10 fish were originally released in the upstream site (RKm 203.3).

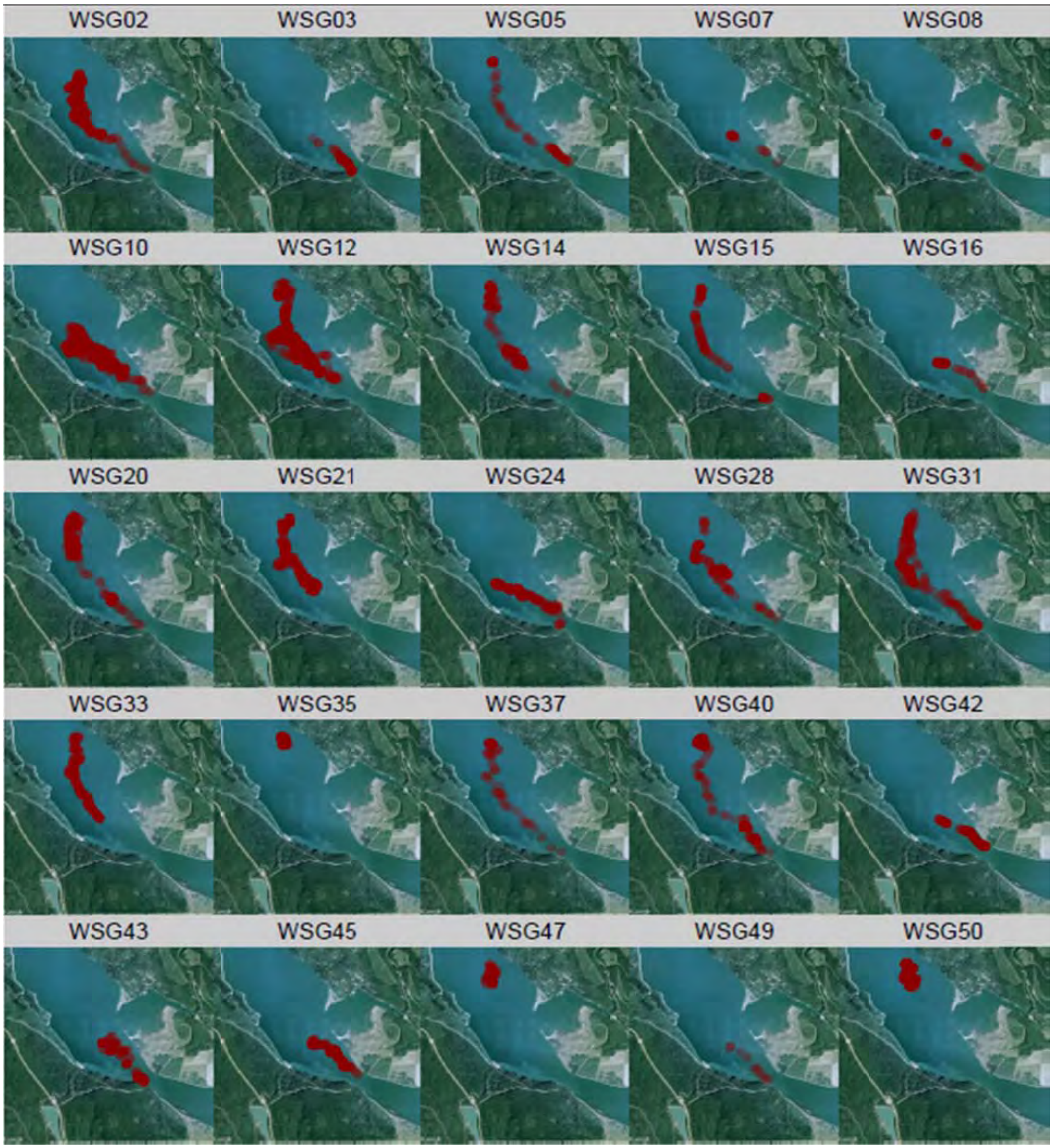

Figure 16: Mapped locations of individual juvenile White Sturgeon that were only detected in the first two weeks of the study (May 15 – May 28, 2012). Fish positions were plotted as partly transparent, to show differences between areas used rarely (transparent) and often (solid). Maps are based on Google Earth maps, taken Dec-31-2001, when ALR elevation at Nakusp was approximately 423 m.

Seasonal differences in fish locations were apparent (Figure 17). 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 (Figure 18). For example, in the summer, 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.

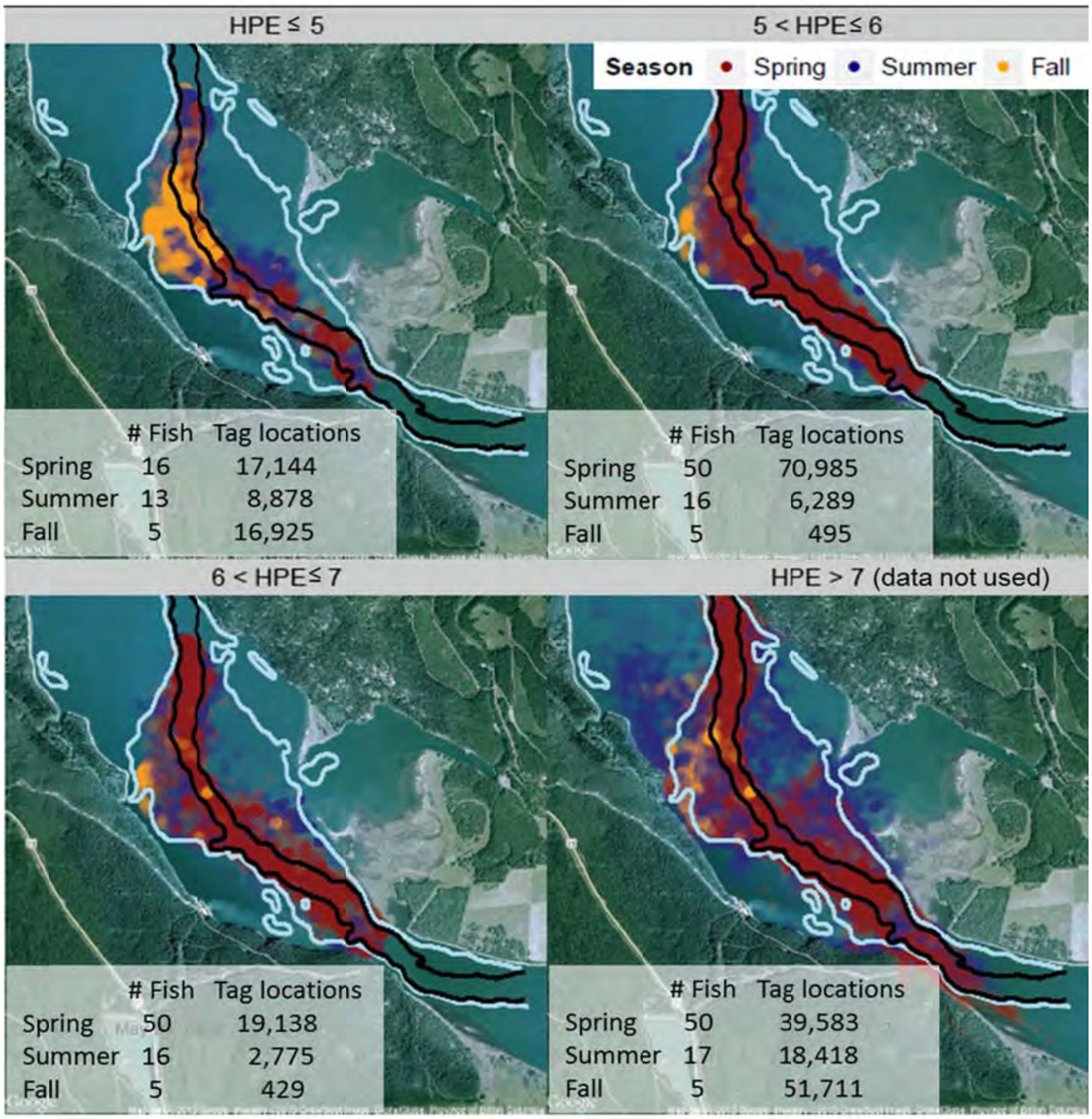

Figure 17: Mapped positions of juvenile White Sturgeon within the VPS array. Panels show the positions included using various HPE cutoff values. Point colour corresponds to season, and colour strength corresponds to use, with more solid colours representing heavier use. The thalweg and floodplain contours are shown as black and light-blue lines, respectively. The number of fish and positions in each season within each HPE stratum are provided in the facets. 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 after the first two weeks post release are shown.

