Project 3972

Adult White Sturgeon Monitoring - Nechako River 2008

March 2009

Prepared for:

RioTinto Alcan
158 West Stewart St
Vanderhoof, B.C.

Prepared by:

Greg Sykes, M.Sc., R.P. Bio.
Biologist/Project Manager
Triton Environmental Consultants Ltd.

TRITON ENVIRONMENTAL CONSULTANTS LTD.

#201 –1157 Fifth Ave.
Prince George, BC. Canada V2L 3L1
Phone (250) 562-9155
Fax (250) 562-9135
www.triton-env.com

Acknowledgements

Triton Environmental Consultants Ltd. would like to thank the following for their contribution to the 2008 Nechako River Adult White Sturgeon Monitoring Program:

- Rio Tinto Alcan (formerly Alcan Primary Metals) and their representative Justus Benckhuysen for providing partial funding and support that made the project possible.
- The Interdepartmental Recovery Fund of Environment Canada for providing partial funding that made the project possible.
- The Ministry of Environment (MOE) and their representative Cory Williamson for providing assistance with telemetry, historical data, and access to telemetry data collected by MOE base stations.
- The Carrier Sekani Tribal Council and their representative Brian Toth for providing assistance with the deployment of egg mats. Thanks to Bill Shepert and James (Jako) Prince for assistance with the field work.
- Travis Mitchell (Guardian Aerospace) for his expert flying on the telemetry and low-level overview flights.
- Debra Baher and Wayne Selewski who made their properties available for the installation of the telemetry base stations.
- Freshwater Fisheries Society of BC staff for handling and independent identification of the collected eggs.
- Dr. J Mark Shrimpton for the use of telemetry equipment.
- Cory Williamson and Steve McAdam (Ministry of Environment), Justus Benckhuysen (Rio Tinto Alcan), Clyde Mitchell and Bill Rublee (Triton Environmental Consultants Ltd.) provided many helpful suggestions that improved this report.

Table of Contents

List of Figures

List of Tables

List of Appendices

1 Introduction

The Nechako River population of white sturgeon (*Acipenser transmontanus*) is ranked as a critically imperilled species in British Columbia (BC Conservation Data Centre 2008), as well as a species listed as endangered under Schedule 1 of the Species at Risk Act (SARA). Genetic analysis indicates that the Nechako River population is distinct from that of the Fraser River, suggesting that there is no or limited inter-breeding between the populations (Smith *et al*. 2002). Research also suggests that the Nechako population is experiencing recruitment failure, with the population dominated by larger and older fish with few juveniles (Nechako White Sturgeon Recovery Initiative (NWSRI) 2008). At present the reasons for the recruitment failure are unknown, however, a recent report has suggested that alteration of critical spawning habitats may play a role (McAdam *et al.* 2005).

Extensive radio tagging programs in recent years have allowed for the tracking of adult white sturgeon movements in the Nechako River. As of the spring of 2008, there were approximately 79 radio tagged adults in the system. Approximately 27 of these tags were implanted by Golder Associates in the fall of 2005 (Golder Associates, 2006) with the remainder implanted in the spring of 2006 through 2008 by the BC Ministry of Environment (MoE) in conjunction with the Carrier Sekani Tribal Council (CSTC). The MoE/CSTC tagging was initiated by the Nechako White Sturgeon Recovery Initiative- Technical Working Group (NWSRI-TWG), to capture brood stock, and subsequently incubate, hatch and raise juvenile sturgeon for release in order to meet the goals of the breeding plan (NWSRI 2005). These programs also provided an assessment of fish reproductive state, which helped focus telemetry effort and the interpretation of telemetry data for the study reported here.

Radio tagging efforts (NWRSI), and work completed by Triton Environmental Consultants Ltd. (Triton) in 2004 through 2007 formed the basis for the monitoring and sampling plan for 2008. In particular, a previously identified spawning area in the vicinity of Vanderhoof (Triton 2004) was the focus for the work in 2008. In addition, the physical conditions in the river around the time of the congregation in 2004 to 2007 (*i.e.* water temperature and discharge) were examined to identify the critical monitoring period for 2008. In particular, the information on timing and location of the 2004 and 2006 congregations was used since those years had similar temperature and flow regimes as was expected to occur in 2008. The 2008 Nechako white sturgeon spawning assessment project was initiated in order to monitor Nechako River white sturgeon during the expected period of spawning activity (mid-May to mid-June), and to complete field surveys should a congregation of sturgeon be observed.

This report outlines the methods used to monitor the timing and location of white sturgeon spawning in the Nechako River in 2008, presents the results of field activities undertaken in May and June of 2008, and details a preliminary model that assesses the ability of a suite of environmental cues to predict the timing of white sturgeon spawning in the Nechako River.

2 Methods

2.1 TEMPERATURE AND FLOW MONITORING

Monitoring of the Water Survey of Canada (WSC) station at the Burrard Avenue bridge (station 08JC001) was initiated upon award of the contract and continued until completion of the field program. The station provides real-time data on water temperature, primary water level and discharge. Additionally, an Onset StowAway® TidbiT™ temperature logger was installed at the Baher property (rkm 138), near the upstream end of the egg mat study area as a backup to the WSC station. A previous comparison the WSC station with temperature loggers installed specifically for the project indicated little difference between the data sources (Triton 2005). As the WSC station was operable through the study period, the backup temperature logger data was not analyzed or included as part of this report.

2.2 RADIO TELEMETRY

Two Lotek receivers (SRX_400-W7) were used for the project. One was borrowed from the Department of Fisheries and Oceans in Prince George and was established in a base station at the property of Debra Baher near the upstream end of the known spawning area. This receiver was also used during aerial surveys along with a second receiver owned by Triton. Lastly, the MOE receiver in the base station located downstream of the Burrard Avenue Bridge (Salewski property - rkm 135) was regularly downloaded by the Triton crew throughout the project.

Telemetry overflights of the Nechako River between the Stuart and Nautley rivers were conducted between the 6th of May and the 15th of August in order to determine the presence or absence and movement patterns of tagged fish in the study area (Figure 1).

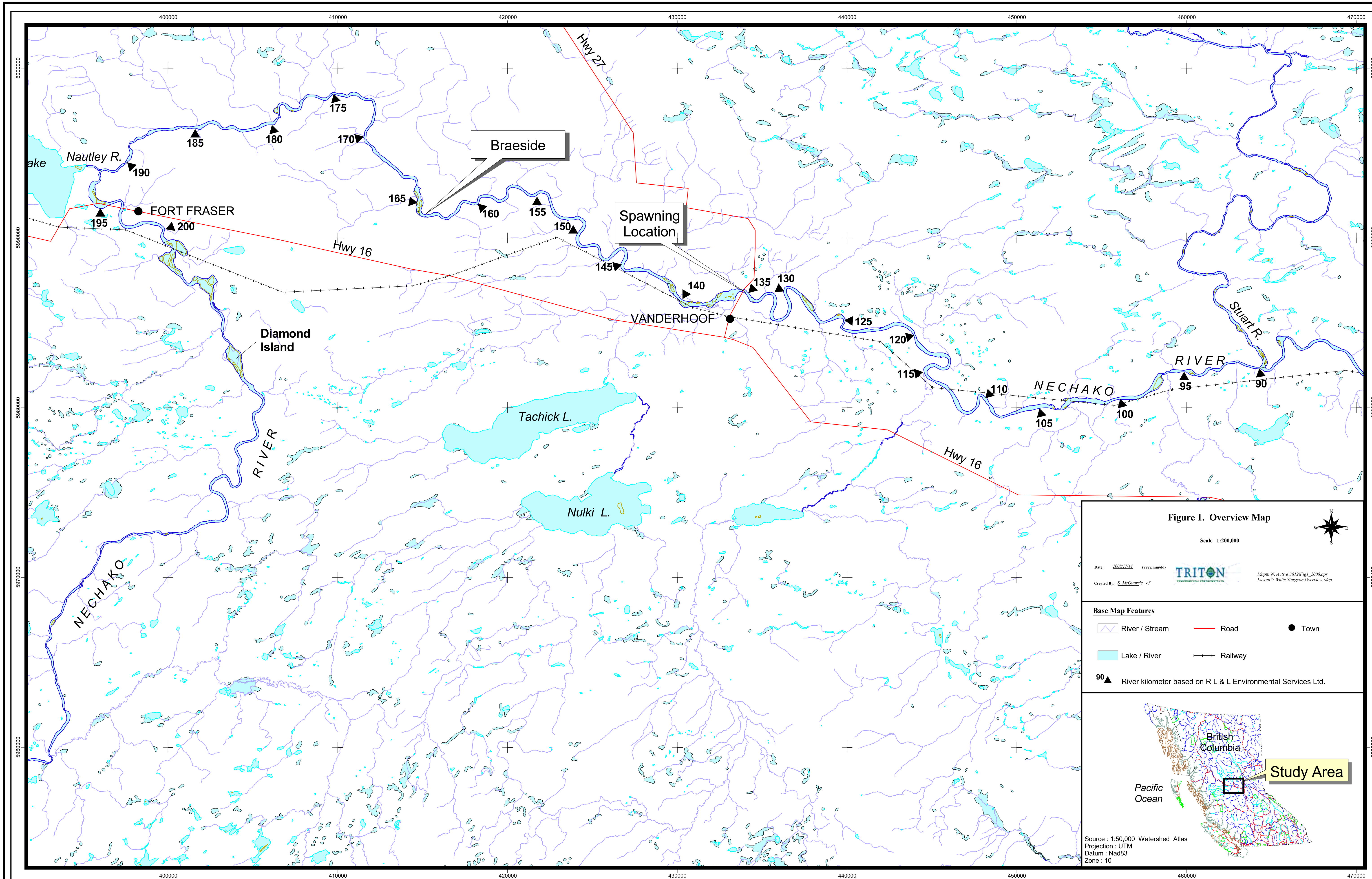


Figure 1. Overview Map

Telemetry flights originated from the Vanderhoof airport and were flown over the Nechako River from Vanderhoof (river km 136) downstream to the Stuart River confluence (rkm 90), at which point the plane would turn around and follow the river upstream past the confluence of the Nautley River (rkm 191) to Diamond Island (rkm 211), and finally back downstream to Vanderhoof. This flight pattern resulted in two complete passes of the study area on each flight; a total distance of approximately 240 rkm. Both passes of the telemetry flights were flown at a height of 200 – 250 m above the river.

A fixed-wing plane (Cessna 172) wired for telemetry work was used to complete the aerial surveys. "H" antennae were mounted with the vertical orientation set at an angle slightly forward of 45° down, on both wings of the aircraft. Two Lotek receivers (SRX_400-W7), one per antenna, were used during the overflights. To reduce the chance of missing a tag during scan time, the 7 active frequencies (149.800, 149.700, 148.680, 148.420, 148.400, 148.320, and 148.380) were split between the two receivers and were continually scanned during the flight at a rate of 7 seconds per frequency.

As each signal was received, the frequency, code, and river kilometre were recorded on data collection sheets. If at anytime the river kilometre location was unknown a UTM coordinate of where the signal was received was taken using a Garmin 12XL handheld GPS unit. Effort was not spent circling the plane to try and identify the exact location of each fish, as the goal of the telemetry data was to document general movement trends and timing. It is estimated that given the speed of the aircraft, altitude, and angle of approach the error of a given telemetry position could range from 100 – 500 m. However, in the event that a tag was located but a code was not initially resolved, the aircraft circled the area until it was thought that all codes had been received.

2.2.1 TELEMETRY BASE STATIONS

The telemetry base station located downstream of the Burrard Avenue bridge, which in previous years (2004-2006) had been operated by Triton, was taken over by MoE at the end of 2006. The station was moved to the property of Wayne Salewski (located one property downstream from the Triton location in 2004-2006 (rkm 135)) and ran continuously from the fall of 2006 to the end of the monitoring program in 2008. A second telemetry base station was established by Triton at the upstream end of the braided section of the river near Vanderhoof (rkm 139), on the property of Debra Baher (rkm 138). This location was near the upstream end of the sturgeon congregation observed in 2004 and near the upstream most egg mat sites that captured eggs in 2006. The station, which was also used in 2007, was established on May 13th, 2008, and remained in use until the end of the program on June 23rd, 2008

2.3 LOW LEVEL OVERFLIGHTS

As water temperature approached conditions similar to those observed during the 2004/2006 spawning congregations, low level observation flights were initiated. The plane used for visual overflights in previous years was no longer available and therefore observations were made in the Cessna 172, flown by Travis Mitchell of Guardian Aerospace based out of the Vanderhoof airport. This was the same plane used for aerial telemetry and, although it did not have a viewing window in the belly, by banking the plane the pilot was able to provide an unobstructed view of the spawning area. Flights were conducted approximately 150 - 200 m above ground from the upstream extent of the 2004 spawning area to approximately 1 km downstream of the Burrard Avenue bridge. Since the telemetry plane was used, low level observations were generally conducted in conjunction with the regular telemetry flights and therefore separate overview flights were not required. The exception was two shorter overview/telemetry flights completed on June 1st and 4th, during the period when spawning was expected to occur based on temperature. Those two flights, which covered approximately 5 km (rkm 135 – 140) were each 0.5 hours in length and included 6-8 passes through the identified spawning grounds. Both visual and radio telemetry data was collected.

2.4 SAMPLING FOR EGGS

Egg mats provide an artificial surface to which the adhesive sturgeon eggs can attach, and have been used successfully in numerous sturgeon studies (*e.g.* Parsley and Beckman 1994; Paragamian *et al*. 2001; Triton 2004, 2006, 2007). Egg mats were constructed from polyurethane industrial filter fabric sandwiched between an angle iron frame with cross supports following the procedure outlined in McCabe and Beckman (1990). Mats were deployed in sets of two with one buoy line attached to the upstream mat which allowed for retrieval of the gear. Mats were distributed evenly throughout the spawning area (rkm 134-

139) within the thalweg of the channel. Areas where eggs had been collected in the past were sampled again. As there was substantial boat traffic in the area, fluorescent buoys were used as they were clearly visible even in low light conditions. Separate anchors were not required as the two angle iron frames had a low profile and were heavy enough to remain stationary under typical flows.

2.5 HABITAT ANALYSIS

Water depth and water velocity was collected in conjunction with the deployment of egg mats. Water velocity was measured using a velocity sensor (Swoffer Instruments, Seattle, Washington) and depths were collected using a graduated rod. Water velocities were collected as close to the channel bottom as possible (near-bed), without having the substrates interfere with the measurement (typically 10 cm above bed height). Near-bed velocities are measured as they are reflective of conditions experienced by the demersal sturgeon eggs and incubation conditions that may be targeted by spawning adults.

Water depth, water velocity and substrate composition have been collected across habitat transects of the river in previous years. Substrates in the area have previously been described (*e.g.* Triton 2006) based on visual observations according to the categories defined by Kaufmann and Robison (2003) as either fines (< 2 mm), gravels (2-64 mm), cobbles (64-256 mm), boulders (256 – 4000 mm), or bedrock (> 4000 mm).

2.6 PREDICTIVE MODEL

An Information Theoretic Model Comparison (ITMC) approach was used to assess which environmental variables were best able to predict migration to the spawning area based on telemetry data gathered in 2004, 2006, 2007 and 2008. This technique involves generating a set of biological hypotheses as candidate models and then ranking or weighting the models to select the one that best explains the observed phenomenon (Anderson *et al.* 2000; Johnson and Omland 2004).