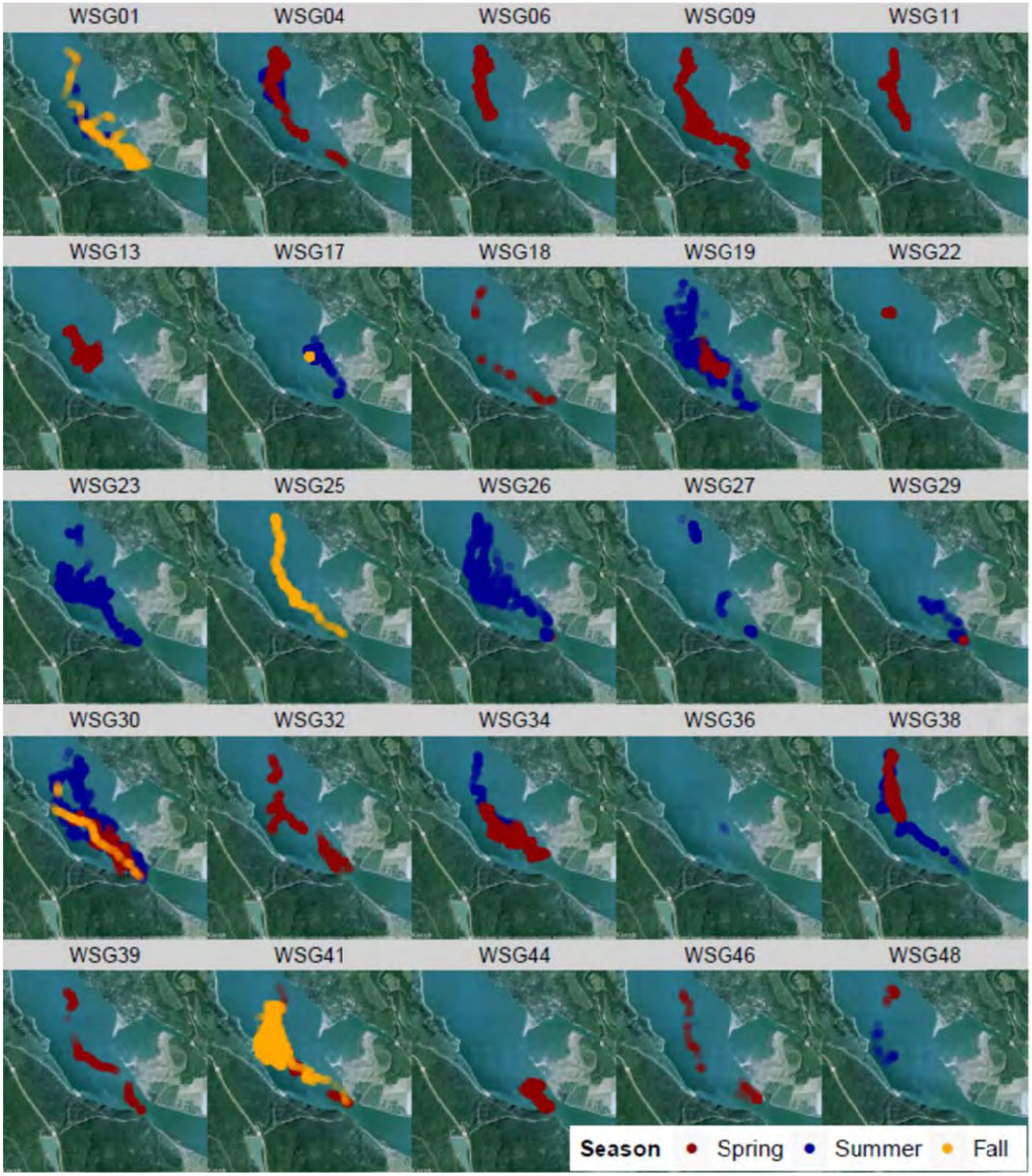

Figure 18: Mapped positions of juvenile White Sturgeon within the VPS array, shown by season and individual tag number (WSG01-WSG50). Only tag locations starting from week three of the study are shown, as detailed in Section 2.4.5. Fish positions were plotted as partly transparent, to show differences 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.

In addition to individual variability, the choice of HPE cutoff value also had considerable effect on the emerging pattern of habitat use (Figure 17 and Figure 19). With an increase in the HPE cutoff value, more fish were positioned in the shallower parts of the study area. For example, while at HPE ≤ 5 spring-time use of habitat was restricted to thalweg only, at 5 ≤ HPE < 6, the floodplain habitat was used as well (Figure 19). The stratum of HPE > 7, not used for other analyses, exhibited the greatest use of shallows among all strata.

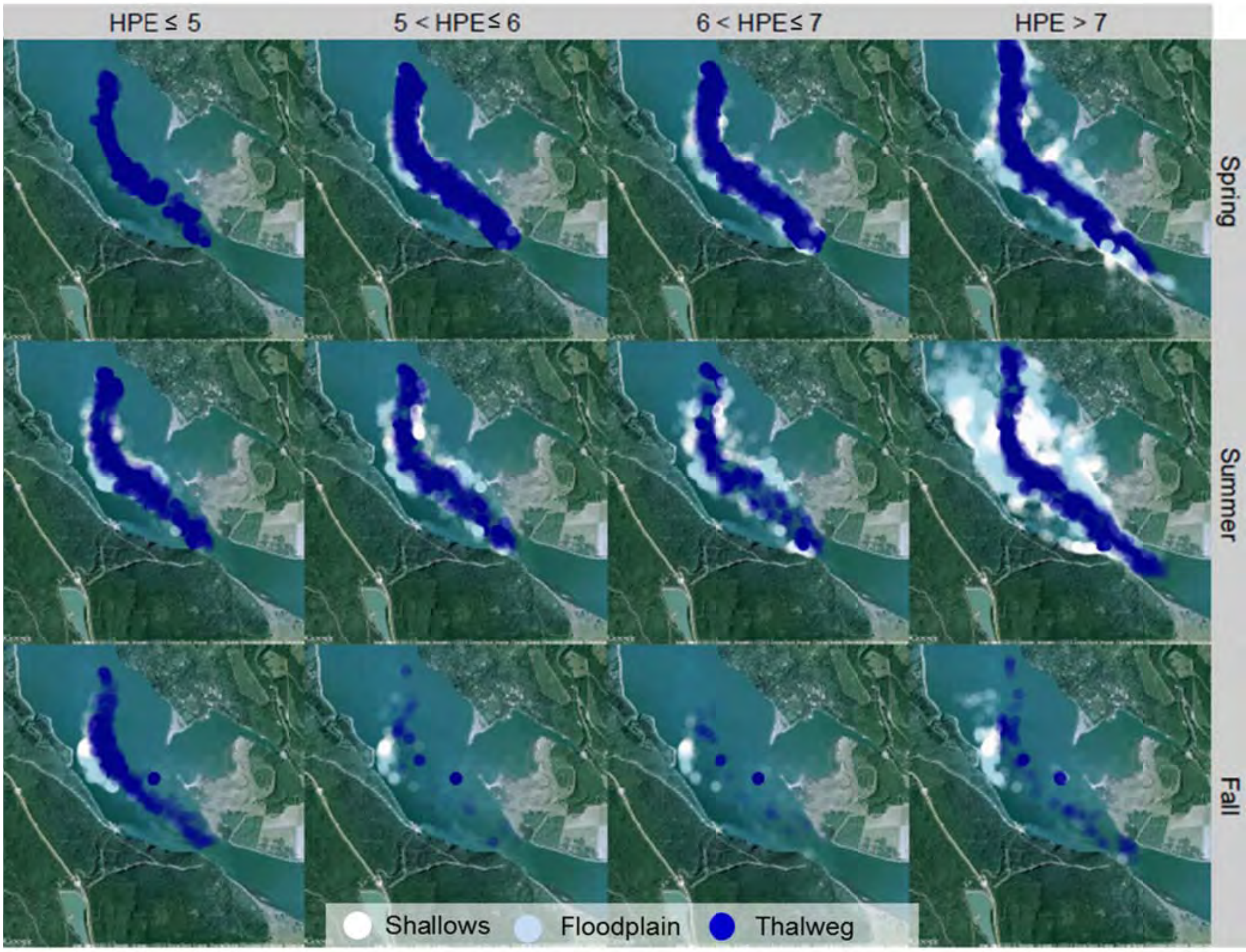

Figure 19: Spatial distribution of juvenile White Sturgeon, by season and HPE cutoff values. Point colour corresponds to habitat classification (shallows, floodplain, or thalweg). Maps are based on Google Earth maps, taken Dec 31, 2001, when ALR elevation at Nakusp was approximately 423 m.

The extent of minimum daily movement (daily distance traveled by individual fish) varied by season and habitat type (Figure 20). 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).

The total movement (minimum distance travelled throughout study period) ranged between 117 m and 50 770 m (median = 13 849 m). The total 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).

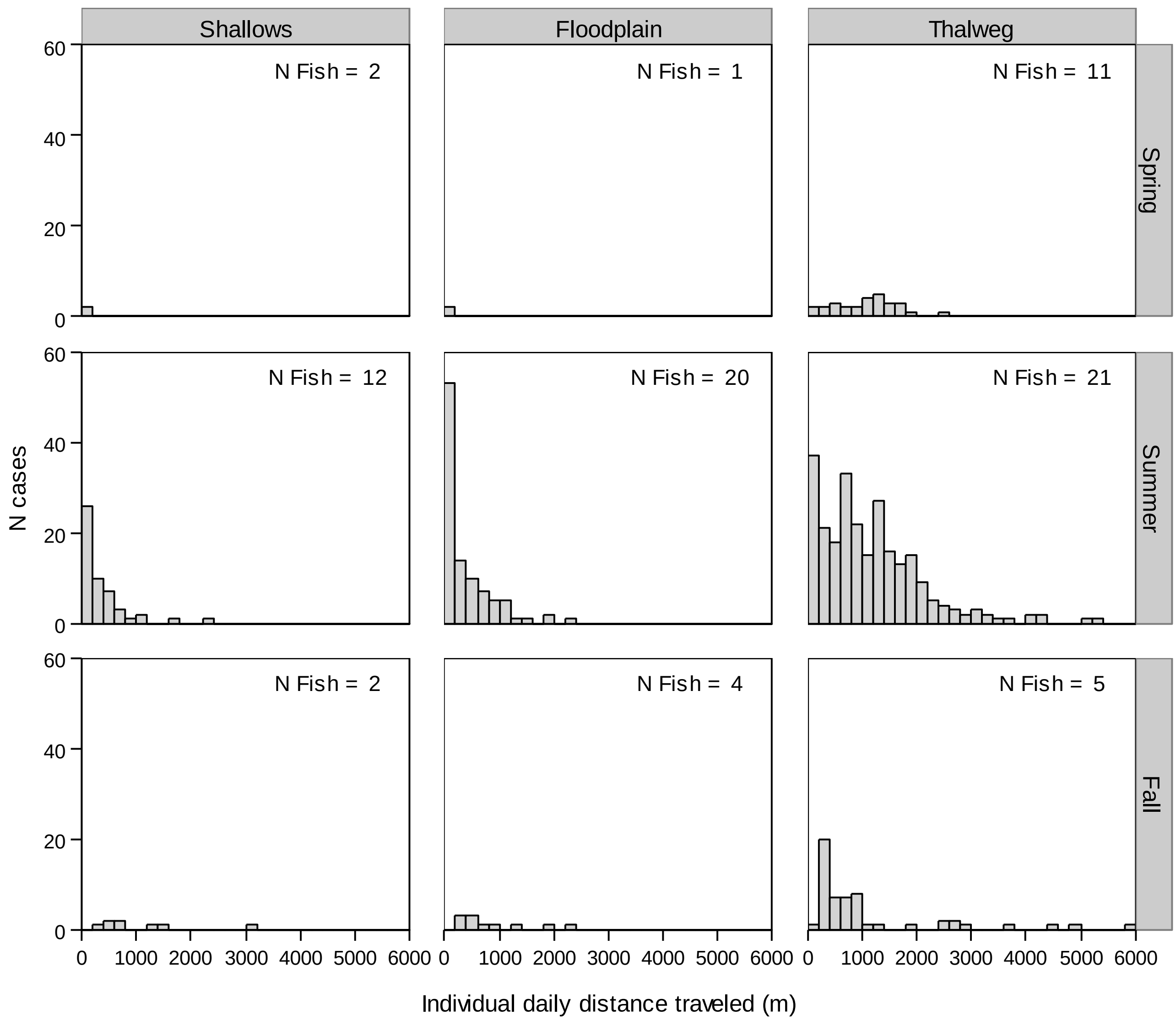

Figure 20: Histogram of minimum daily distances traveled by individual juvenile White Sturgeon, by season and habitat classification. (shallows, floodplain, or thalweg). The number of fish (N cases) within each stratum is provided; plots include only positions that were at most 0.5 h apart.

The number of sampled days in each season during the study varied greatly, especially after removal of the first two weeks of sampling data to account for fish acclimation. The summer season accounted for the majority of the sampling period (June 21 to September 20), whereas sampling in the spring occurred for less than a month (May 29 to June 20), and sampling in the fall was slightly longer than a month (September 21 to October 30). 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 20), whereas the total distribution of June movements shows increased use of shallows and thalweg (Figure 21). The decrease in use of non-thalweg habitat occurred in October. While in September juvenile White Sturgeon traveled over 2,000 m in the floodplain and shallow areas, in October only two records, both at or below 500 m, were observed (Figure 21). The shifts in behaviour in late June and (likely) early October suggest that the division by season used in this study is appropriate.