2.6.1 MODEL SELECTION AND EVALUATION

The candidate models were analysed using logistic regression. This type of analysis is used for binomially distributed data that is coded as either a "1", if the behaviour being studied happened or "0" if it did not. The binomial distribution is appropriate for white sturgeon migratory behaviour since data could be coded as either 0 (no migration; fish located at overwintering holes) or 1 (migration, fish located at rkm 135-138 spawning area). Based on these classifications, telemetry data was analysed and movements during the spawning period (May to June) were summarized and coded. Both mature and potentially immature fish were included in the dataset. The rationale for including immature fish was that even if these fish do not spawn, past telemetry results show they do appear to respond to spawning cues. In addition, since the tags are active for up to 5 years, it is possible that a fish assessed as immature at the time of tagging could mature and spawn within the life-span of the tag. Lastly, the inclusion of those data points increased the size of the data set and hence the power of the analysis. The result of the analysis was 1454 records (1180 = "0"; 274 = "1").

Model selection was based on Akaike's Information Criterion (AIC), which provides an estimate of how well a model approximates the process that generated the observed data (Johnson and Omland 2004). The model with the lowest AIC score is selected as best for the empirical data at hand (Anderson *et al.* 2000). In a situation where the difference in AIC score between two models is less than 2, other factors such as the models predictive ability and parsimony should be considered when selecting the best model. Further details on the use of AIC are provided in the 2006 white sturgeon monitoring report (Triton 2006).

To generate the predicted probability of migration, a predictive model of the form:

$$Y = \frac{\exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_i x_i)}{1 + \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_i x_i)}$$

(where: x_i is the value of the parameter, β_I is a coefficient produced by the logistic regression analysis, and β_0 is an intercept term) was used. The predictive ability of each of the leading models was assessed by calculating the area under the curve (AUC) of the receiver operating characteristic (ROC) graph produced when the predicted output of each model was compared with the actual sturgeon migration data (see Triton 2006 for more information). A model with an AUC of 1.0 is a perfect predictor whereas a model that has no predictive ability (essentially a 50:50 guess) has an AUC of 0.5. Boyce *et al.* (2002) state the general guidelines for interpreting the value of the AUC of a ROC curve in regards to predictive ability as poor (0.5 – 0.7), reasonable (0.7 – 0.9), and very good (0.9 – 1.0). All statistics for the study were calculated using Stata (version 9.2).

2.6.2 MODEL DEVELOPMENT

A set of candidate models to explain white sturgeon migratory behaviour was developed based on the parameters outlined in Table 1.

Table 1. Parameters used in analysis of white sturgeon spawning migration.

Parameter	Description
Maximum Temperature (˚C)	Maximum daily water temperature (˚C) logged at WSC Station #08JC001.
Average Temperature (˚C)	Mean daily water temperature (˚C) calculated from hourly data logged at WSC Station #08JC001.
$ATU_{ice\text{-}off}$	Accumulated Thermal Units from date when river was ice-free.
Photoperiod	Hours of daylight (sunrise to sunset) for Vanderhoof, BC.
Daily Flow (m^3/sec)	Mean daily flow (m^3/sec) calculated from river stage data gathered at WSC Station #08JC001.

The model developed in 2007 failed to accurately predict a decline in the probability of migration over the course of the monitoring period (see Triton 2007). In order to address this weakness, quadratic terms were added to the 2008 model analysis such that each parameter contained a linear and a squared component (for example the parameter "maximum temperature" would be described by the quadratic equation "maximum temperature + maximum temperature^2"). Quadratics are useful when describing data that does not follow a linear pattern, such as the migration data which shows a period of increase followed by a period of decrease.

Physical data on river conditions including river flow (m^3/sec) and temperature ˚C) was gathered for the same period as the telemetry data from the WSC station #08JC001 located at the bridge crossing of the Nechako River at Vanderhoof. Daily means of temperature and flow, as well as maximum daily temperature were used to determine if a threshold level provided the cue to migrate. Accumulated thermal units (ATU) were calculated as a sum of the daily mean temperature beginning on the date the river was free of ice, and were used to assess if fish were responding to a long-term temperature trend. In addition, photoperiod is known to be a controlling factor for many physiological and behavioural changes in other fish species (*e.g.* salmonid smolting) and was therefore included in the analysis. Before models combining variables were developed an analysis of collinearity between the parameters was completed since it has been shown that in situations where two or more parameters have a strong collinear relationship, an infinite number of regression coefficients can be generated that will work equally well in the model produced (Menard 2001). A linear regression was used to calculate a *tolerance statistic* for each of the parameters in the model. A tolerance statistic is equivalent to $1\text{-}R^2$ and values less than 0.1 suggest strong collinearity (Menard 2001). Due to collinearity issues surrounding maximum daily temperature, mean daily temperature, and ATU no models were tested that included combinations of those parameters.

Using all possible combinations of these five parameters, it would be possible to develop a large number of candidate models. However, the ITMC approach is based on an analysis of a set of biologically relevant models and one of the major criticisms of the technique is that often too many models are tested (Guthery *et al*. 2005). As a result, only those models that represented hypotheses that were thought to be plausible explanation of sturgeon migration were analysed, which resulted in 14 candidate models.

2.6.3 MODEL DIAGNOSTICS

For each model analyzed, the logistic regression produces an output table which includes a coefficient and z-statistic for each parameter. The coefficient is used in the calculation of predicted results and the sign of the coefficient gives an indication of whether it has a positive or negative influence on the phenomenon being studied. The z-statistic is used to assess the significance of the individual parameters to the overall regression equation with values close to zero meaning the parameter was having a non-significant ($p>0.05$) effect on the regression equation.

Once the "best" model has been identified, further diagnostics were completed including the calculation of Pearson's standardized residuals to describe the difference between the observed and predicted values. Standardized residuals have a normal distribution and therefore should have a mean of 0 and a standard deviation of 1. In addition, 95% of the residuals should fall between –2 and 2 with larger and smaller values identifying cases where the model works poorly or that exert more than their share of influence on the model parameters (Menard 2001).

3 Results

3.1 TEMPERATURE AND FLOW MONITORING

Figure 2 shows that daily mean discharge for 2008 peaked on May 22nd at 280 m^3/s, which was more than double the discharge for the same date in 2004 (127 m^3/s) and 2006 (104 m^3/s). However, it is only 57% of the discharge for the same date in 2007 (487 m^3/s). Following the peak in discharge on May 22nd, flows began to drop and by mid June they were similar to that of 2004/2006. During the period where spawning was assumed to have occurred, the hydrograph was descending from 229 m^3/s on June 1st to 177 m^3/s on June 9th. This is higher than the discharge at which spawning occurred in either 2004 (131 m^3/s) or 2006 (98 m^3/s) but lower than 2007 (474 m^3/s).

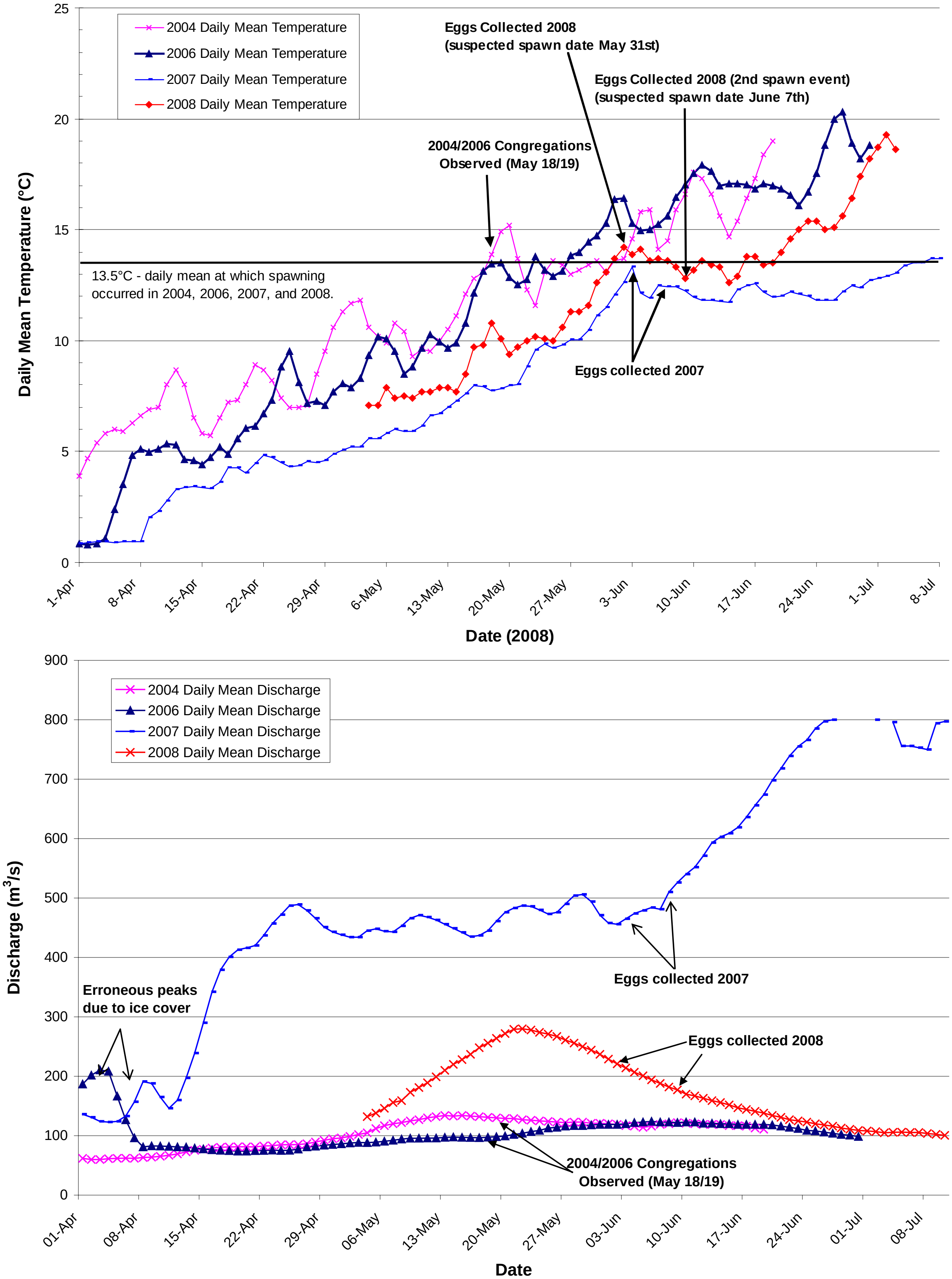


Figure 2. Daily mean temperature (top) and daily mean discharge (bottom) at the Burrard Avenue bridge (WSC Station 08JC001) for April 1 to July 5, 2004, 2006, 2007 and 2008.

Mean daily water temperature at the Burrard Avenue bridge during the monitoring period ranged from 7.1°C on May 4th to a high of 19.3°C on July 2nd. The maximum daily water temperature ranged from 7.8°C on May 4th to a high of 19.8°C on July 2nd. Compared to previous years, the daily mean temperatures were the inverse of the pattern observed for discharge, with 2008 being higher than 2007 but lower than either 2004 or 2006 (Figure 2). In 2004 and 2006, daily mean temperatures on the date when spawning occurred (May 18th and 19th) were 13.9°C and 13.5°C, respectively. However, in 2008, daily mean water temperatures for those dates were 3°C cooler (10.8°C and 10.1°C). Daily means in 2008 of 13°C or greater were not recorded until May 31st and eggs were collected three days later on June 2nd. This is similar to the timing in 2004 and 2006 when daily means of 13°C were achieved on May 17th in both years and spawning was observed 1 day later in 2004 and 2 days later in 2006. Detailed flow and temperature data can be found in Appendix 1.

Water turbidity was not assessed in 2008 as visibility was regularly being assessed during the low level overview flights of the spawning area completed in conjunction with each telemetry flight. Throughout the study period, visibility was estimated to be 1 to 1.5 m. This was sufficient to be able to clearly see substrates and egg mats beginning the first week of June. Prior to that, high discharge limited visible areas to the perimeters of the islands (within approximately 10 m from shore) and shallower side channels. For comparison, in 2004 and 2006, the mats were clearly visible from the onset of the program (beginning of May) but during the high flow conditions in 2007 they were never visible.

3.2 AERIAL TELEMETRY

A total of 19 telemetry flights were conducted between the 6th of May, 2008 and the 15th of August, 2008. This included 5 extended flights (Prince George to Nautley and Stuart River) and 2 shorter overview flights (km 135 to 140). There was an average of 27 active tags recorded during each flight, with the highest number of tags (39) being recorded on the June 6th extended flight. The majority of fish detected were found between km 90 (Stuart River confluence) and km 136 (the Burrard Avenue bridge). Although that area was the focus of the majority of the flights, even on the extended flights fish were predominantly located in that section.

The general movement trend of tagged fish in 2008 was similar to that of previous years. Fish were initially located within the overwintering locations at km 110, 116 and 125 but began to move out of these areas in early May. Leading up to the spawning event, movements upstream to just below the spawning area were observed (rkm 130-134). Between the 1st and 9th of June, multiple tags were detected within the spawning area (rkm 135-137). This included 5 females, 3 of which were ripe and had been used as brood stock (148.320 – 22, 23, and 28); 1 that was ripe and taken as brood stock but not used (148.320 – 24); and one that was close to ripe (code 14; 148.320 – 20). A total of 5 males were also in the vicinity of the spawning area from the 1st to the 9th. This included 2 brood stock fish (code 5; 148.320 – 26, 27), 2 code 4 fish (149.700 – 25 and 41) which will likely spawn in 2009, and 1 code 3 (148.320 – 21). Detailed telemetry results for individual fish showing migrations during the study period are provided in Appendix 2 (Figures 12-14).

A total of 10 tags were identified downstream of the Stuart confluence during the 5 extended telemetry flights. Four of those were fish that had been assessed as being sexually mature (code 5 males: 148.320 – 16, 149.800 – 56 and 58; or code 15 females: 148.400 - 6) in previous years. Five of the tags remained below the Stuart for the duration of the monitoring period, while the remaining five were detected both above and below the Stuart confluence. A database review completed in early 2008 identified a potential important rearing area in the vicinity of km 30-40 (Triton 2008). Several historic records exist of fish migrating to that area during June and July, presumably for feeding and rearing. In 2008, 3 fish were detected in that general area during extended flights completed in June, July and August. No grouping of fish were detected downstream of the Stuart River during the period where river conditions were considered appropriate for spawning.

A total of four tags were identified at the Braeside location (rkm 162). In 2007, five fish were detected at this location and it was suspected that it may be another spawning site, however, no eggs were collected or visual observations made (Triton 2007). In 2008, June 13th was the only date where more than one tagged fish was identified at this location. A total of three fish were detected including one female (148.320 – 19), which had been used as brood stock and returned to the river on June 4th at km 136. Records show that following release the fish moved to the Braeside location and remained in that area between the 10th and 13th before moving upstream to km 178 for the remainder of the summer. The other two fish detected were both males including one assessed as code 3 in 2005 (149.700 – 42) and one that is suspected to have spawned in 2006 (149.800 – 51). Both of those fish were originally located upstream of Braeside (rkm 180), moved downstream around the 13th and returned upstream the following week. It is unknown whether or not these movements were associated with spawning however, it is possible that both were mature (i.e. code 5) based on the number of years since their assessment.

A total of 10 tags were identified within the Stuart River during the 5 extended telemetry flights. Tags were identified throughout the river from km 16 to km 80 with no one area appearing to contain higher densities of fish. Six of the tags were from fish that were originally identified within the Nechako earlier in the monitoring program and then migrated into the Stuart, potentially heading to Stuart Lake. This included 1 female (148.320 – 22; 2008 brood stock), 4 males (148.320 – 10, 2007 brood stock; 148.320 – 27, 2008 brood stock; 149.700 – 36, juvenile; and 149.700 – 39, juvenile), and 1 unknown (148.320 – 14). The remaining tags were either only identified within the Stuart (149.700 – 43, code 12 female in 2005) or moved into the Stuart briefly before returning to the Nechako (148.320 – 12, unknown sex; 148.320 – 20, code 14 female in 2008; and 149.800 – 55 code 5 male in 2006).