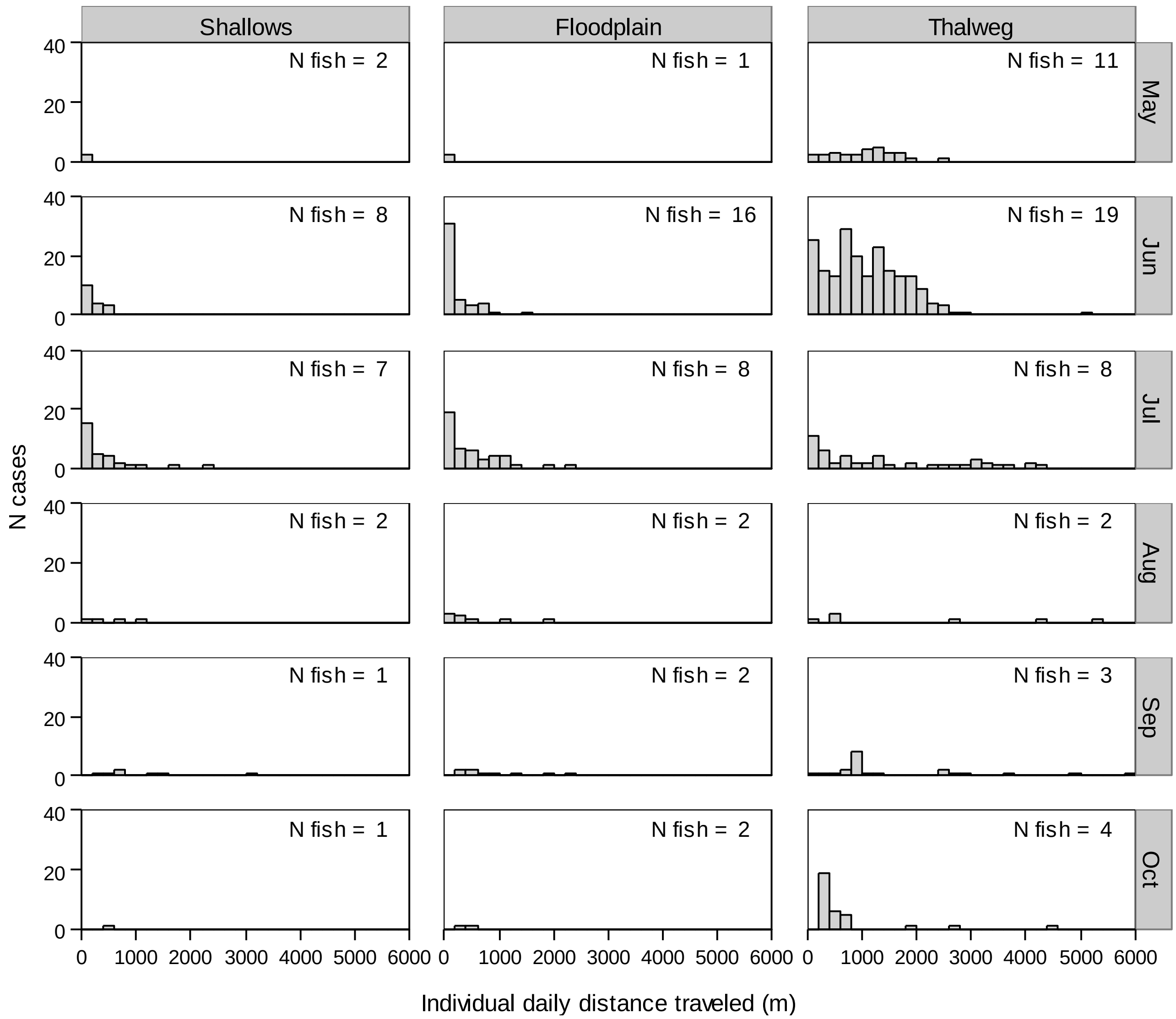

Figure 21: Histogram is of daily distances traveled by individual juvenile White Sturgeon, classified by month (May to October) and habitat. The number of fish within each stratum is provided on each panel. Note that the period shown for May only includes May 29 - 31; plots include only positions that were at most 0.5 h apart.

The daily length of time spent in the different habitat classifications also changed with season (Figure 22). In the spring, juvenile White Sturgeon spent very little time in the shallows and in the floodplain, and spent most of the time (10 to 24 h per day) in the thalweg area. In comparison, in the summer, the distribution in the thalweg stratum became bimodal, with many cases of both limited (0 to 4 h) and prolonged (23 to 24 h) time spent within the thalweg. The use of the shallows and floodplain strata increased as well, with some juveniles spending up to 14 h in the floodplain. In the fall, the majority of the time was spent in the thalweg (distribution mode = 24 h).

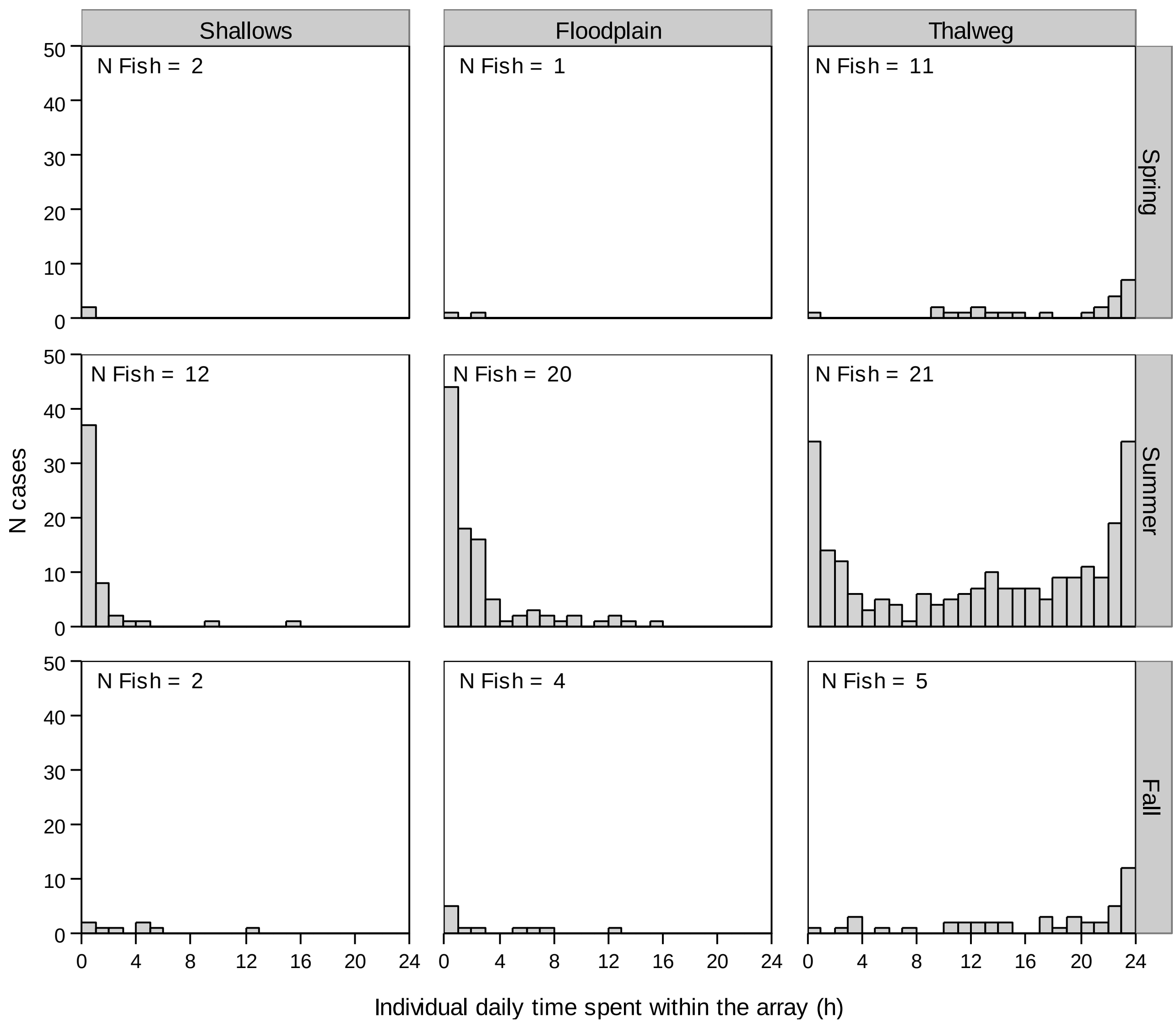

Figure 22: Histograms of daily lengths of time spent by individual juvenile White Sturgeon within each habitat depth classification in each season. The number of fish recorded within each stratum is provided within the panel; plots include only positions that were at most 0.5 h apart.

The division of time spent in different habitat classifications by month rather than by season provided similar findings (Figure 23). 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 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 23).

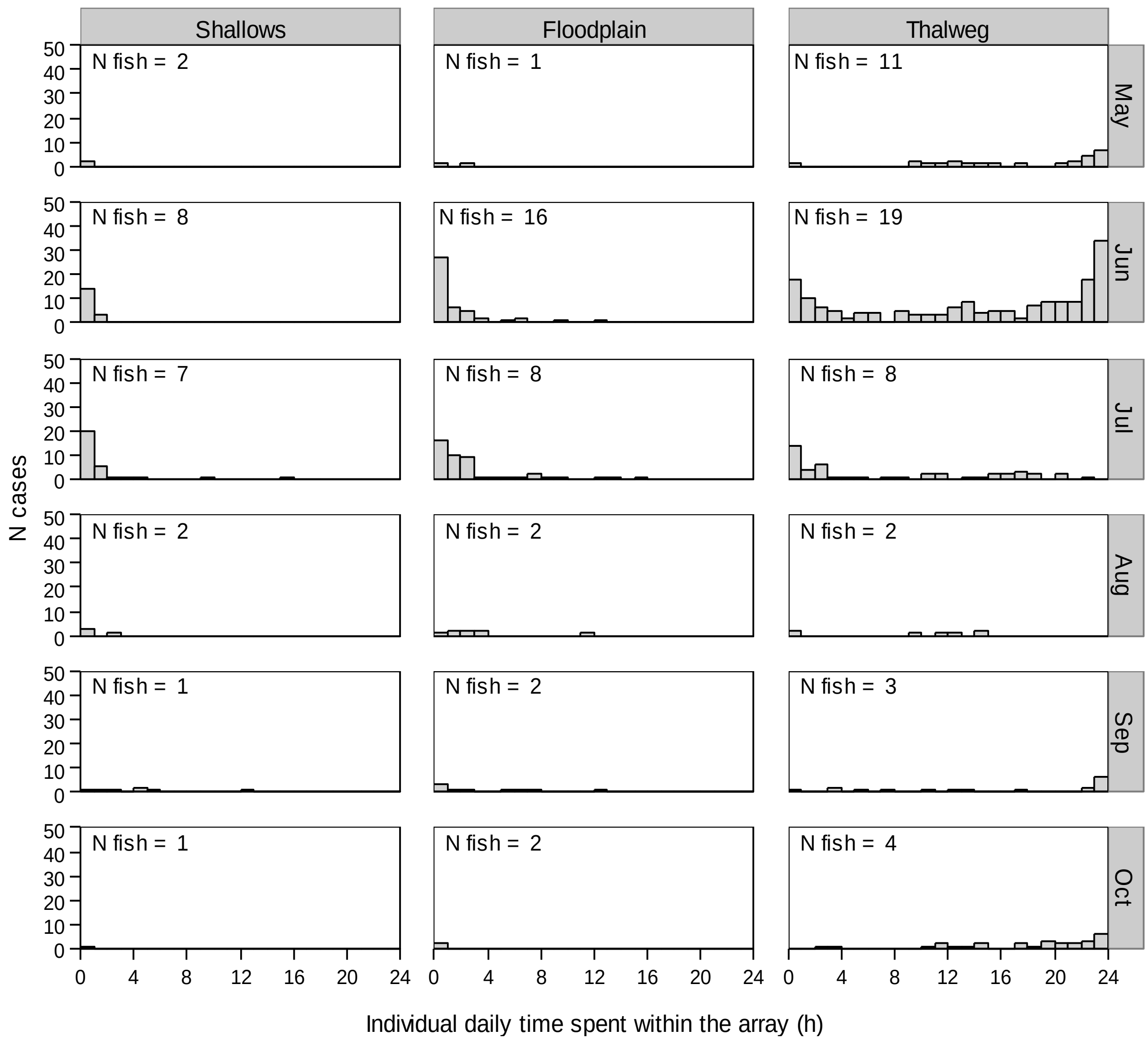

Figure 23: Histograms of daily lengths of time spent by individual juvenile White Sturgeon within each habitat classification in each month. The number of fish recorded within each stratum is provided within the panels. Note that the period shown for May only includes May 29 - 31; plots include only positions that were at most 0.5 h apart).

Based on a visual assessment of plotted data, there were no clear relationships between traveled distance or movement speed and discharge throughout the study period (Figure 24).

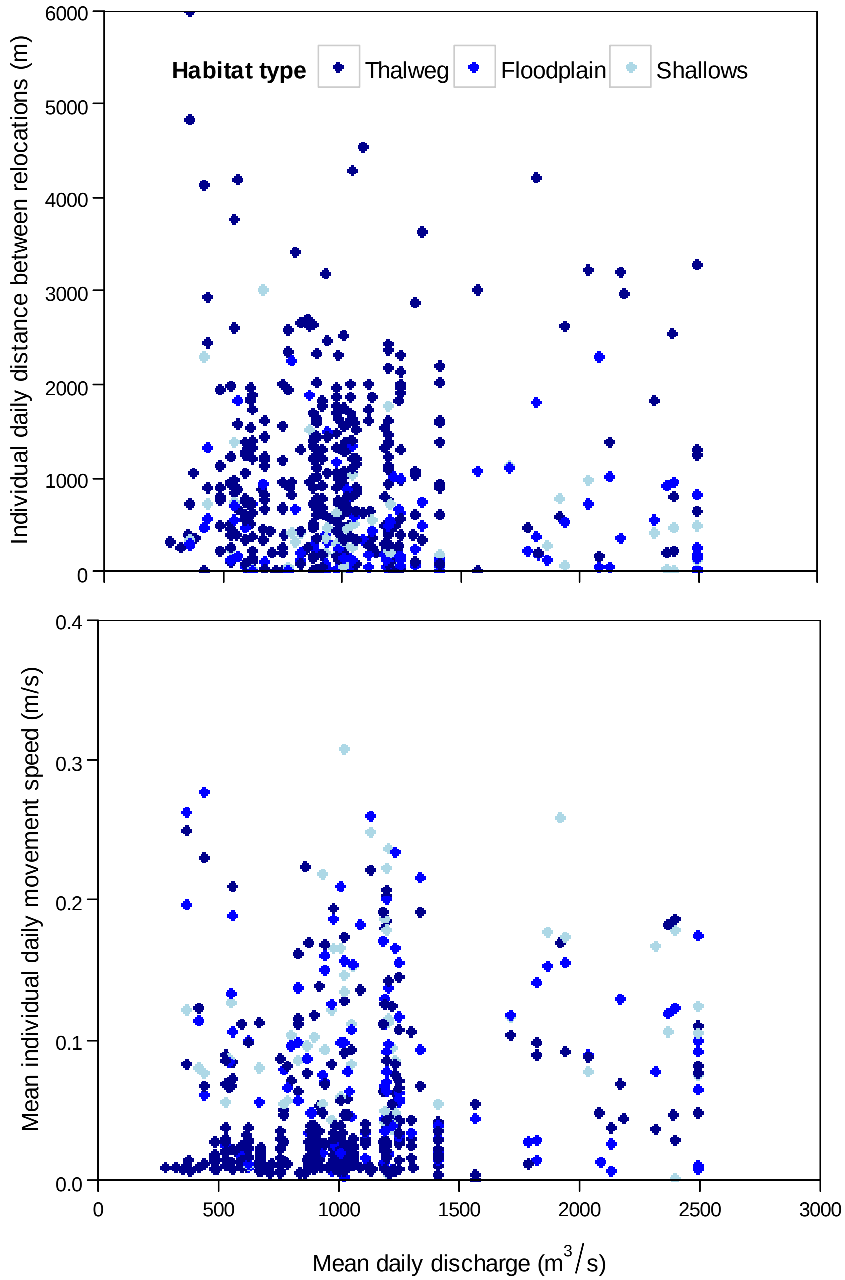

Figure 24: Daily individual minimum distance traveled between tag locations (top) and minimum daily average movement speed (bottom) versus daily average discharge; point colour represents habitat classification (thalweg, floodplain, shallows).

Plots of sturgeon movements in and out of the Akolkolex River indicated that juvenile White Sturgeon were found in the Akolkolex bay area more often in daytime than nighttime (Figure 25). The majority of the fish recorded by the mouth of the Akolkolex were categorized as fish that remained within 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 cases, and 28 nighttime cases), and 75 cases in the fall (44 daytime and 31 nighttime). The frequency of return of fish into the array in the Akolkolex area was similar to the frequency of leaving the array (Figure 25). Overall, the results indicate that juvenile White Sturgeon did not foray into the Akolkolex River 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.

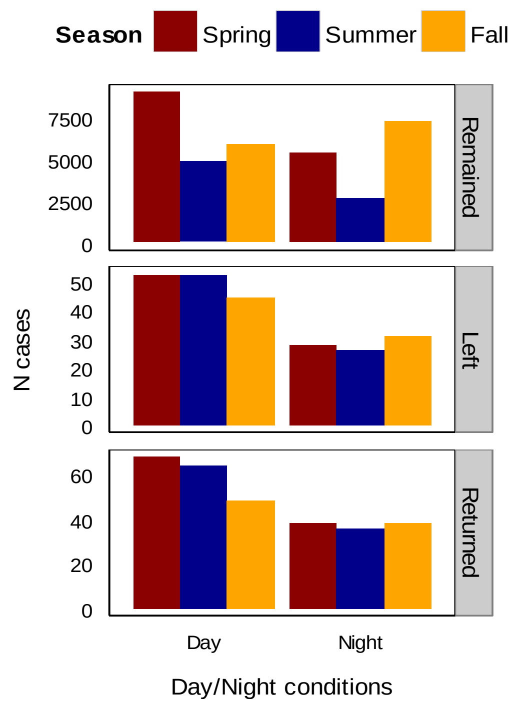

Figure 25: Number of positions based on detections of juvenile White Sturgeon (N cases) at the three receivers near the Akolkolex River mouth by season. Different panels show detections for fish that remained within the telemetry array (recorded continuously on at least one of the three receivers) near the mouth of the Akolkolex River, left for more than 0.5 h, or returned to the array after at least 0.5 h of being undetected.

4.0 DISCUSSION

In this study, the VPS array was effective in collecting the data required to address the study objectives. Once the data were filtered and processed, they described fine-scale movements (HPE ≤ 7) of juvenile White Sturgeon released in the area of the VPS. The resulting data allowed analysis of movement patterns versus daylight, habitat type, ALR status, and season and supplied information on the behaviour of the tracked fish, which was used to recommend refinement of future sampling programs. While the VPS was effective at collecting movement data, the restricted spatial extent of the array that resulted from the required proximity between VR2W units and the cost of equipment, meant a high proportion of fish left the study area over the course of the study period (i.e., half of the released 50 fish left the array area within two weeks from release). Sample size continued to decrease throughout the period of the study and only five fish remained in the area in the fall. In general, the VPS approach provided an effective means of sampling fish movements as long as the tagged individuals remained within the study area; however, the restricted size of the array prevented us from monitoring the movements of higher numbers of fish over an extended time period.