3.3 TELEMETRY BASE STATIONS

Downloading of both the Vanderhoof base station as well as the station setup at the property of Debra Baher, located upstream of the spawning area, began on May 13th,

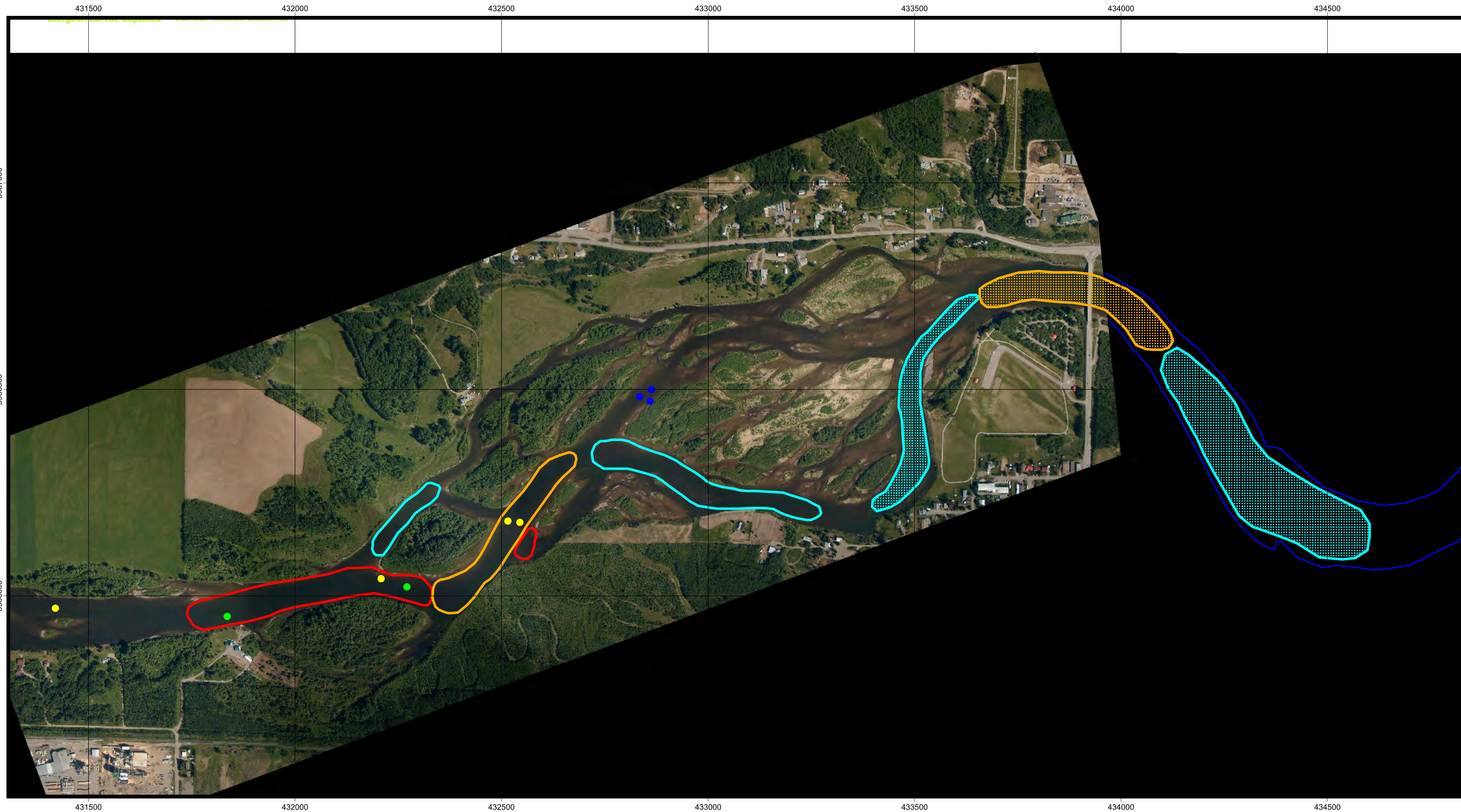
2008. Both stations were downloaded regularly (*e.g.* every day or couple of days) for the months of May and June. Appendix 2 details the fish recorded by the base stations.

During the monitoring period, six fish (148.320-20 and 26; 148.420-15; 149.700-39 and 41; 149.800-50) were detected by the Baher base station (rkm 138). In general, these fish did not pass the station but remained downstream occasionally moving into detectable range (estimated to be rkm 137). Only 148.320-26 was regularly detected upstream of the spawning area (i.e. upstream of rkm 138) on subsequent telemetry flights.

The base station downstream of the Burrard Avenue bridge (rkm 135) detected 30 different tags during the monitoring program. During the spawning events, which are thought to have occurred between June 1st and June 8th (see Section 3.5), 14 fish were recorded by the base station. Table 2 provides details on each of those fish. The record contains four brood fish that were released back into the general area during that period (148.320 – 22, 24, 27, and 28). In addition there were three males (149.700 – 25, 40, and 41) that were assumed to have been part of the spawning congregation in 2006 (Triton 2006). The remaining fish were either juveniles or of unknown sex.

3.4 VISUAL OBSERVATIONS

Overview flights were conducted on July 1st and 4th, however, visual observations of the spawning area were also conducted in conjunction with all regular and extended telemetry flights. A total of 9 fish were observed between June 2nd and 6th (June 2nd n=2; 4th n=4; and 6th n=3). This included a pair of fish that was observed on June 4th and a group of 3 fish observed on June 6th. The remaining observations were of individual fish. Radio tags were also detected within the spawning area on each of those days (June 2nd – 4 tags 149.700-41, 148.320-20, 22, 23; June 4th – 5 tags 149.700-25 and 41, 148.320-20 and 24, 149.800-48; June 6th – 5 tags 149.700-25, 149.800-50, 148.320-20, 22, 24, 28). Figure 3 shows the location of each of the observed fish.



LEGEND

2004 Congregation Locations
- Numerous Fish, Multiple Pairings
- Occasional Single Fish
- Several Fish, Some Paired

2006 Congregation Locations
- Occasional Single Fish
- Several Fish, Some Paired

2008 Visual Observations
- June 2
- June 4
- June 6

NO.	DATE (yyyy/mm/dd)	REVISION	BY

NECHAKO RIVER STURGEON PROJECT 2008

Figure 3. Visual Observations

100 0 100 200 300 400 500 600 Meters

Scale: *1:10,000*

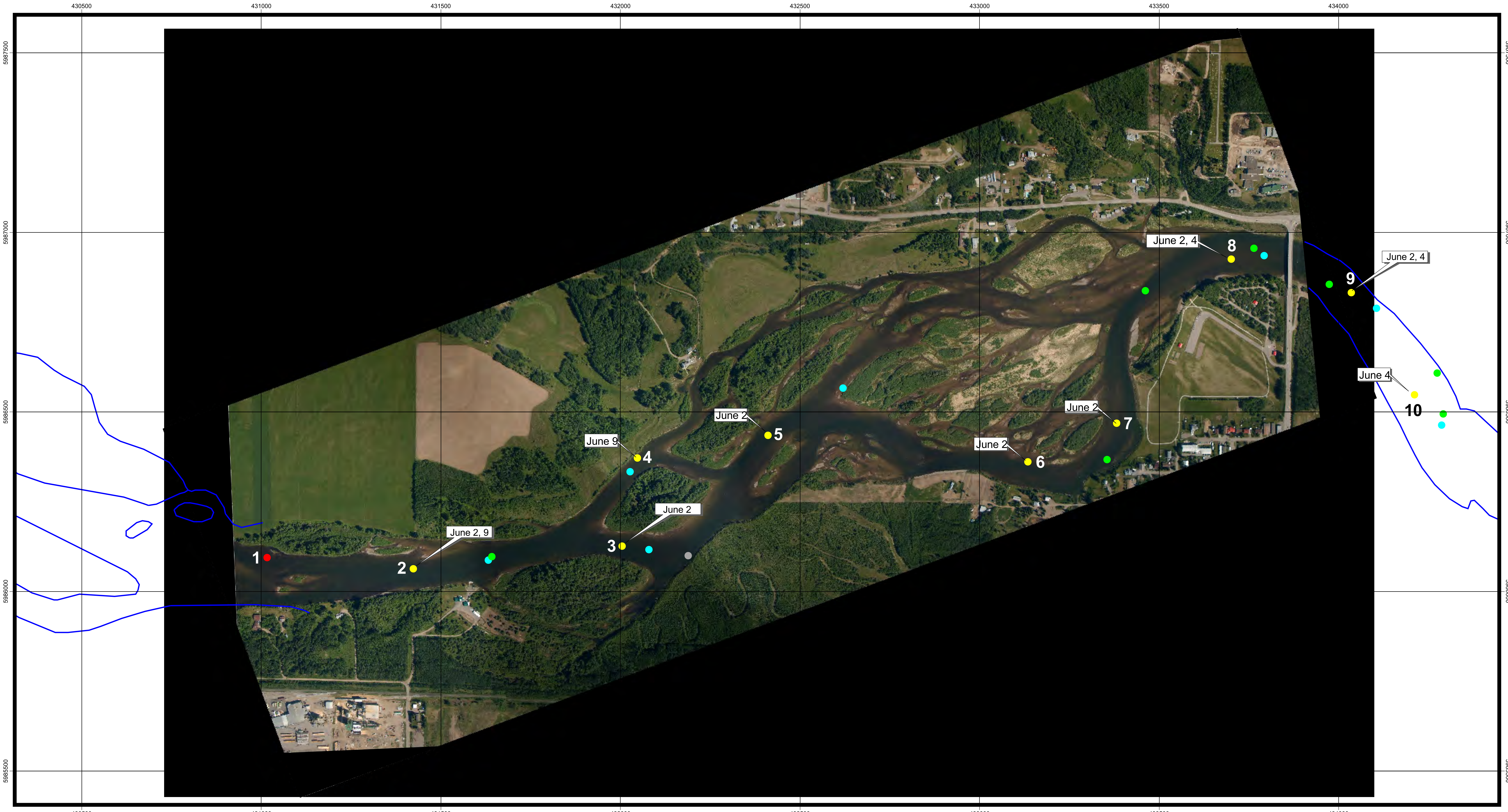
Basemap Source:	Map Datum:	Project No:	File No:	Date:
Air Photo Mosaic by Dave Gordon -June 16 2004	UTM Zone 10. NAD 83	3812	Map#: 3812\apr\2008\Fig3a_2008.apr Layout#: Figure 3.	2008/11/14

TRITON ENVIRONMENTAL CONSULTANTS LTD.

3.5 SPAWNING ASSESSMENT

Based on the egg sampling results, a wild spawning event occurred between May 26th and June 2nd. Due to water depth, no fish were visually observed prior to June 2nd and therefore spawning was not visually confirmed. However, telemetry data and assessment of collected eggs suggests that spawning likely occurred on May 31st or June 1st. Additional eggs were then collected on June 4th, however, these were assumed to have been from the same event based on the fact that 3 of the 4 were crushed or ruptured suggesting they had been on the mat for an extended period of time. An additional group of 18 eggs were collected on June 9th and were assumed to have been deposited around June 6th to 8th based on developmental stage. The development stage of the eggs confirmed that they were from a second wild spawning event, as opposed to being left over from the June 1st event. Both spawning events occurred within (between rkm 134 and 138) the known spawning area. Table 3 provides a summary of telemetry data for the spawning area from May 31st to June 9th.

The distribution of eggs collected from the initial (June 1st) event suggests it was fairly widespread with eggs collected from 7 of the 10 sets ranging from upstream of the braided section to downstream of the Burrard Avenue bridge (Figure 4). Eggs from the second event (June 9th) were only collected from sets 2 and 4, which are located immediately upstream of the start of the braided area (set #2) and in the left hand channel of the upstream island (set #4). As a result this was likely a smaller event involving fewer fish than the earlier event. Figure 4 shows the sample site locations for 2008 as well as the location of egg captures in previous years (2004, 2006, and 2007). The results from 2008 are consistent with results from those years suggesting similar spawning locations were used as in previous years.



LEGEND

- 2008 Egg Mats (Eggs collected)
- 2008 Egg Mats (No eggs collected)
- 2007 Egg Mats (Eggs collected)
- 2004 Egg Mats (Eggs collected)
- 2006 Egg Mats (Eggs collected)

NO.	DATE (yyyy/mm/dd)	REVISION	BY

NECHAKO RIVER STURGEON PROJECT 2008

Figure 4
Sampling Site Location

N W E S

100 0 100 200 300 400 Meters

Scale: *1:10,500*

Basemap Source:	Map Datum:	Project No:	File No:	Date:
Air Photo Mosaic by Dave Gordon -June 16 2004	UTM Zone 10. NAD 83	3729	Map#: 3812\apr\2008\Fig6a_2008.apr Layout#: Fig6.	2008/11/14

TRITON ENVIRONMENTAL CONSULTANTS LTD.

Table 2. Summary of telemetry data (aerial and base station) and sexual maturity of fish within the Vanderhoof spawning area (km 135-137) during the period where white sturgeon spawning was assumed to have occurred in 2008.

Date	***Frequency***	***Code***	***Sex***	***Maturity[1]***	***Assess Date***	***Comment***
May 29	148.320	20	F	14	May-08	
		21	M	3	May-08	
		22	F	15	May-08	Brood fish. Released May 22 at km 129.
		23	F	15	May-08	Brood fish. Released May 22 at km 129.
	148.400	9	unknown	97	23/09/2004	
	149.700	25	M	4	15/09/2005	Congregation 2006, likely spawned.
		40	M	4	17/09/2005	Congregation 2006, likely spawned.
		41	M	4	18/09/2005	Congregation 2006, likely spawned.
	149.800	46	98	98	10/05/2006	
May 30	148.320	21	M	3	May-08	
	149.700	40	M	4	17/09/2005	Congregation 2006, likely spawned.
May 31	148.320	21	M	3	May-08	
	148.400	9	unknown	97	23/09/2004	
	149.700	25	M	4	15/09/2005	Congregation 2006, likely spawned.
		26	F	11	15/09/2005	
		40	M	4	17/09/2005	Congregation 2006, likely spawned.
		41	M	4	18/09/2005	Congregation 2006, likely spawned.
	149.800	46	unknown	98	10/05/2006	
June 1	149.800	46	unknown	98	10/05/2006	
	148.320	20	F	14	May-08	
		21	M	3	May-08	
		22	F	15	May-08	Brood fish. Released May 22 at km 129.
June 2	148.320	20	F	14	May-08	
		21	M	3	May-08	
		22	F	15	May-08	Brood fish. Released May 22 at km 129.
		23	F	15	May-08	Brood fish. Released May 22 at km 129.
					Eggs Collected	
June 3	148.400	9	unknown	97	23/09/2004	
	149.800	46	unknown	98	10/05/2006	
June 4	148.320	20	F	14	May-08	
		27	M	5	May-08	Brood fish. Released June 3 at km 136.
	149.700	25	M	4	15/09/2005	Congregation 2006, likely spawned.
		41	M	4	18/09/2005	Congregation 2006, likely spawned.
	149.800	46	98	98	10/05/2006	
		48	M	2	10/05/2006	
					Eggs Collected	
June 6	148.320	20	F	14	May-08	
	148.320	22	F	15	May-08	Brood fish. Released May 22 at km 129.
		23	F	15	May-08	Brood fish. Released May 22 at km 129.
		24	F	15	May-08	Brood fish. Not used. Released June 3 at km 136.