4.1.1 VPS effectiveness

The effectiveness of acoustic receivers detecting transmitter signals is influenced by water velocity, turbidity, and water temperature, especially thermocline formation. We measured low velocities and turbidity values between April and October and temperature data indicated near isothermal conditions throughout the water column in the study area. This indicated physical conditions for detection of transmitters by the VPS array were favourable and increased confidence in the accuracy of positioning data obtained during this study.

The main sources of errors in position estimates include:

1) the accuracy of the GPS unit used to record the positions of reference and synchronization tags and receivers.

2) errors associated with the theory of movement of sound through water; the theoretical values of sound propagation as a function of temperature, depth, etc., are used in VPS analysis by Vemco.

In this study, a handheld GPS unit was used to record the positions of the receivers and the sync tags. In comparison, a differential GPS unit (DGPS) would offer accuracy of up to 10 cm, provided best implementation. The second source of error, stemming from sound propagation theory, could have a major effect in this study. When error extent is low, there is a strong relationship between HPE and HPEm values of receivers and sync tags. In this study, no strong relationship was observed between the two variables, which indicated potentially high errors of HPE estimates. However, the use of HPE cutoff values restricted the use of VPS data to reasonably accurate data points only. The array's HPEm values, the distance between true and VPS-estimated locations of sync tags, were low (95^{th} quantile of 4.2 m). These values should be interpreted in context of the distance between receivers (approximately 300 m) and the total length of the array (approximately 3 km). The relative importance of the positioning error is, therefore, negligible within the context of this study, as the precision of tag locations was suitable for the scale of movements and behaviour that were of interest.

Limiting the dataset to positioning estimates with HPE ≤ 7 resulted in a high level of positioning accuracy throughout the analysis. In addition, examination of fish relocations under several HPE cutoff values provided a sense of how positioning estimates (and hence relocation distances and speeds) changed with increased positioning error. HPE values were used as positioning confidence radii based on 95% quantile regression of HPEm values of sync/ref tags with HPE ≤ 7. The high percentage of fish found outside of the overlap between elevation contour lines and the HPE radius indicated a high confidence in assignment of the three habitat classifications (thalweg, floodplain, and shallows) used in this study. The ability to determine what type of habitat juvenile White Sturgeon used during the spring to fall period will aid the development of future sturgeon capture programs.

This study used estimates of tag locations from the VPS array to calculate juvenile White Sturgeon locations, movement distances, and speeds. These movement distances and speeds have two inherent sources of bias:

1) the positioning error associated with the VPS-generated fish positions, which influences estimates of traveled distance, and therefore speed; and,

2) distance traveled is estimated as a straight line between every two positioning points, which results in minimum, rather than true distance (and speed).

The use of a HPE cutoff (HPE ≤ 7) maximized use of the data (71% of the total dataset) and reduced the amount of erroneous positioning estimates, which addressed the first source of error. The second source of bias becomes more important as time between relocation increases. However, the 90th quantile of time between positions in the analysed dataset equalled 12.8 min, indicating that in most cases, this source of error was likely negligible. The cases where long periods (> 0.5 h) were observed between position estimates (n = 1853; 1.3% of total data) were filtered during data processing to limit the bias of distance and speed estimates. The movement distances and speeds presented in this report should be interpreted as minimum estimates, when using these metrics to describe behaviour and assess the influence of reservoir levels or discharge.

Plotting positioning data according to elevation and HPE cutoff value indicated that with higher HPE cutoff values, a greater portion of tag locations were in shallow habitats compared to analysis with a lower HPE cutoff (Figure 19). This suggests that the probabilities of signal detection could be lower in the shallower compared to deeper habitats, perhaps due to signal attenuation in shallow or non-uniform bathymetry. If further telemetry studies of juvenile White Sturgeon are conducted in the MCR, additional receivers in shallow water habitats are recommended to improve detection and reduce uncertainty of fish movements in shallow areas.

4.1.2 Juvenile White Sturgeon Habitat Use

The management questions to be addressed through the multi-year monitoring program (as taken from the Terms of Reference; 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 MCR?

6) Can modifications be made to the operations of Revelstoke Dam and/or ALR to protect or enhance juvenile white sturgeon habitat?

The first management question of this monitoring program relates to the habitat locations used by juvenile White Sturgeon in the MCR. This study provides new information about the macro-habitat types utilized by juvenile White Sturgeon in the study area. Further, the results suggest that habitat preferences may depend on the time of year, as there were clear seasonal differences in the habitat use and movements of juvenile White Sturgeon within the study area of the MCR. In the spring, juvenile White Sturgeon were detected almost exclusively in the thalweg and rarely in the pre-impoundment floodplain or reservoir shallows areas. During the summer, juvenile White Sturgeon were detected in all three habitat classifications, although primarily in the thalweg and floodplain areas. In the fall, the greatest usage was recorded in the thalweg, although limited use of the floodplain also was recorded. These use patterns correspond to some degree with the operational characteristics of ALR. In the spring, the reservoir is low and during this period, floodplain and shallows habitats are limited in availability within the study area. As the reservoir fills in the late spring and early summer to peak levels, floodplain and shallows habitats increase in availability. ALR levels in the fall were lower than in summer but still substantially higher than the spring and as such, floodplain and shallow habitats were available in the fall, The low use of these areas in the fall by juvenile White Sturgeon suggest other factors (e.g., temperature) affected habitat use in that period.

In all seasons or months, greatest use was recorded within the thalweg or in the floodplain area closely associated with the thalweg area. Usage of primarily thalweg habitat in the spring, all habitat types in summer, and primarily thalweg and floodplain in the fall was also supported by the analysis of the length of time spent in each habitat. Although all three habitat types were utilized in the summer, juvenile White Sturgeon spent the most time in the thalweg, with mostly short duration (0 to 4 hours) forays to the shallows and floodplain areas. Seasonal variation in the use of thalweg habitats also was reported in a study of adult and juvenile White Sturgeon in the Lake Roosevelt reservoir of the Columbia River in northern Washington, USA (McLellan et al. 2011). These authors found that 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 were distinct seasonal trends in juvenile White Sturgeon habitat use patterns, sample size in the fall was small (n=5), which limited the strength of conclusions presented here; further study is needed to better support these trends.

The second management question relates to the physical and hydraulic properties of the juvenile White Sturgeon habitats. Although this study did not assess hydraulic or physical habitat attributes in detail, the data can be used to assess the water depths at locations where juvenile White Sturgeon were located. The sampling area was divided into three habitat classifications, which were based on geomorphology of the pre-impoundment river channel, and were used as a surrogate for water depth when assessing the habitats utilized by juvenile White Sturgeon in the study area. Therefore, one assumption of the analysis was that at each tag position estimated by the VPS array, the juvenile White Sturgeon was located near the bottom of the river at that site. Although not tested in this study, several previous studies suggest that the assumption of juvenile White Sturgeon mostly occupying benthic habitats is reasonable. McLellan et al. (2011) found in a study using depth-sensing telemetry tags that depth measurements of tagged adult and juvenile White Sturgeon typically corresponded to the total depth at the location, suggesting benthic orientation of White Sturgeon in their study area in the Lake Roosevelt reservoir of the Columbia River in northern Washington, USA. Diet analyses of juvenile White Sturgeon in Lake Roosevelt found a high proportion of benthic invertebrates, which also suggested benthic orientation of juveniles (Parsley et al. 2010). On the other hand, juvenile White Sturgeon in ALR are known to forage on mysid shrimp (*Mysis relicta*) that migrate vertically within the water column between day and night (Martinez and Bergersen 1991), which raises the possibility that White Sturgeon juveniles may feed higher in the water column when foraging on mysids. To reduce uncertainty about depths and habitats used by juvenile White Sturgeon and better address the study's management questions, the use of acoustic transmitters with a depth sensor function is recommended for future investigations in the study area.