Date	Frequency	Code	Sex	Maturity[1]	Assess Date	Comment
		26	M	5	May-08	Brood fish. Released June 4 at km 129.
		28	F	15	May-08	Brood fish. Released June 4 at km 129.
		29	unknown	Not assessed	May-08	
	149.700	24	M	2	15/09/2005	
		25	M	4	15/09/2005	Congregation 2006, likely spawned.
	149.800	46	98	98	10/05/2006	
		48	M	2	10/05/2006	
		50	M	5	12/05/2006	Congregation 2006, likely spawned.
June 7	149.700	24	F	15	May-08	Brood fish. Not used. Released June 3rd at km 136.
June 8	149.800	50	M	5	12/05/2006	Congregation 2006, likely spawned.
June 9	148.320	20	F	14	May-08	
	148.320	24	F	15	May-08	Brood fish. Not used. Released June 3rd at km 136.
	149.700	24	M	2	15/09/2005	
	149.800	46	98	98	10/05/2006	
		50	M	5	12/05/2006	Congregation 2006, likely spawned.
					Eggs Collected	
June 10	none					
June 13	none					

[1] Description of maturity codes provided in Appendix 4

The female fish detected within the spawning area immediately prior to eggs being collected were either sexually immature (149.700-26, code 11), assessed as not ripe (148.320-20, code 14) or was a fish that had been used as brood stock (148.320-22, code 15) and released into the river prior to the wild spawning event that is assumed to have occurred between May31st and June 1st. It is assumed that the brood fish would not have taken part in the wild spawning after having been artificially induced to spawn, however those released downstream of the spawning area at km 129 did move upstream into the spawning area suggesting they will still respond to the spawning cues. Female tagged fish that may have been involved in spawning in 2008 are limited to 148.320 – 24, a code 15 fish taken for brood stock but not used. This fish was released back into the river on June 3rd and therefore may have contributed eggs to the second spawning event. In addition, there was one fish assessed as code 14 (148.320 – 20) which was in the area for the duration of the spawning period. This fish was assessed and tagged in 2008 and, since it wasn't classed as code 15, it is unlikely that it would have spawned. It is more likely this fish will be mature in 2009. Detailed movements for those 2 fish are provided in figure 5.

Male fish that likely spawned in 2008 include 149.700 – 25, 40, and 41, and 149.800 – 50. All of these fish were code 5 males in 2006 and assumed to have spawned that year. Recent assessments completed during the 2006-2008 brood programs have shown that males are capable of spawning at 2 and even 1 year intervals (Pers. Comm. Cory Williamson, MOE). Codes 25 and 41 remained through both the spawning events while code 40 left after the 1st event and code 50 was only present for the 2nd event. Detailed movements for each are provided in Figure 6.

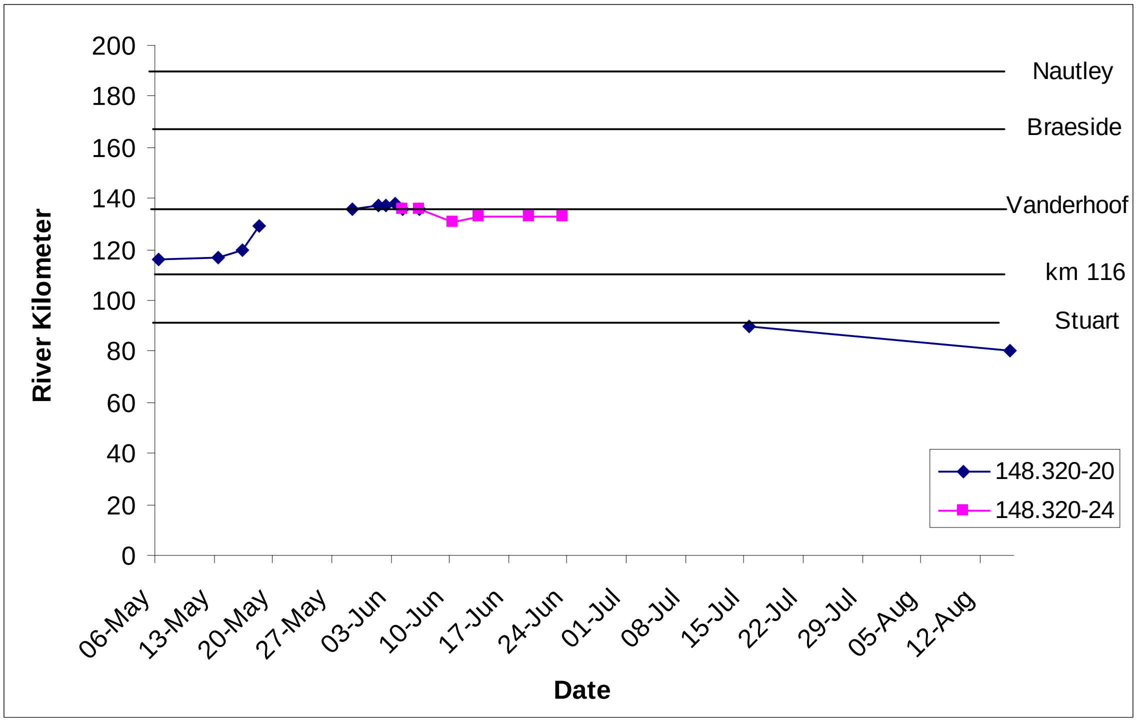


Figure 5. Detailed movements of potential female spawners (non-brood stock) based on radio telemetry.

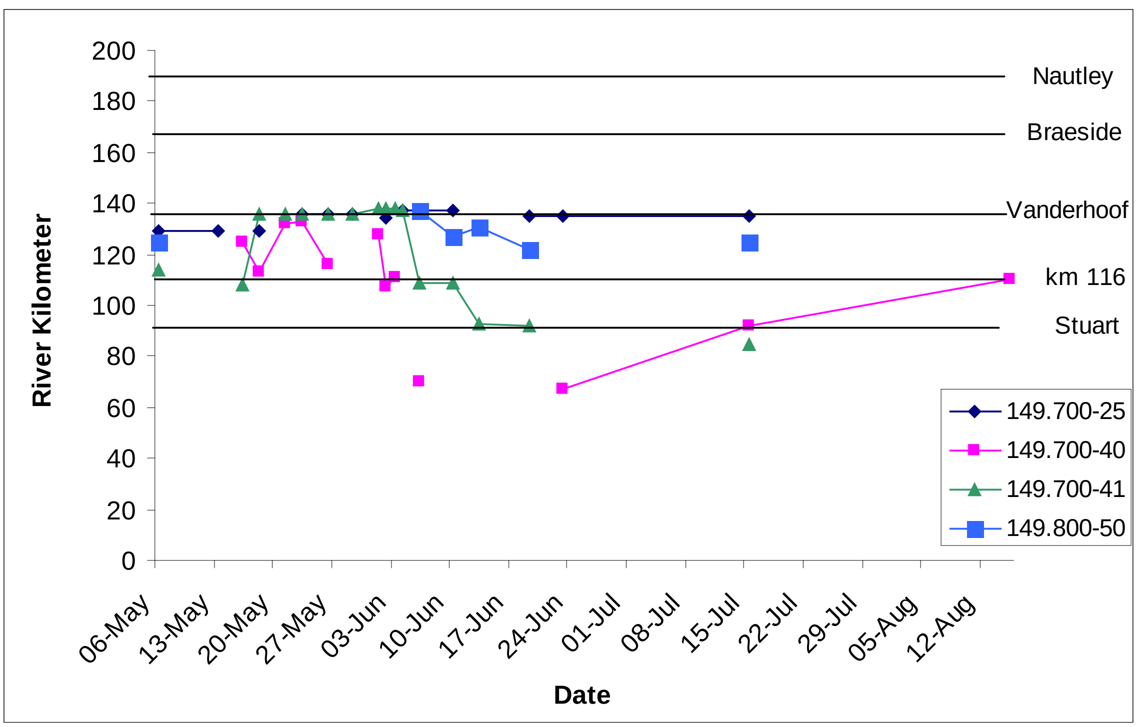


Figure 6. Detailed movements of potential male spawners (non-brood stock) based on aerial telemetry.

3.6 SAMPLING FOR EGGS

3.6.1 EGG MATS

A total of 40 egg mats were deployed in groups of 4 (2 pairs deployed in a line) between river kilometer 135 and 140 on May 26th (Figure 4). Depths ranged from 1.5 to 3.3 m, and near-bed velocities ranged from 0.55 to 1.63 m/s. The mats were checked and cleaned on June 2nd, 4th, and 9th and retrieved on June 16th. Mats were set for a combined total of 20,050 hours. A total of 56 sturgeon eggs were captured, with the majority of eggs captured in the vicinity of the Burrard Avenue bridge (rkm 135-136). Eggs were collected on 3 separate days: June 2nd (33 eggs), June 4th (5 eggs) and June 9th (18 eggs). The catch per unit effort (CPUE) for the egg mats ranged from 0.000 – 0.003 eggs/hour/m^2, which was a decrease from 2007 when CPUE ranged from 0.000 - 0.007 eggs/hour/m^2. However, the 2007 CPUE may have been artificially skewed by the release of brood fish in the vicinity of the mats that may have contributed some of the eggs collected that year (Triton, 2007). Egg mats were generally stable, with minimal downstream movement. All sets were well marked with orange buoys for the duration of the sampling period and no gear was lost or damaged.

3.6.2 EGG IDENTIFICATION AND VIABILITY

Eggs collected from egg mats during the study were carefully stored in vials of river water and held in a cooler to ensure a stable temperature. All the eggs collected from the egg mats, with the exception of 12 that were either ruptured or covered with fungus, were transferred to Freshwater Fisheries Society staff for inspection within two hours of collection. The identification of the eggs was confirmed and any eggs that appeared viable were incubated in the temporary hatchery at Vanderhoof. The collection and subsequent hatching of the eggs proved a wild spawning event occurred in 2008 that produced viable eggs. Of the 44 eggs turned over to the Freshwater Fisheries Society temporary hatchery, 12 were covered in fine sediment. These eggs may have been coated after adhering to the mat, however since not all of the eggs on the mats were coated it suggests they were coated first and then drifted onto the mats. Seven of the eggs transferred to the hatchery hatched (6 from the June 2nd group and 1 from the June 9th group). One of the June 2nd larvae subsequently died, however the remaining 6 larvae survived until June 30th, when they were culled.

3.7 HABITAT DOCUMENTATION

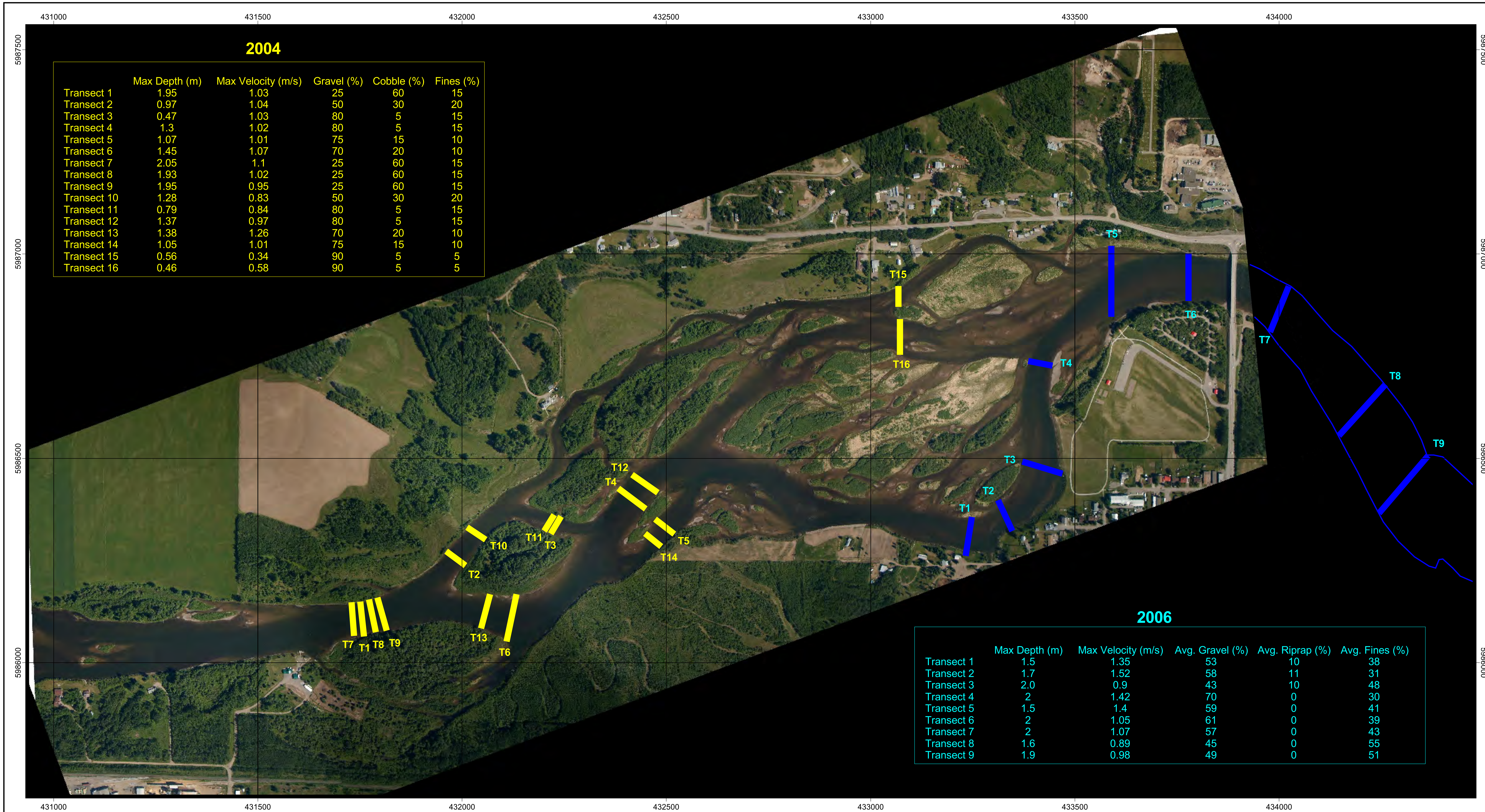
Spawning in 2008 occurred in the same general area as in 2004 and 2006. Figure 7 summarizes habitat parameters for the spawning area that were collected in 2004 and 2006. These are considered representative of conditions in 2008 based on observations of substrates and conditions that were made during the deployment and retrieval of egg mats. A total of 25 transects were visited (16 in 2004 and 9 in 2006) in order to gather habitat data for the spawning area. The transects were located in the main channels and side channels where sturgeon were observed to be congregating, as well as in channels upstream and downstream of that area.

Water Velocity

Water velocities in 2008 were collected from each of the 10 egg mat sites. Half of the water velocities (50%) collected were above 1.0 m/s. The highest water velocity recorded was 1.63 m/s at the egg mat site upstream of start of the braided section in the main channel thalweg (set #2). The average near bed velocities measured in 2008 were 0.99 m/s which were only slightly lower than that of 2007 (1.03 m/s) but higher than that of 2006 (0.96 m/s).

Substrate

The results of the substrate analysis completed in 2004 and 2006 (Figure 7) are representative of conditions in 2008. It shows that the study area is primarily dominated by gravel and fine substrates. Gravel was the dominant substrate at transects located where sturgeon were observed to be congregating in 2004 and 2006 with cobble substrates located upstream of the section of braided channel. Fine substrates were abundant at sites located in the vicinity of the Burrard Avenue bridge (downstream of rkm 136.5) but were also prevalent within back channel habitats throughout the study area. Throughout the spawning area, coarse substrates (gravel and cobble) tend to be embedded with fine substrates.



2004

	Max Depth (m)	Max Velocity (m/s)	Gravel (%)	Cobble (%)	Fines (%)
Transect 1	1.95	1.03	25	60	15
Transect 2	0.97	1.04	50	30	20
Transect 3	0.47	1.03	80	5	15
Transect 4	1.3	1.02	80	5	15
Transect 5	1.07	1.01	75	15	10
Transect 6	1.45	1.07	70	20	10
Transect 7	2.05	1.1	25	60	15
Transect 8	1.93	1.02	25	60	15
Transect 9	1.95	0.95	25	60	15
Transect 10	1.28	0.83	50	30	20
Transect 11	0.79	0.84	80	5	15
Transect 12	1.37	0.97	80	5	15
Transect 13	1.38	1.26	70	20	10
Transect 14	1.05	1.01	75	15	10
Transect 15	0.56	0.34	90	5	5
Transect 16	0.46	0.58	90	5	5

2006

	Max Depth (m)	Max Velocity (m/s)	Avg. Gravel (%)	Avg. Riprap (%)	Avg. Fines (%)
Transect 1	1.5	1.35	53	10	38
Transect 2	1.7	1.52	58	11	31
Transect 3	2.0	0.9	43	10	48
Transect 4	2	1.42	70	0	30
Transect 5	1.5	1.4	59	0	41
Transect 6	2	1.05	61	0	39
Transect 7	2	1.07	57	0	43
Transect 8	1.6	0.89	45	0	55
Transect 9	1.9	0.98	49	0	51

LEGEND

- 2004 Habitat Transects (T)
- 2006 Habitat Transects (T)

NO.	DATE (yyyy/mm/dd)	REVISION	BY

NECHAKO RIVER STURGEON PROJECT 2006

Figure 7.
Habitat Transects

Scale: 1:9,000 (100 0 100 200 300 400 Meters)

Basemap Source: Air Photo Mosaic by Dave Gordon -June 16 2004
Map Datum: UTM Zone 10. NAD 83
Project No: 3729
File No: Map#: 3729\apr\Fig6.apr Layout#: Fig6.
Date: 2006/11/14

TRITON ENVIRONMENTAL CONSULTANTS LTD.

3.8 PREDICTIVE MODEL

The results of the model selection analysis are presented in Table 4. The 14 models are presented in order of ascending rank based on AIC_c scores. Based on lowest AIC_c score the selected model included a combination of Average Daily Temperature, Flow, and Photoperiod. A ROC analysis was completed to assess predictive ability and it was found that the model was correct 81% of the time.

The coefficients generated from the best model (Maximum Temperature + Flow + Photoperiod) are provided in Table 3. All parameters with the exception of flow and flow^2 have a significant effect on the regression equation based on the calculated z-statistic ($p<0.05$) supporting their inclusion in the model (Table 4). However, since the model without the flow parameters ranked 5th, it suggests that although those parameters area only having a small influence on the overall performance of the model, it is still important.

Table 3. Summary of calculated model selection statistics for the 14 candidate models.

Model[1]	Rank	# of Parameters[2]	AIC_c	AIC_{Diff}	AIC_w
Avg Temp + Flow + Photo	1	7	1118.551	0.00	1.000
Avg Temp + Flow	2	5	1168.657	50.11	0.000
Max Temp + Flow	3	5	1173.071	54.52	0.000
Max Temp + Photo	4	5	1187.145	68.59	0.000
Avg Temp + Photo	5	5	1192.035	73.48	0.000
ATU + Photo + Flow	6	7	1199.177	80.63	0.000
Photo + Flow	7	5	1207.873	89.32	0.000
ATU + Flow	8	5	1233.075	114.52	0.000
Flow	9	3	1252.189	133.64	0.000
Max Temp	10	3	1291.647	173.10	0.000
Avg Temp	11	3	1319.457	200.91	0.000
ATU + Photo	12	5	1372.811	254.26	0.000
Photo	13	3	1373.361	254.81	0.000
ATU	14	3	1392.827	274.28	0.000

[1] Each parameter contains a linear and squared component.
[2] Includes an intercept term for each model.

Table 4. Logistic regression output coefficients for the top ranked model (based on AICc).

Parameter	Coefficient	Std. Error	z statistic	p-value	Lower 95% CI	Upper 95% CI
Avg. Temp	2.17	0.31	7.01	0.00	1.56	2.77
Flow	<-0.001	0.00	-1.55	0.12	-0.01	0.00
Photoperiod	46.17	8.05	5.73	0.00	30.38	61.95
Avg. Temp^2	-0.07	0.01	-6.23	0.00	-0.09	-0.05
Flow^2	<0.001	0.00	-0.05	0.96	0.00	0.00
Photoperiod^2	-1.45	0.25	-5.84	0.00	-1.94	-0.96
Constant	-382.77	65.53	-5.84	0.00	-511.20	-254.34

3.8.1 Predictive Ability

Predicted probabilities of migration for 2004, 2006, 2007 and 2008 were generated using the coefficients from the best model. Standardized residuals were also calculated and were found to have a mean of -0.22 and a standard deviation of 1.60, which was reasonably close to the expected values of 0 and 1, respectively. However, it was found that 17% of the residuals were either greater than 2 or less than -2. A comparison of the observed and predicted probability of migration from 2004, 2006, 2007 and 2008 are shown in Figure 8.

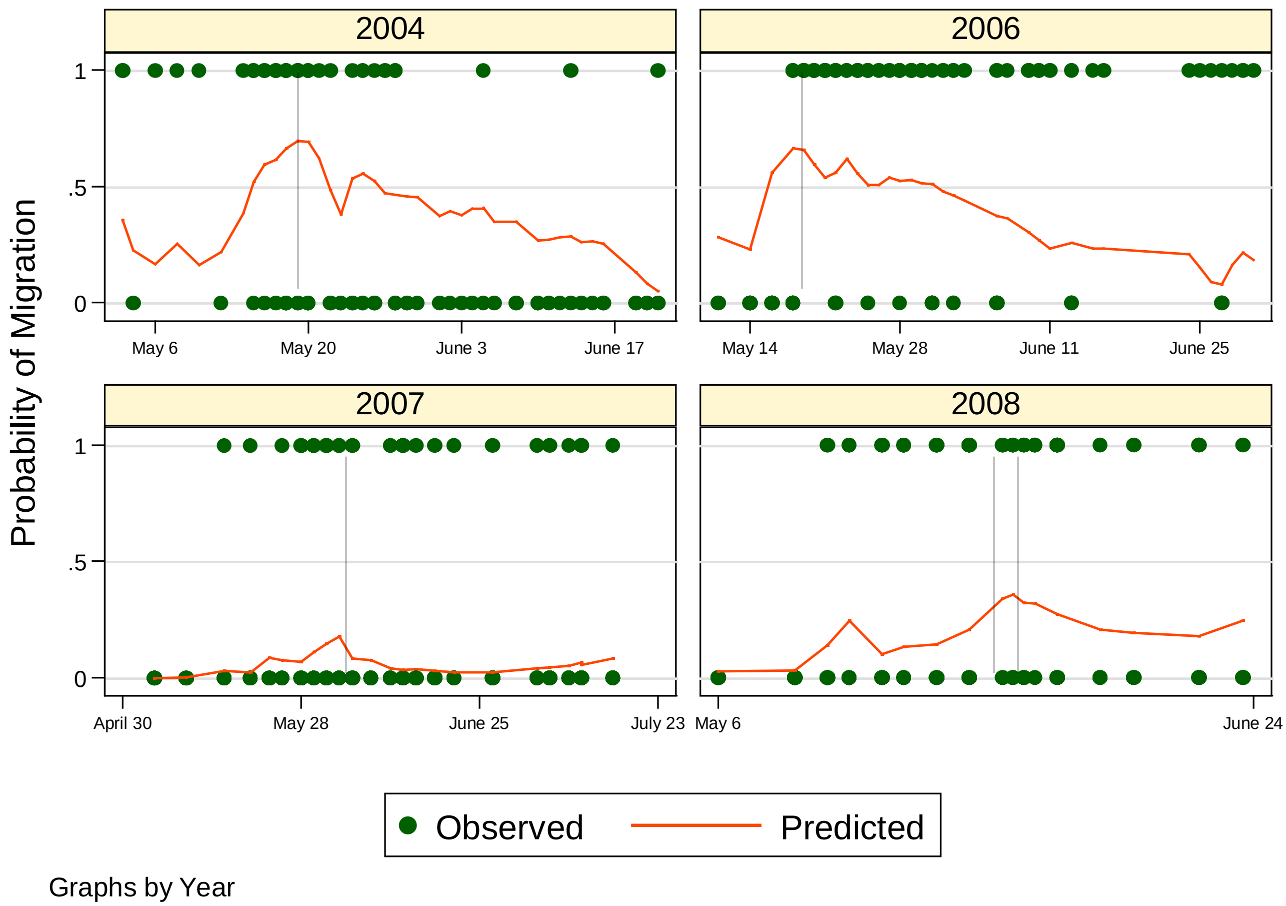


Figure 8. Predicted and observed probability of white sturgeon migration to the spawning area based on "best" model for 2004, 2006, 2007, and 2008. Vertical lines identify when spawning occurred each year (approximated for 2007 and 2008 based on egg collection dates).

4 DISCUSSION

During the 2008 adult white sturgeon monitoring program, flow levels were initially higher than in 2004 and 2006, making visual observations difficult through May and early June. However, the collection of fertilized sturgeon eggs on three different days (June 2nd, 4th and 9th) and from nine different egg mat sample sites confirms that spawning did occur. The following sections summarize the findings of the 2008 program and provide recommendations for future work.

4.1 SPAWNING CONGREGATION

White sturgeon spawning in 2008 occurred in two separate events. The initial event was estimated to have occurred between May 26th and June 2nd, based on the telemetry data and egg sampling results. This is approximately 2 weeks later than the spawning events of 2004 and 2006 (May 18th/19th), but approximately the same as 2007 (June 2nd). The variability in spawning date can be attributed to differences in water temperature since in all 4 years spawning occurred when water temperatures reached the same level (approximately 13°C; Triton 2004, 2006, 2007). In both 2007 and 2008, discharge in the spring was higher than in 2004 or 2006, resulting in a delay in water temperatures reaching that level (Figure 2) and as result spawning was delayed. Temperature is known to play an important role in the sexual development of most fish and therefore it is not unexpected that white sturgeon would spawn later in cooler years.

The relationship between the timing of sturgeon spawning and water temperatures has been further demonstrated by the modeling analyses completed from 2005-2007. Each of the selected models to explain observed sturgeon migration patterns included a temperature component (mean daily temperature) highlighting the importance of that parameter to migration. This relationship is important from a management perspective since manipulation of the flow regime that result in temperature changes can be expected to alter the timing of sturgeon spawning. Spawning that occurs too early or too late could potentially impact survival of eggs, larvae and juveniles due to lack of available food (in the case of spawning occurring early) or insufficient time for rearing and growth before winter (in the case of spawning occurring late). While it is unlikely that future management scenarios will result in a decrease in discharge in the spring potentially resulting in an earlier spawning date, it is conceivable that discharge in the spring could be increased resulting in a potential delay in spawning. However, data collected in 2007 showed that even with a 4-fold increase in discharge in May (400 m^3/s vs. 100 m^3/s in 2004; Figure 2), spawning was delayed only 2 weeks. While it is unlikely that such a relatively short delay would have adverse effects on subsequent survival of juveniles, ensuring that water temperatures appropriate for spawning are achieved between mid-May and mid-June is recommended in all future management decisions for the Nechako River.

The duration of the initial spawning event in 2008 is difficult to estimate due to the lack of visual observations for the first half of the monitoring period. Egg mats were deployed on May 26th and eggs were collected on June 2nd. Telemetry data showed increased activity in the vicinity of the spawning area beginning on May 29th. Therefore, spawning likely occurred during a 4 day period. For comparison the duration of the 2006 and 2007 spawning event was estimated to be 3 days whereas in 2004 it was estimated to be 36 hours (Triton 2004, 2006 and 2007). General spawning periods reported included spawning over several weeks in the Fraser River (Perrin *et al.* 2003) to several months in the Columbia River (Parsley *et al.* 1993). However spawning periods in larger systems may reflect spatial/temporal differences in spawning cues and/or multiple spawning populations. Data from individual spawning sites in the Fraser River provide estimates of spawning periods varying from 1 to 9 days (Perrin *et al.* 2003). Kootenai River female sturgeon demonstrated a residency of between 1-28 days (average 10.5) in the documented spawning reach (Paragamian and Kruse 2001).

On June 9th, additional eggs were collected at 2 of the 10 egg mat sets. The development stage of the eggs suggests that they were part of a second spawning event that occurred between the 4th and 9th. This is the first time that a second spawning event has been confirmed since monitoring began in 2004. However, the potential for multiple events were noted in previous years of monitoring, particularly in 2007 when a secondary congregation was observed around rkm 162. The short duration of the spawning events that have been observed in the Nechako could be due to the small size of the population, habitat limitations, or condition being appropriate for only a brief period, or combinations of all three. It should also be noted that the second spawning event in 2008 may have been the result of an unused brood female being released into the river on June 3rd (148.320 code 24). This fish was released at the Burrard Ave Bridge and telemetry records show that it remained in the vicinity of the spawning area from the 3rd to the 9th. Since eggs were only collected at two of the egg mat sets with one located immediately upstream of the other, it is possible that they were all from the same fish. With no visual observations or genetic analysis of the eggs collected, it is not possible to say with certainty whether the second event was a natural deviation from the "normal" spawning pattern (i.e. a single spawning event as occurred in 2004, 2006 and 2007), or the result of artificial manipulation (i.e. release of a ripe female into the spawning area).

Broadcast spawners, such as sturgeon, invest a substantial amount of energy into the development of a large quantity of eggs. Within a small population like that of the Nechako River the strategy of spawning as soon as conditions are favourable appears to provide the greatest potential benefits. In particular, having multiple fish spawning in the same location over a short period of time allows for greater genetic diversity of offspring due to increased options for mate choice as well as the possibility of "sneaking" (other males darting in just as eggs are released). Visual observations of spawning in 2004 showed multiple males grouped with larger females (Triton, 2004). The congregation also provides safety in numbers from predators for eggs and larvae. The strategy of multiple smaller spawning events would not provide the same benefits and therefore, would not be expected unless unavoidable (for example due to increased competition and habitat limitations as a result of a larger population). In larger populations, such as in the Fraser River or Lower Columbia River, the presence of more spawners in a given year likely contributes to the prolonged spawning period. As result, it seems likely that had the unused brood fish been in the river before June 2nd, it likely would have spawned with the rest of the natural spawners in the river. However, since it was not released until the 3rd, it was forced to delay spawning resulting in a smaller, secondary event.

Regardless of cause of the second event, it does provide additional information on white sturgeon spawning behavior. First, it confirms that spawning can occur outside of the relatively short window when it naturally occurs in the system. In this case, the fish was released the day after eggs were initially collected and spawned two to six days later. As a result, river conditions (i.e. temperature and flow) were still similar to that of the initial spawning event and males were still present within the spawning area. While it remains unknown how long a female can be delayed without reabsorbing the eggs, it is clear that there exists some flexibility in the timing of spawning. Secondly, the location of the eggs collected (i.e. upstream of the top and in the river left side channel) may provide an indication of the preferred spawning location within the entire spawning area. During previous spawning congregations, which consisted of multiple spawning pairs or groups, fish have been observed and eggs have been collected throughout the broadly defined spawning area (i.e. km 135 to 137). During the second, smaller event in 2008, the competition from other spawners was removed and it can be assumed that the fish spawned at a preferred location. Hydrology and/or substrate conditions immediately upstream of the braided section could therefore provide information on preferred spawning habitat conditions.