Overall, results from the VPS telemetry array suggest that juvenile White Sturgeon used a wider range of depths, and made more frequent, longer, and faster movements in the summer compared to spring and fall. Reasons for these seasonal differences are unknown but could be at least partly related to the level or status of ALR. ALR was filling during the spring, emptying in the fall, and transitioned from filling, to full (stable), to emptying during the summer. Hence, the level of ALR was low during the spring, high in the summer, and intermediate in the fall. Thus, the period in the spring when movements were shorter and usually restricted to the thalweg was associated with low reservoir levels, whereas habitats in the floodplain and shallows were only used in the summer and fall, when reservoir levels were higher. It may be that water depths or some other habitat variable make the floodplain or shallow areas unsuitable for juvenile White Sturgeon when reservoir elevations are low. As seen in Figure 9, maximum depths in the floodplain and shallows habitats were typically greater than 10 m only in the summer, when greatest use of these areas was recorded. Studies on juvenile White Sturgeon in other areas of the upper Columbia River have shown a definite preference for depths greater than 10 m (Golder 2009b; McLellan et al 2011), which may suggest 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 status (i.e., emptying, filling, 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 (Figure 15). Overall, movements and behaviour were not strongly associated with the filling/emptying status of the reservoir. Movements of juvenile White Sturgeon were not related to discharge, based on graphical assessment, likely because the effects of discharge fluctuations are mostly attenuated by ALR in the study area. This study provides the first data on use of the thalweg and other habitats by juvenile Sturgeon in the study area. Additional years of study are required to assess how high reservoir levels in 2012 may have affected behaviour, and how inter-annual variation in ALR level and operations may affect habitat use (management question #4).

In addition to habitat selection, the movements of juvenile White Sturgeon also differed by season, with greater distances traveled and greater speeds in summer compared to spring and fall. The increase in movement distances and speeds from spring to summer corresponded with the increasing use of floodplain and shallows habitats in late June. Taken together, the results regarding habitat usage and movements can be used to guide future studies that sample juvenile White Sturgeon in the study area. For instance, sampling efforts in fall could be focused in the thalweg, where fish are known to be concentrated in October, or if the collection of juvenile sturgeon is required in the outside of the thalweg, it may be best to undertake the sampling between late June and late September. The information about the movements of juvenile White Sturgeon presented in this report is expected to help improve the study design and catch-rates in future studies, which will help address presently unanswered management questions, such as survival rates in the MCR (management question #5).

One of the management questions of this study (Section 1.1.1) concerns the habitat locations used by juvenile White Sturgeon in the MCR. The analysis of fish movement near the Akolkolex River mouth provides 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. The use of the Akolkolex bay area was likely to be higher at 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. It is currently unknown whether the Akolkolex bay is used as a feeding area or what physical attributes make this area suitable for juvenile White Sturgeon.

5.0 RECOMMENDATIONS FOR REFINEMENTS TO FUTURE CAPTURE PROGRAMS

The results of the present study support several previously known characteristics of juvenile White Sturgeon habitat use in the Columbia River downstream from HLK (Hildebrand et al 1999; Golder 2009b; McLellan et al 2012):

1) the preference for deep (typically greater than 10 m), calm water area with fine substrates;

2) increased rate and extent of movements during the summer period as compared to the spring and fall; and,

3) greater use of shallow water habitats in the summer as opposed to other seasons.

In addition to the confirmation that juvenile White Sturgeon in the MCR exhibit similar habitat use and behaviour patterns to their counterparts in other areas of the Columbia River (McLellan et al. 2011), the present study also indicated that juveniles exhibited frequent and relatively extensive movements in the study area, particularly in the summer. This finding was important, since one of the reasons suggested for the low recapture rate of hatchery released juveniles was that after release, these fish simply remained within a very small area and did not exhibit frequent fine scale movements.

Based on the results of this study, recommendations for future capture programs include:

- When collecting White Sturgeon in the MCR area, effort should be focused on the thalweg, where the fish were shown to spend the majority of their time. In addition, fish that used the thalweg travelled longer distances. Therefore, passive gear (gill nets or set lines) deployed at the thalweg area would have a higher probability of catching juvenile sturgeon.

- Consider conducting sample efforts in the late spring (early-mid June), when reservoir levels are lower, fish are concentrated in the thalweg but still active, and the amount of area to be sampled is reduced compared to the summer and fall.

- As most movements were documented along the longitudinal aspect of the thalweg, deploy sample gear (gill nets and set lines) at right angles to the thalweg channel and transitional thalweg-floodplain side slopes in an attempt to intercept juveniles moving up and down the thalweg area.

In the event that future VPS studies are conducted in the MCR, we would make the following recommendations to improve the effectiveness of the array:

- Extend VPS cover to additional shallow areas in order to better detect use of shallow habitats. The majority of shallow-area detections in this study had exceedingly high HPE values associated with them. Adding stations in shallow areas as they become inundated may reduce the extent of positioning error and provide higher resolution data on juvenile White Sturgeon habitat use.

- Acoustic tags with a depth recording component should be utilized. Depth tags add a third dimension to the location of fish and improve the accuracy of fish positioning by screening positioning data against bathymetry data.

- Bathymetry data should be obtained, and fish positioning data should be combined with bathymetry to provide fine-scale analysis of depth and type of habitat (shallows, thalweg, slope) used by the fish.

6.0 LITERATURE CITED

BC Hydro. 2007. Columbia River Project Water Use Plan Monitoring Program Terms of Reference, Columbia River White Sturgeon Management Plan: CLBMON-21 Mid Columbia River juvenile White Sturgeon detection and habitat program and tracking of existing sonic tagged sturgeon.

Deslauriers, D. 2011. Factors influencing swimming performance and behaviour of the Shortnose Sturgeon (*Acipenser brevirostrum*). MSc thesis, University of New Brunswick, Saint John, NB, Canada. 122 pp.

Espinoza, M., T.J. Farrugia, D.M. Webber, F. Smith, and C.G. Lowe. 2011. Testing a new acoustic telemetry technique to quantify long-term, fine-scale movements of aquatic animals. Fisheries Research 108: 364-371.

Environment Canada 2013 – it's actually in the refs, just slightly screwy – it's appended to Golder in prep (just before Hildebrand et al 1999. I can't move it to its spot.

Espinoza et all 2011 – was in the references already; (Espinoza, M., T.J. Farrugia, D.M. Webber, F. Smith, and C.G. Lowe. 2011. Testing a new acoustic telemetry technique to quantify long-term, fine-scale movements of aquatic animals. Fisheries Research 108: 364-371.)

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

Golder Associates Ltd. 2008. Middle Columbia River monitoring of juvenile White Sturgeon habitat use and movements of sonic-tagged sturgeon, 2007 - 2008 Data Report. Report prepared for BC Hydro, Revelstoke, BC. Golder Report No. 07-1480-0069F: 25 p. + 3 app.

Golder Associates Ltd. 2009a. Monitoring of juvenile White Sturgeon habitat use and movements of sonic-tagged sturgeon: 2008 investigations. Report prepared for BC Hydro, Revelstoke, B.C. Golder Report No. 08-1480-0030F: 34 p. + 3 app.

Golder Associates Ltd. 2009b. Upper Columbia River juvenile White Sturgeon monitoring: Phase 5 investigations, November, 2006. Report prepared for BC Hydro, Revelstoke, B.C. Golder Report No. 06-1480-0049F: 66 p. + 6 app.

Golder Associates Ltd. 2010. Middle Columbia River juvenile White Sturgeon monitoring: 2009 Investigations. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 09-1480-0045F: 47 p. + 3 app.

Golder Associates Ltd. 2011. Middle Columbia River juvenile White Sturgeon monitoring: 2010 Investigations. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 10-1492-0113F: 47 p. + 4 app.

Golder Associates Ltd. 2012. Middle Columbia River juvenile White Sturgeon monitoring: 2011 investigations. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 11-1492-0035F: 22 p. + 2 app.

Golder Associates Ltd. In preparation. CLBMON-15a Mid-Columbia River Physical Habitat Monitoring. Synthesis Report (Years 1 – 6). Report prepared for BC Hydro, Revelstoke, BC. Golder Report No. 12-1492-0084. 41 p. + 6 app. Environment Canada. 2013. Species at Risk Public Registry. http://www.sararegistry.gc.ca/default e.cfm

Hildebrand, L., C. McLeod, and S. McKenzie. 1999. Status and management of White Sturgeon in the Columbia River in British Columbia, Canada: an overview. J. Appl. Ichthyol. 15: 164-172.