4.2 HABITAT

Based on the results of the egg sampling, spawning in 2008 occurred in the same general area as in 2004, 2006, and 2007. Figure 7 summarizes habitat parameters for the spawning area that were collected in 2004 and 2006. The data on substrate composition collected in 2004-2006 is considered representative of conditions in 2008 at a broad scale; however due to the high discharge in 2007 it is likely that smaller scale changes within the spawning area have occurred. At the time of spawning in 2004/2006, discharge was approximately 110 m^3/s while in 2007 it was 456 m^3/s. In 2008 spawning discharge ranged from 177 - 221 m^3/s. This translated into an average depth at the egg mat sites of 2.2 m compared to 1.32 m at the egg mat sites in 2006, and 2.96 m in 2007. However, the mean near-bed velocity at the egg mat sites of 0.99 m/s was approximately equal to those measured in 2007 and 2006 (1.03 m/s vs. 0.96 m/s, respectively). The area immediately upstream of the top island, which may be a preferred location is characterized by higher velocity discharge (1.6 m/s in 2008 and consistently greater than 1.0 m/s in previous years) with cobble dominated substrates (gravel and fines subdominant).

In 2004 and 2006 depth and velocity preferences for Nechako sturgeon spawning habitat where found to be low when compared to literature values. In particular, the mean maximum depth of 1.8 m observed in 2004 and 2006 in the vicinity of the congregation is below documented values in Columbia River studies, where the highest spawning suitability was noted at 4 meter depth and deeper (Parsley and Beckman 1994; Figure 9). However, that is a regulated system and spawning occurs in the immediate vicinity of a dam tailrace and therefore is not likely representative of "natural" conditions. Spawning depths in the Fraser River (based on egg capture data), an un-regulated system, indicated that water depths averaged 2.9 meters, which are noted as being less than what was found in other regulated rivers (Perrin *et al.* 2003). However, for the Nechako in 2008, the average depths were greater than 2 m, with a maximum of 3.3 m observed at the sites where eggs were collected. These values are more representative of what has been observed in other populations.

Maximum velocities recorded in the vicinity of the 2008 spawning ranged from 0.55 to 1.63 m/s, which is slightly broader than the range observed in 2004 and 2006 (0.89 to 1.52 m/s). These velocities were reflective of the lower to mid range of habitat preference for Columbia River (Parsley and Beckman 1994), and only lower than values measured in the Fraser River (average 1.8 m/sec, based on egg capture locations, Perrin *et al.* 2003).

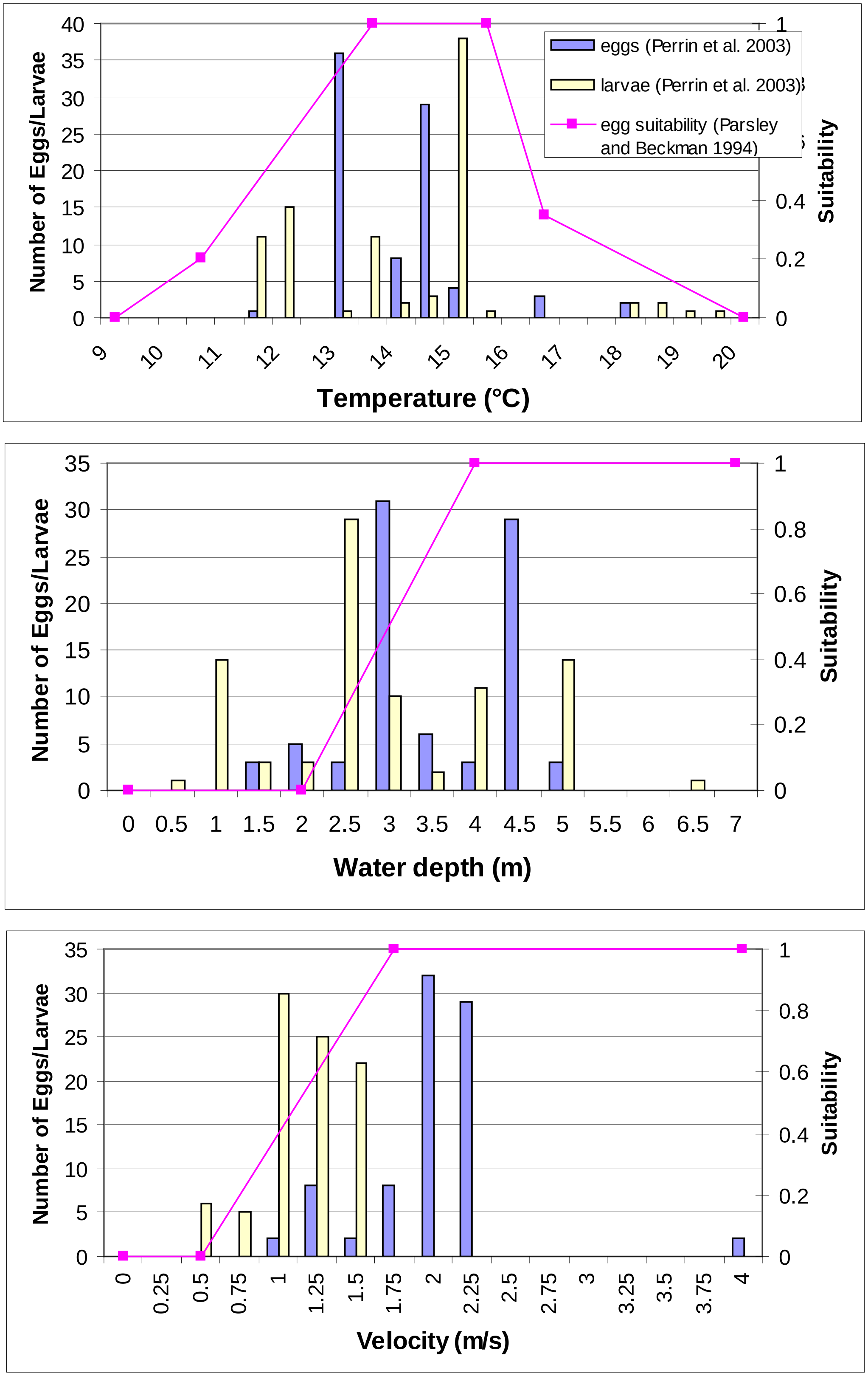


Figure 9. Water temperature, depth and near-bed velocity at sites where sturgeon eggs and larvae were collected in the Fraser River (Perrin *et al*. 2003). Suitability of use conditions for spawning in the Columbia River (Parsley and Beckman 1994) are also shown. Figure taken from Perrin *et al*. 2003.

Water temperature during spawning in 2008 was similar to that observed previous years (Figure 10). In both 2004 and 2006 mean daily temperatures on the day spawning was observed were 13.9°C and 13.5°C, respectively, with daily maximums of 16°C and 14.6°C, respectively. In addition, in both years temperatures had been above 13°C for several days leading up to the spawning event. In 2007, daily mean temperatures of 13°C (daily maximum of 14.5°C) were not recorded for the first time until the day before eggs were first collected. In 2008 mean daily temperatures of 13°C and daily maximums of 14.6°C were reached two days prior to eggs being collected for the first time. These results, suggest a strong relationship between the date of spawning and water temperature. This relationship was confirmed by the model analysis (Table 3) with either daily mean or daily maximum temperature being included in each of the top five models.

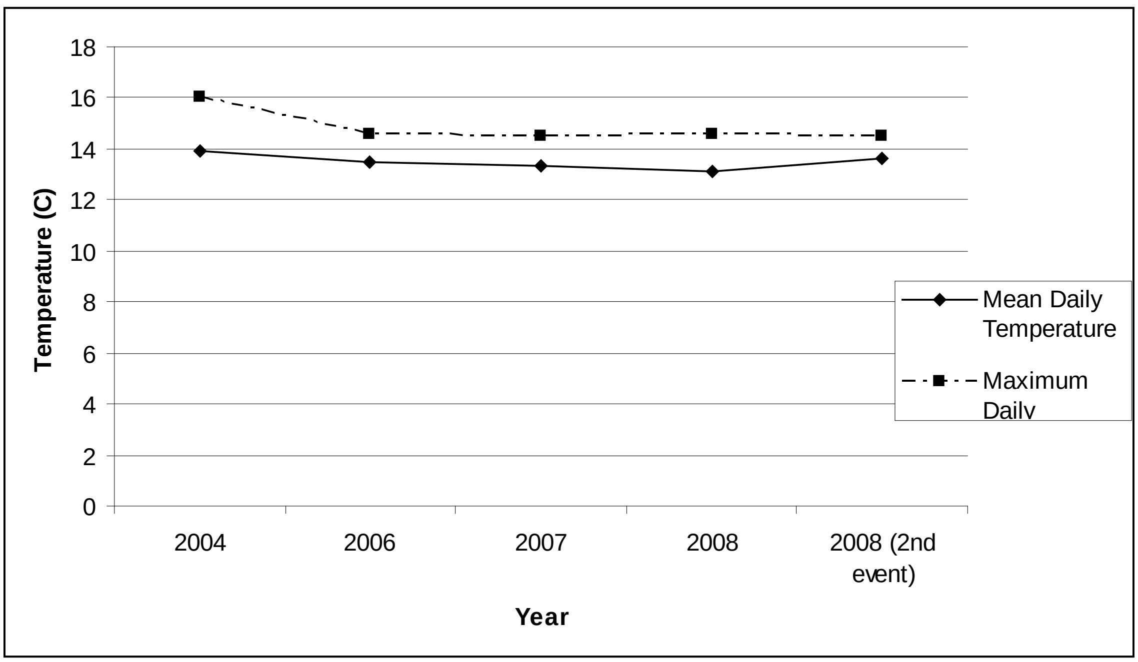


Figure 10. Daily mean and maximum temperatures recorded for the day white sturgeon spawning was observed (2004 and 2006) or the day immediately prior to eggs being collected (2007 and 2008).

4.3 OBSERVATION AND SAMPLING TECHNIQUES

Similar to 2004, 2006, and 2007, egg mats proved effective at capturing eggs in 2008 and confirming that spawning had occurred. Without the positive egg sampling results, it would not be possible to say with certainty that spawning had occurred (for example based on visual observation or telemetry alone). Eggs were collected at 9 of the 10 mat groups placed in 2008. The only set that did not catch eggs was located the farthest upstream, potentially above the spawner locations. Slower habitats were avoided (i.e. those with velocities less than 0.5 m/s) in favour of the main thalweg, which provided the best opportunity for collecting dispersing eggs. Grouping the egg mats increased the sampling area in a given location and the placement of the mats in a line increased the chances of collecting the drifting eggs. Over the past four years, it has been observed that often only 1 mat in a set of 4 will capture eggs. As a result, it is recommended that in future sampling programs mats continue to be placed in groups within the thalweg of the channel and oriented in a line. The density of eggs collected on the mats does provide an indication of spawning locations, with higher densities suggesting spawning was close by, and therefore spreading mats out is important. For the 4-5 km spawning area in the Nechako, a sampling intensity of 40 mats has been effective at determining the occurrence of spawning as well as broadly defining the location of spawning and egg dispersal patterns. However, increased sampling effort in areas where eggs are consistently collected could provide additional information on finer scale habitat preferences (for example place mats across a channel to compare captures at varying depths and velocities). Lastly, although the egg mats have been effective at proving a spawning event has occurred, the relatively low catch-per-unit-effort associated with the technique suggest they would not be a cost effective means to collect naturally fertilized eggs for a recovery program. However, as fertilized eggs that are collected on the mats represent unique genetic stock from the hatchery fish, it is recommended that efforts be made to preserve that potential source of genetic diversity for the population. This can be accomplished by ensuring that there is space in the hatchery set aside to accommodate “wild” eggs and larvae and that there is sufficient staff and resources to rear the fish for as long as possible the give them the best chance of survival.

Egg collection locations give an indication of spawning locations and egg dispersal mechanics. Eggs were first collected on June 2nd at sites 2, 3, and 5-9 (Figure 4). Based on these result, spawning could potentially have occurred through the entire spawning area from upstream of the top island to downstream of the Burrard Avenue bridge. However the single egg collected at site 6 (upstream of Stoney Creek) and 12 of the 16 collected at site 9 (downstream of bridge) were covered in sediment suggesting they may have drifted to those locations. On the 4th, eggs were only collected at sites 8 – 10, downstream of the Burrard Avenue bridge and 3 of the 4 were ruptured. These eggs were assumed to have been from the same spawning event as those that were collected on the 2nd and may have also drifted onto the mats. On June 9th, eggs were only captured at mats 2 and 4 suggesting spawning was limited to upstream of the top island.

In addition to the location of eggs collected in 2008, Figure 4 also shows the locations of eggs that were collected in 2004, 2006 and 2007 (no eggs were collected in 2005). The results show that there are two key locations within the spawning area where eggs have been consistently collected. The first area is upstream of the top island. Eggs were collected there in 2006, 2007 and 2008. In 2004, sampling was limited but eggs were collected in the main channel to the right of the island immediately downstream of that location. The eggs collected at mat group # 2 in 2008 (Figure 4) were located the farthest upstream of any eggs that have been collected and therefore that location represents the upstream limit of confirmed spawning. In 2004 and 2008, numerous fish were visual observed in that area (Figure 3) and the only larvae that has been collected was from the left-hand side channel of the top island (Triton 2004). Lastly, this was also the area where eggs from the second spawning event in 2008 were collected. The selection of this area in the absence of competition from other spawners could suggest a preference for the habitat conditions in that area. The second important egg sampling location is immediately upstream and downstream of the Burrard Avenue bridge. Eggs have been collected at this location in each year that it was sampled with the exception of 2005, when it is unknown if spawning occurred. It is speculated that many of the eggs collected in this area drifted downstream and were deposited in this area based on the numbers that have been collected covered in sediment. However, eggs free of sediment that subsequently hatched have also been collected and in 2006 fish were observed in this area (Figure 3) suggesting that spawning may be occurring in the vicinity of the bridge. In addition, in 2003 groups of fish were observed 150 - 200 m upstream of the bridge (May 26th) as well as between rkm 134 and 135 (May 28th) (Pers. Comm. Cory Williamson, MOE). In 2006, fish were observed breaching immediately upstream of the Burrard Avenue bridge (Pers. Comm. Mike Keehn).

In 2008 Northwest Hydraulics Consultants (NHC) completed a hydrodynamic model to predict depths and flow velocities within the spawning area at a range of discharge levels. The model predicted that the highest velocity flows within the braided reach at moderate to high discharge levels would correspond to the two key egg sampling locations (upstream of the top island and between Stoney Creek and the Burrard Avenue bridge; NHC 2008). This suggests the flow velocity is a factor when selecting spawning habitat and that higher velocities are preferred. Flow is considered to be extremely important to fresh-water fishes since it impacts habitat quality, quantity and accessibility, as well as food availability and the energetic demands associated with swimming (Moyle and Cech 2004). Once spawning has occurred, both eggs and larvae require a continuous supply of oxygen and are therefore dependent on flow. Flow also controls both the deposition and removal of fine substrates which can smother eggs or larvae or prevent adhesion of eggs in the case of broad-cast spawners. Lastly, dispersal of eggs and larvae are dependent on flow. All of these factors provide support to the importance of flow in the selection of spawning habitats. A predictive model such as the one developed by NHC can therefore provide an important management tool when assessing how future flow regimes might impact white sturgeon spawning in the Nechako River.