Koenker, R. 2013. quantreg: quantile regression. R package version 4.98. URL: http://CRAN.R-project.org/package=quantreg

Martinez, P.J., and E.P. Bergersen, 1991. Interactions of zooplankton, *Mysis relicta*, and kokanees in Lake Granby, Colorado. American Fisheries Society Symposium 9:49-64.

McLellan, J.G., S.G. Hayes, M.D. Howell, and R.K. Steinhorst. 2011. Seasonal use of channel and off-channel habitats and depth distribution of white sturgeon in the Marcus area of the Upper Columbia River determined using an acoustic telemetry array. Phase II (October 2010 – June 2011). Prepared for: Toxics Cleanup Program, ERO, Department of Ecology, Spokane, WA. 81 pp.

Parsley, M.J., van der Leeuw, B.K., and Elliott, D.G., 2010, Characterization of the contents and histology of the gastrointestinal tracts of White Sturgeon (Acipenser transmontanus) captured from Upper Lake Roosevelt, Washington, October 2008: U.S. Geological Survey Open-File Report 2010-1193, 24 p.

R Core Team, 2013. R: A language and environment for statistical computing. Vienna, Austria. http://www.R-project.org

Upper Columbia White Sturgeon Recovery Initiative (UCWSRI), 2006. Upper Columbia River adult White Sturgeon capture, transport, and handling manual.

Webber, J.D., S.N. Chun, T.R. MacColl, L.T. Mirise, A. Kawabata, E.K. Anderson, T.S. Cheong, L. Kavvas, M. McGee Rotondo, K.L. Hochgraf, R. Churchwell, J.J. Chech, Jr. 2007. Upstream swimming performance of adult white sturgeon: effects of partial baffles and a ramp. Transactions of the American Fisheries Society 136:402-408.

Wickham, H. 2009. ggplot2: elegant graphics for data analysis. Springer New York.

7.0 CLOSURE

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APPENDIX A

Release Data

Table A1 Summary of hatchery juvenile white sturgeon released in the middle Columbia River below Revelstoke Dam, 2007 - 2012.

Release Date	Brood Year	Release		Sonic-Tagged?	Number of Fish
		Location[a]	Time		
8-May-12	2011	Shelter Bay	Day	No	6517
15-May-12		VPS area	Day	Yes	50
2012 Release (2011 Brood Year) Total					**6567**
20-Apr-11	2010	Shelter Bay	Day	No	7578
		Centennial Launch	Day	No	500
2011 Release (2010 Brood Year) Total					**8078**
23-Apr-10	2009	Centennial Launch	Day	No	400
		Big Eddy	Night	No	9175
22-Apr-10		Big Eddy	Day	Yes	10
		Begbie Creek	Day	Yes	10
		Mulvehill Creek	Day	Yes	10
		Tree Island	Day	Yes	10
		Arrowhead	Day	Yes	10
2010 Release (2009 Brood Year) Total					**9625**
23-Apr-09	2008	Centennial Launch	Day	No	600
		Big Eddy	Night	No	7518
		Big Eddy	Day	Yes	10
		Begbie Creek	Day	Yes	10
		Mulvehill Creek	Day	Yes	10
		Tree Island	Day	Yes	10
		Arrowhead	Day	Yes	10
2009 Release (2008 Brood Year) Total					**8168**
29-Apr-08	2007	Centennial Launch	Day	No	600
		Big Eddy	Night	No	5884
		Big Eddy	Night	Yes	50
2008 Release (2007 Brood Year) Total					**6534**
3-May-07	2006	Moses Creek	Noon	No	1984
		Moses Creek	Midnight	No	2172
		Moses Creek	Noon	Yes	25
		Moses Creek	Midnight	Yes	25
2007 Release (2006 Brood Year) Total					**4206**

2007 - 2012 Release Total	**43,178**
2007 - 2012 Release Total (Not Sonic-tagged)	**42,928**
2007 - 2012 Release Total (Sonic-tagged)	**250**

[a] See Appendix B, Figure B1 for locations.

Table A2 Summary of hatchery juvenile white sturgeon (2011 brood year) implanted with sonic tags and released in the VPS area on 15 May 2012.

Sonic Tag ID Code	PIT Tag No.	Release River Kilometre	Family[a]	Release Time	Fork Length (cm)	Weight (g)
41914	985121022646462	202.5	11-6	Day	34	329
41915	985121013465233	202.5	11-1	Day	32	242
41916	985121013446504	202.5	11-1	Day	32	216
41917	985121013457441	203.3	11-5	Day	34	255
41918	985121013461023	203.3	11-1	Day	38	389
41919	985121013451956	203.3	11-6	Day	29	180
41920	985121013495652	202.5	11-3	Day	32	284
41921	985121013496760	202.5	11-1	Day	32	230
41922	985121013460946	202.5	11-5	Day	31	241
41923	985121013461078	202.5	11-4	Day	35	344
41924	985121013463491	203.3	11-3	Day	31	210
41925	985121013446482	202.5	11-1	Day	32	233
41926	985121013461514	203.3	11-5	Day	35	300
41927	985121013446801	203.3	11-1	Day	31	237
41928	985121013447508	203.3	11-1	Day	35	284
41929	985121013493898	202.5	11-4	Day	34	262
41930	985121013463588	203.3	11-3	Day	31	231
41931	985121013461520	203.3	11-6	Day	31	231
41932	985121013464188	203.3	11-5	Day	26	146
41933	985121013454131	203.3	11-3	Day	30	191
41934	985121013501320	202.5	11-4	Day	31	221
41935	985121013445406	203.3	11-1	Day	29	175
41936	985121013452940	202.5	11-3	Day	33	236
41937	985121013446593	202.5	11-4	Day	39	403
41938	985121013459350	202.5	11-6	Day	34	310
41939	985121013458374	203.3	11-4	Day	33	258
41940	985121013460619	203.3	11-5	Day	30	181
41941	985121013529944	203.3	11-4	Day	34	270
41942	985121013442115	203.3	11-3	Day	31	196
41943	985121013463097	203.3	11-5	Day	35	299
41944	985121013460907	203.3	11-4	Day	32	218
41945	985121013460824	203.3	11-5	Day	32	216
41946	985121013460769	202.5	11-5	Day	31	229
41947	985121013478671	202.5	11-6	Day	29	193
41948	985121022655135	203.3	11-6	Day	33	268
41949	985121013454650	203.3	11-6	Day	31	238
41950	985121013457405	202.5	11-5	Day	33	261
41951	985121013495086	202.5	11-4	Day	33	278
41952	985121013451967	202.5	11-4	Day	35	356
41953	985121013456648	203.3	11-3	Day	34	272
41954	985121013446972	202.5	11-5	Day	34	255
41955	985121013461625	202.5	11-4	Day	33	257
41956	985121013451762	202.5	11-1	Day	32	194
41957	985121013446938	202.5	11-3	Day	33	264
41958	985121013461635	202.5	11-1	Day	31	229
41959	985121013451901	203.3	11-3	Day	31	258
41960	985121013457707	203.3	11-6	Day	30	188
41961	985121022646720	202.5	11-6	Day	34	295
41962	985121013442049	202.5	11-3	Day	32	253
41963	985121023019232	203.3	11-6	Day	29	191

[a] First two digits represent the brood year, last digit represents the family number within that brood year (e.g., 11-1 = 2011 brood year, family 1).

APPENDIX B

Physical Data

Table B1 Descriptive statistics of physical habitat variables measured monthly between April and October in the VPS study area, Middle Columbia River, 2012.

Variable	Location	Mean	SD	Min.	Max.	n
Depth (m)	1	13.6	3.1	10.5	17.5	5
	2	13.7	3.3	10.2	17.8	5
	3	11.9	3.2	8.4	15.9	5
	4	13.1	3.3	9.7	17.3	5
Surface Water Velocity (m/s)	1	0.3	0.2	0.1	0.6	5
	2	0.3	0.2	0.1	0.6	5
	3	0.3	0.2	0.2	0.6	5
	4	0.5	0.2	0.3	0.9	5
Turbidity (NTU)	1	3.1	1.7	1.9	6.0	5
	2	2.8	1.9	1.5	6.2	5
	3	2.8	1.8	1.6	5.8	5
	4	2.6	1.6	1.5	5.3	5
Secchi Depth (m)	1	3.3	1.0	2.1	4.3	4
	2	3.9	1.2	2.7	5.0	4
	3	3.8	1.2	2.6	4.9	4
	4	3.9	1.3	2.7	5.1	4

SD= standard deviation; Min.= minimum; Max. = maximum; n = sample size.

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