4.4 PREDICTIVE MODEL

The model that was selected as “best” in the present study involves a combination of average daily temperature, daily flow and photoperiod. These factors when considered together do a better job explaining the observed white sturgeon migration patterns than each parameter individually, as was made apparent by comparing AIC_c scores (Table 3).

This is the same model that was selected in 2007, with the only difference being that the 2008 version used a quadratic equation to describe each of the parameters as opposed to only linear parameters in 2007. The agreement of the two modeling analyses strengthens the argument that threshold temperature controls spawning migration. The original model developed in 2006 identified ATU along with flow and photoperiod as being best able to describe the observed data, suggesting that temperature experience was more important to migration. However, since that model was based on only 185 data points as opposed to 1454 in the 2008 version, the results of the current analysis are considered more accurate. Further modeling could also be done to assess the role of environmental parameters in when spawning occurs. Review of the data collected suggests a mean daily temperature threshold of 13.5 °C is required for spawning to occur (Figure 2). With data on spawn timing from 2003 – 2008, sufficient data may now be available to assess that assumption statistically.

The primary consideration when using ITMC is that the models must be based on solid biological theory (Anderson *et al.* 2000; Anderson and Burham 2002). Therefore, assessing what the model is saying from a biological standpoint is critical to determining how useful it is from a management perspective. The importance of flow was discussed in the previous section and the selection of the other two parameters is equally defensible. Temperature is the primary abiotic factor in the life history of fish influencing everything from metabolism and growth, to physiology, reproduction and behavior (Moyle and Cech 2004; Wooton 1992). It is therefore not unrealistic to think that temperature would have an influence on the timing of white sturgeon migration. Rising water temperatures in the spring likely increase swimming ability, making migrations less energetically demanding, as well as influencing gamete production prior to spawning. Once spawning is complete, temperature influences the incubation time of eggs and yolk-sac larvae as well as the growth rate of active feeding larvae. Therefore, if temperatures are too low, the energetic demands of migration might be too high, gamete production and release might be greatly reduced and eggs might not incubate or be subject to increased predation due to an extended incubation period. Similarly, since the early life stages of fish are generally more sensitive to increased temperature than are the juvenile or adult stages (Rombough

1997), the eggs and larvae may not survive if spawning is delayed for too long allowing temperatures to rise too high. Photoperiod is known to play a driving role in controlling the timing of both physiological and behavioral changes in many species of fish. Increasing daylight in the spring has been linked to smolting and migration in juvenile salmonids and experiments have shown that for many species, physiological changes can be delayed, accelerated, or prevented simply by manipulating photoperiod. As a result, it is reasonable to expect that for white sturgeon this parameter may play an important role in controlling both the physiological preparations for spawning as well as the timing of the migration to spawning area.

Determining how exactly the parameters interact to control white sturgeon spawning is beyond the scope of the developed model. As was mentioned in the methods section, the sign of the coefficients generated for each of the parameters included in the selected models gives and indication of whether or not that parameter has a positive or negative effect on the phenomenon being studied. In the case of quadratic parameters, the linear and squared components of the equation have opposite signs since one is describing the increase in probability and the other describes the decrease in probability. In the selected model increasing temperature and photoperiod in the spring has a positive influence on the probability of migration, while increasing flow has a negative influence. However, this should not be interpreted to mean that lower flow and higher temperatures are favourable for the spawning migration of white sturgeon. Instead, the model has developed the coefficients to reflect the trends that are specific to the observed data which was included in the analysis. In regards to the negative effect of flow, a potential explanation is that the majority of the “0” data points are associated with increasing flows. As a result, the coefficients generated reflect the fact that there are more records of fish not congregating when flow is higher. As with any modeling analysis, it is important to remember that the value of the coefficients generated and their corresponding sign are specific to the data used during the model generation.

The statistical fit of the developed model must also be considered in order to assess the usefulness of the model from a management standpoint. The ROC analysis showed that the predictive ability of the selected model was only marginal (correct 81% of the time). This is a decrease from the analysis of the 2007 model, which was correct 84% of the time. It was expected that the inclusion of another years of data would improve the predicative capabilities of the model, but that did not happen. While the model was able to predict general trends in migration pattern that match the observed data (Figure 8), the results were not conclusive enough to suggest it could be used to predict future migration patterns in its current state. It is thought that the reason for the models inaccuracy is that while the dataset is getting larger, much of the data included is confounding in the sense that not all fish spawn each year and on any given day more fish will be detected outside of the spawning area then within. Therefore the model is based to a large degree on the behavior of fish that will not migrate regardless of environmental cues because they are not sexually mature thus limiting its ability to predict migration for those that are mature. In order to improve the models predictive ability, the data on fish that did not migrate to the spawning area each year would have to be removed. Although this would reduce the size of the dataset, the result would be better able to specifically address the question of migration controls.

4.4.1 MANAGEMENT IMPLICATIONS

Despite the models inability to accurately predict spawning migrations, the identification of the key parameters involved in migration does have management implications. Based on the results it is likely that fluctuations in river temperature and flow during the spawning period could have an affect on the timing of spawning. It is therefore important that further studies be completed to assess the potential impacts of current and future flow and temperature regimes within the system. A model focused specifically on migrating fish or those that are known to have spawned each year could be used for this purpose by predicting white sturgeon migration patterns based on a series of hypothetical management strategies.

5 Recommendations for Future Work

As outlined in the *Nechako White Sturgeon Habitat Management Plan* (NWSRI, 2008), the overall goal of the recovery program is to restore natural recruitment for the population. To that end there were 3 objectives identified: 1) identify habitat management options supported by available data; 2) address data gaps; and 3) implement habitat management activities. The sturgeon monitoring programs completed from 2004 to 2008 have contributed a substantial amount of information towards the first objective. In particular the monitoring program has documented the reproductive behaviour of the population over several years and flow patterns and has identified a spawning location. The collection of viable eggs and larvae has confirmed spawning has occurred in 4 of the 5 years studied and habitat conditions within the spawning area have been documented. The importance of environmental parameters such as water temperature, flow and photoperiod at controlling the onset of migration and spawning has also been demonstrated and potential effects of manipulation of the flow regime during the spawning period has been discussed. Given the amount of data that has been collected to date on the Vanderhoof spawning area there is the potential that future monitoring programs based on the same procedures that have been used from 2004 to 2008 may not yield substantial new information. As a result a focus on other locations to potentially identify new spawning areas is recommended.

In 2007 the Braeside location was identified as a potential second spawning area (Triton 2007). The physical characteristics of that location (braided channel, substrate and discharge) seem suitable for spawning based on data collected at the Vanderhoof location and the presence of tagged fish there during the spawning period in 2007 suggest further investigation of this area is needed. Ideally the program would consist of a combination of visual assessments, telemetry, and egg sampling. However, it is recognized that funding availability may limit what can be accomplished. If this is the case, it is recommended that an egg mat sampling program be given priority. In both 2007 and 2008 the successful collection of eggs at Vanderhoof was the only means of confirming that spawning had occurred since visual observations and telemetry data were not conclusive. Based on the knowledge that has been gained sampling for eggs at the Vanderhoof location, the mats can be deployed at Braeside in locations that would provide the best chance of collecting eggs if spawning is occurring. Lastly, since egg mat sampling is a passive technique, they can be extremely cost-effective. For example, it is estimated that the field program including: setup and deployment of the mats, regular checks every 5-7 days for 1 month, and demobilization would require approximately 24 person days. Based on an 8 hour day and at a rate of $60/hour (junior bio 3-5 yrs experience), the total estimated cost of the field program including disbursements would be in the range of $10,000.00 to $15,000.00. It is recommended that any fertilized eggs collected on egg mats be given high priority for rearing as they represent a unique source of genetic diversity for the population.

Additional key habitats might also be able to be identified through telemetry programs that focus on tracking fish that were tagged in locations other than the known overwintering locations (i.e. km 110, 116 and 125). Telemetry data collected on fish from those locations show they generally utilize the same habitats including the previously identified overwintering areas in the river, the Vanderhoof spawning area, and Stuart Lake (Triton 2008). There is the possibility that other sub-populations (for example associated with Fraser Lake) may exist in the system that make use of different habitats. Telemetry programs that focus on capturing fish outside of the known areas, such as upstream of Vanderhoof and in Fraser Lake, would be the best means of identifying these habitats and provide new information on the behavior of the population. The *Nechako White Sturgeon Database Summary Report – 2007* (Triton 2008) provides information on historical sampling that has been completed within the river including all areas where fish have been captured in the past. That information could be used to tailor a sampling program to focus on areas where fish have been successfully captured in the past that are outside of the common sampling areas.

The final recommendation is that the electromyogram (EMG) tagging program that was originally proposed for 2008, be considered for 2009. This program would potentially provide valuable data on spawning duration and frequency for wild fish. However, in order to implement the program, several considerations will need to be made prior to spring 2009. Firstly, EMG tags will need to be acquired. The CSTC had purchased tags for 2008 (Pers. Comm. Bill Sheppert, CSTC) which should still be available but should be confirmed. Secondly, only Lotek SRX600 telemetry receivers can detect the EMG tags. To date, all of the receivers that have been used on the sturgeon monitoring programs have been SRX400's including all MOE, DFO, CSTC, UNBC, and Triton receivers. MOE has upgraded two of their units to SRX600's (Pers. Comm. Cory Williamson) and would potentially be available in the spring. However, their availability will need to be confirmed since rental of the units from Lotek requires several weeks of lead-time. Third, locations for the establishment of base stations should be identified. Ensuring sufficient antennas (which cannot be rented and must be purchased from Lotek), and power supplies (solar panels, batteries) are available, as well as identifying means of mounting the antennas (poles, scaffolding etc) will be required. Lastly, the program requires the capture of ripe females that can be tagged with the EMG tags. In the past, tagging has occurred in conjunction with the brood program and the majority of ripe fish encountered have been taken as brood stock. Success of the EMG program would require several ripe fish to be tagged and released, which might limit the brood program. Alternatively, if the tags are only applied to extra fish (i.e. once the brood quota is fulfilled), it may make the EMG program less cost effective (for example if only 1 or 2 extras are captured).

5.1 RECOMMENDATIONS FOR MODELING

The model developed in the 2008 analysis identifies the key environmental parameters associated with white sturgeon spawning migration in the Nechako River. The results are biologically defensible and are supported by the observations made during the 2004-2008 monitoring programs. However, the analysis also showed that the model's ability to predict migration and identify the spawning period is limited. Therefore future models should focus on improving the models predictive ability so that it can be better applied to management questions. There are two ways of potentially improving the models predictive ability:

1. The historical telemetry data should reviewed to identify the fish that migrated to the spawning area each year. The model dataset can then be refined to include

only telemetry records from those fish. The binary logistic regression technique used in this analysis can then be applied to the refined dataset. The resulting model would be based on data from migrating fish only which should allow it to better predict migration.

2. As an alternative, a count model could be used as opposed to the binary logistic regression. Count models focus on the number of occurrences of the behavior in question as opposed to whether or not it happened. In this case, the resulting dataset would include the number of fish present within the spawning area on a given day and would not be influenced by fish that did not migrate.

Once a model is developed to accurately predict spawning migration, it can be used to address more specific questions such as the date of spawning, as well as assessment of the potential effects of future flow and temperature management strategies would be possible.

6 References

Anderson, D.R., Burnham, K.P., and Thompson, W.L. 2000. Null hypothesis testing: problems, prevalence and an alternative. J. Wildl. Manage. 64(4): 912-923.

Anderson, D.R., and Burham, K.P. 2002. Avoiding pitfalls when using information-theoretic methods. J. Wildl. Manage. 66(3): 912-918.

B.C. Conservation Data Centre. 2008. BC Species and Ecosystems Explorer. B.C. Minist. of Environ. Victoria, BC. Available: http://srmapps.gov.bc.ca/apps/eswp/ (accessed [November 6, 2006]).

Boyce, M.S., Vernier, P.R., Nielsen, S.E., Schmiegelow, F.K.A. 2002. Evaluating resource selection functions. Ecological Modelling 157: 281-300.

Golder Associates Ltd. 2006. Nechako River white sturgeon tagging project – 2005 data report. Completed for the BC Ministry of Environment.

Johnson, J.B., and Omland, K.S. 2004. Model selection in ecology and evolution. Trends in Ecology and Evolution 19(2): 101-108.

Kaufman and Robison, 2003.

McAdam, S.O., Walters, C.J., and Nistor, C. 2005. Linkages between white sturgeon recruitment and altered bed substrates in the Nechako River, Canada. Trans. Am. Fish. Soc. 134(6): 1448-1456.

Menard, S. 2001. Applied Logistic Regression Analysis. Sage University Papers Series on Quantitative Applications in the Social Sciences, 07-106. Thousand Oaks, CA: Sage.

Moyle, P.B. and Cech, J.J. 2004. Fishes: An Introduction to Ichthyology – 5th ed. Upper Saddle River: Prentice Hall.

Nechako White Sturgeon Recovery Initiative. 2008. Nechako White Sturgeon Habitat Management Plan.

Nechako White Sturgeon Recovery Initiative. 2005. Breeding plan for Nechako white sturgeon. Prepared by Susan M. Pollard, BC Ministry of Environment. 35 pp.

Nechako White Sturgeon Recovery Initiative. 2004. Recovery Plan for Nechako White Sturgeon. Prepared by Golder Associates Ltd. 82 pp.

Northwest hydraulic consultants, 2008. Nechako River at Vanderhoof Hydrodynamic Model Upgrade. Prepared for BC Ministry of Environment, Rio Tinto Alcan, and Carrier Sekani Tribal Council.

Paragamian, V. L., G. Kruse. 2001. Kootenai River white sturgeon spawning migration behavior and a predictive model: North American Journal of Fisheries Management. 21:1:10-21.

Paragamian, V. L., G. Kruse, V. Wakkinen. 2001. Spawning habitat of Kootenai River white sturgeon, post-Libby Dam: North American Journal of Fisheries. 21:1:22-33.

Parsley M.J. and L.G. Beckman. 1994 White sturgeon spawning and rearing habitat in the Lower Columbia River. North American Journal of Fisheries Management 14: 812-827

Parsley. M.J., L.G. Beckman and G.T. McCabe Jr. 1993. Spawning and rearing habitat use by white sturgeons in the Columbia River downstream of the McNary Dam. Transactions of the American Fisheries Society 122: 217-227.

Perrin, C. J., L.L. Rempel, M. L. Rosenau. 2003. White sturgeon spawning habitat in an unregulated river: Fraser River, Canada: Transactions of the American Fisheries Society. 132:154-165.

Rombough, P.J. 1997. The effects of temperature on embryonic and larval development. In: Wood, C.M. and McDonald D.G, editors. Global Warming: Implications for Freshwater and Marine Fish. Society for Experimental Biology, Seminar Series 61. Cambridge: Cambridge University Press. Pg 177-224

Smith, C.T., R.J. Nelson, S. Pollard, E. Rubidge, S.J. McKay, J. Rodzen, B. May and B. Koop. 2002. Population genetic analysis of white sturgeon (*Acipenser transmontanus*) in the Fraser River. J. Appl. Ichthyol. 18:307-312.

Triton Environmental Consultants Ltd. 2008. Nechako White Sturgeon Database Summary – 2007. Prepared for Ministry of Environment. Prepared by G. Sykes.

Triton Environmental Consultants Ltd. 2007. Adult white sturgeon monitoring – Nechako River 2006. Prepared for Alcan Primary Metal. Prepared by G. Sykes and R. Liebe.

Triton Environmental Consultants Ltd. 2006. Adult white sturgeon monitoring – Nechako River 2006. Prepared for Alcan Primary Metal. Prepared by Liebe, R., G. Sykes, and R. Manson.

Triton Environmental Consultants Ltd. 2005. Adult white sturgeon monitoring – Nechako River 2005. Prepared for Alcan Primary Metal. Prepared by Liebe, R., G. Sykes, and R. Manson.

Triton Environmental Consultants Ltd. 2004. Adult white sturgeon monitoring – Nechako River 2004. Prepared for Alcan Primary Metal. Prepared by Liebe, R., B. Rublee, G. Sykes, and R. Manson.

Wooton, R.J. 1992. Fish Ecology. New York: Chapman and Hall.

Personal Communication:

Bill Shepert, Carrier Sekani Tribal Council, Fisheries Section Head.

Cory Williamson, Fish Biologist, Ministry of Water, Land and Air Protection, Prince George.

Appendix 1

Water Temperature and Discharge Data

Table 5. Daily mean discharge, and daily mean temperature at the Burrard Avenue bridge (Water Survey of Canada station 08JC001) from May 4th to July 3rd, 2008. Red highlighting identifies dates when eggs were collected.

Date	Daily Mean Temperature (°C)	Daily Maximum Temperature (°C)	Daily Mean Discharge (m^3/sec)
5/4	7.1	7.8	132
5/5	7.1	8.5	138
5/6	7.9	9.2	146
5/7	7.4	8.5	156
5/8	7.5	8.5	159
5/9	7.4	8.9	173
5/10	7.7	8.7	181
5/11	7.7	8.8	189
5/12	7.9	9.2	199
5/13	7.9	8.8	210
5/14	7.7	8.5	220
5/15	8.5	9.8	228
5/16	9.7	11.3	237
5/17	9.8	10.8	248
5/18	10.8	12.5	256
5/19	10.1	10.6	264
5/20	9.4	10	272
5/21	9.7	10.7	279
5/22	10.0	11	280
5/23	10.2	11.3	278
5/24	10.1	11	274
5/25	10.0	11.2	271
5/26	10.6	11.9	267
5/27	11.3	13	261
5/28	11.3	12.5	256
5/29	11.6	12.8	250
5/30	12.6	13.9	244
5/31	13.1	14.6	237
6/1	13.7	15.3	229
6/2	14.2	15.6	221
6/3	13.9	14.9	214
6/4	14.1	15.4	207
6/5	13.6	14.5	201
6/6	13.7	14.7	194
6/7	13.6	14.5	188
6/8	13.3	14.6	182
6/9	12.8	13.6	177
6/10	13.2	14	170
6/11	13.6	15.3	167
6/12	13.4	13.9	163
6/13	13.3	14.1	159
6/14	12.6	13.2	156
6/15	12.9	14.5	152

Date	Daily Mean Temperature (°C)	Daily Maximum Temperature (°C)	Daily Mean Discharge (m^3/sec)
6/16	13.8	15.2	147
6/17	13.8	15	144
6/18	13.4	14.7	141
6/19	13.5	14.7	138
6/20	14.0	15	134
6/21	14.6	15.9	131
6/22	15.0	16.6	127
6/23	15.4	17.1	125
6/24	15.4	16.6	123
6/25	15.0	16.6	120
6/26	15.1	16.8	118
6/27	15.6	17.2	116
6/28	16.4	17.3	113
6/29	17.4	19.5	111
6/30	18.2	20	109
7/1	18.7	20.6	108
7/2	19.3	20.8	107
7/3	18.6	19.7	105

Appendix 2

Telemetry Data

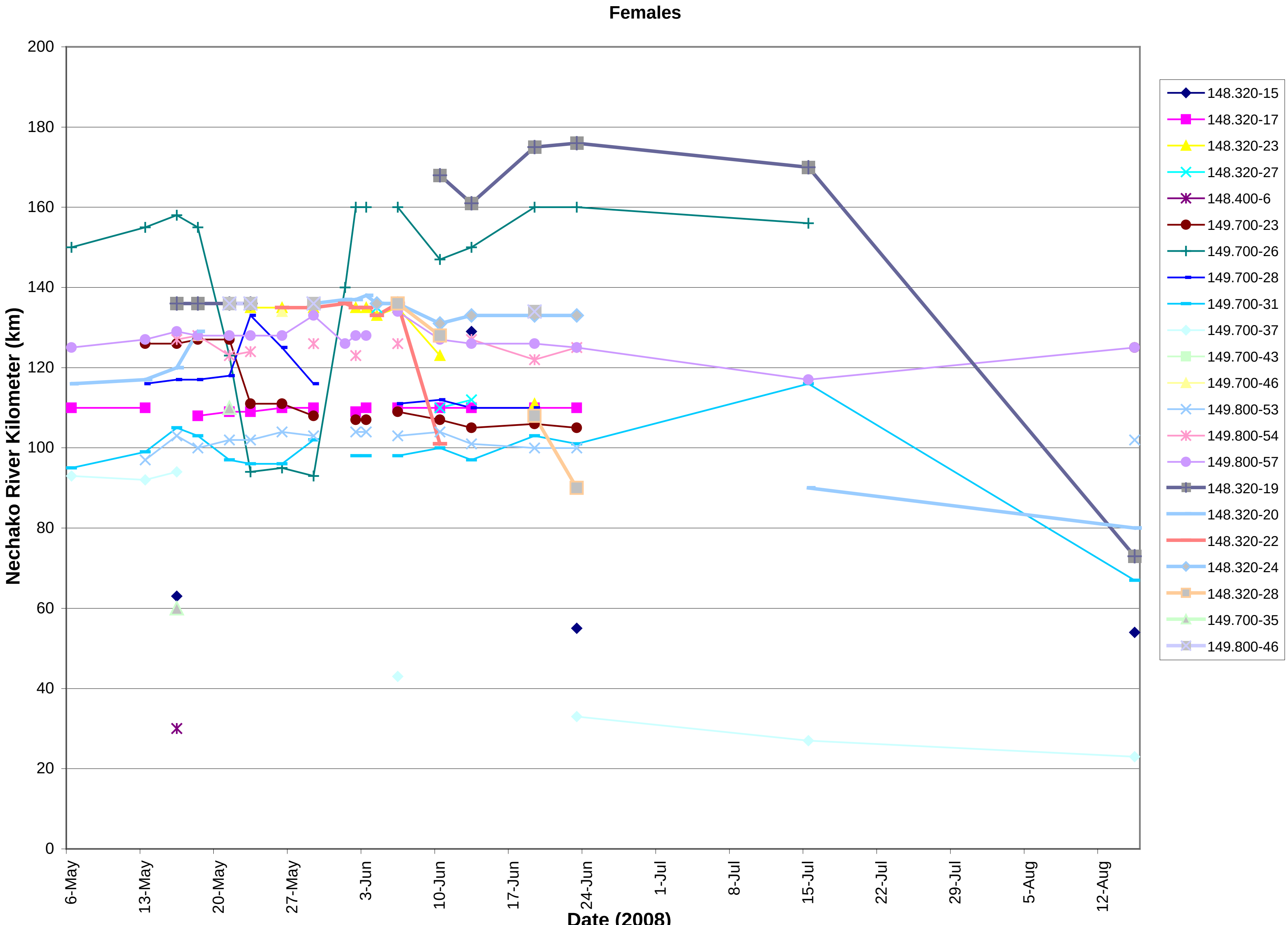


Figure 11. Detailed telemetry data for tagged female fish in 2008.

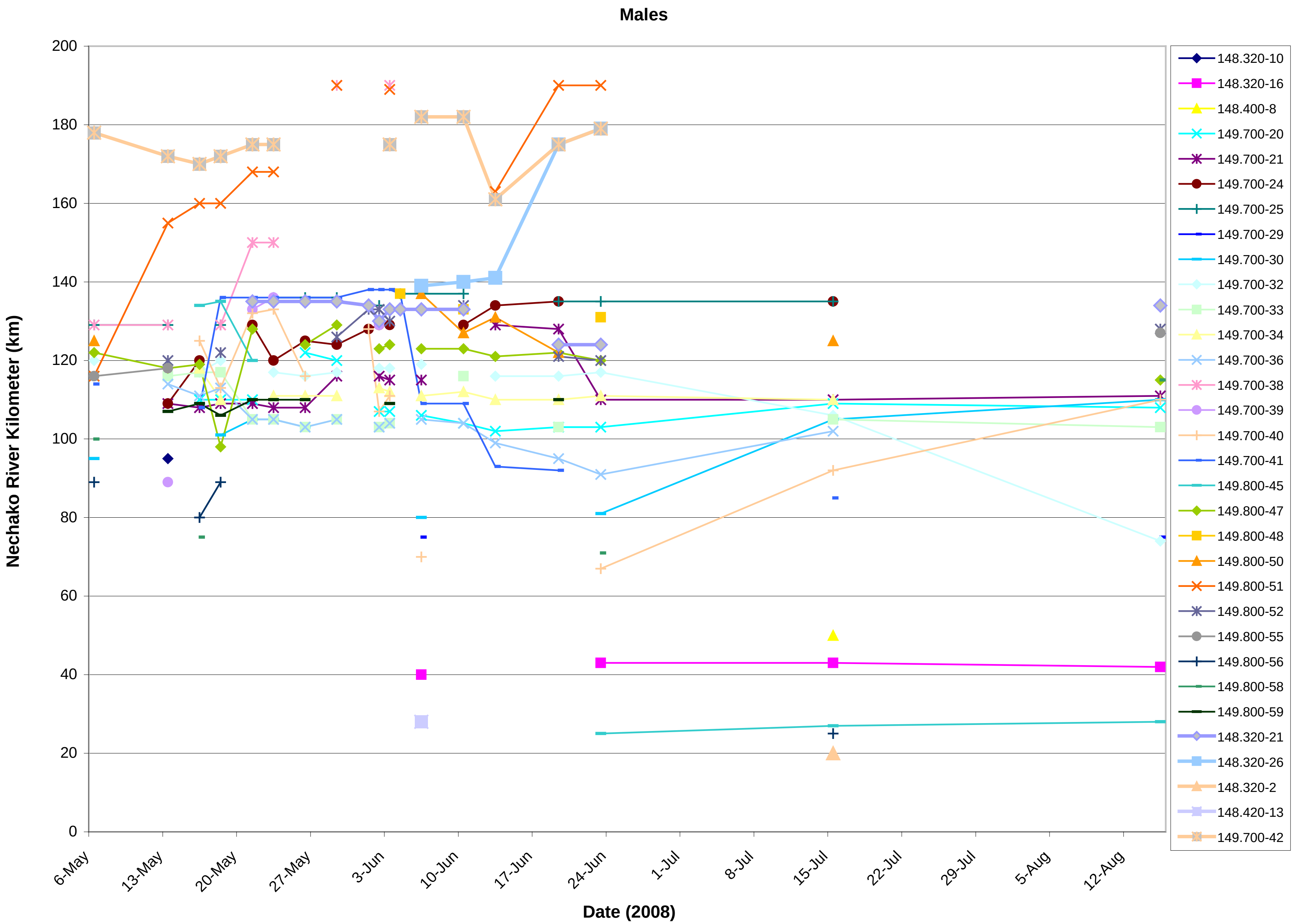


Figure 12. Detailed telemetry data for tagged male fish in 2008.

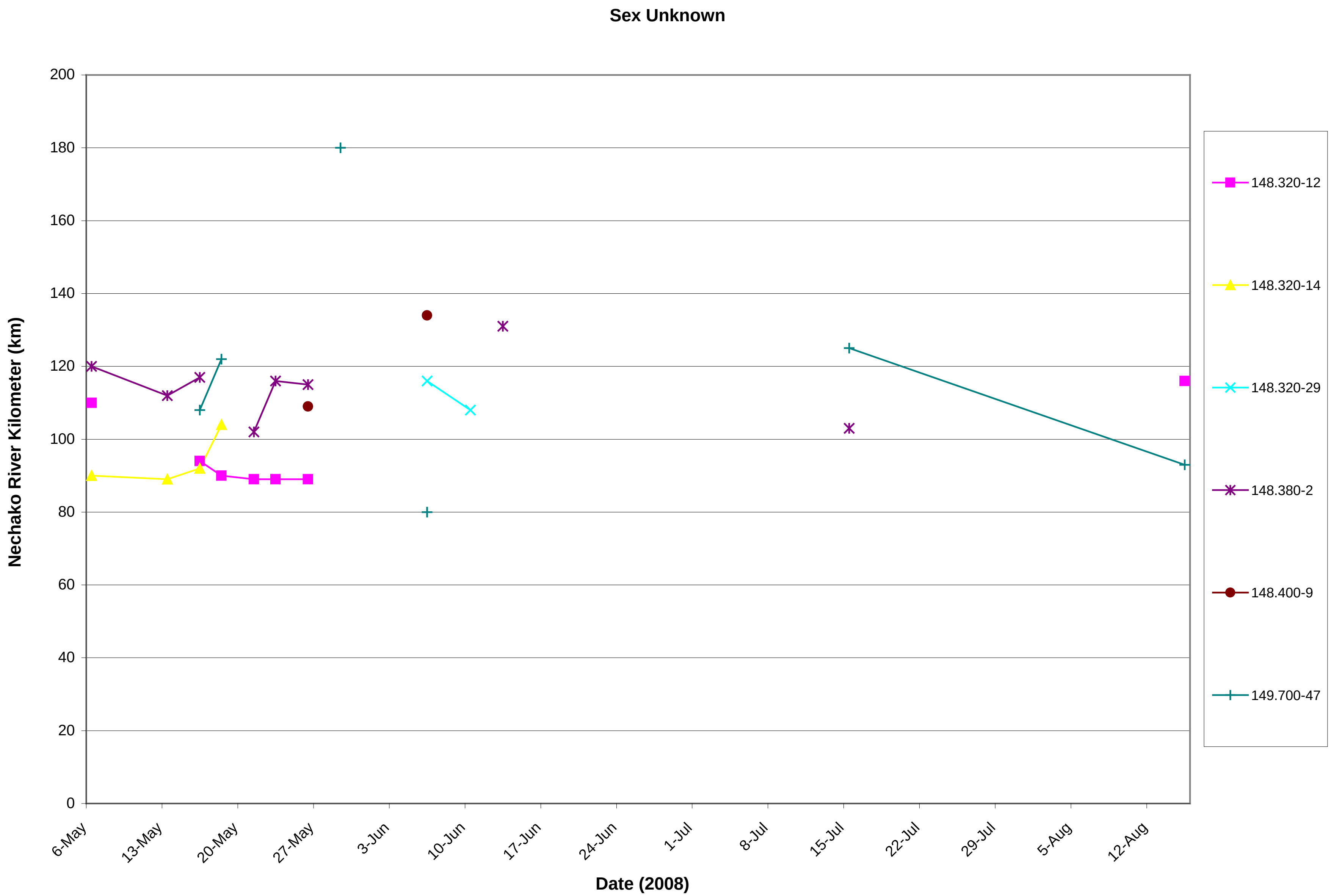


Figure 13. Detailed telemetry data for tagged fish of unknown sex in 2008.

Table 6. Detailed telemetry data from the Baher base station.

Date (2008)	Frequency (MHz)	Code(s) detected
13-May	All frequencies	NSD
14-May	All frequencies	NSD
15-May	All frequencies	NSD
16-May	All frequencies	NSD
17-May	All frequencies	NSD
18-May	149.700	41
19-May	149.700	39, 41
20-May	All frequencies	NSD
21-May	All frequencies	NSD
22-May	All frequencies	NSD
23-May	All frequencies	NSD
24-May	All frequencies	NSD
25-May	All frequencies	NSD
26-May	All frequencies	NSD
27-May	All frequencies	NSD
28-May	All frequencies	NSD
29-May	All frequencies	NSD
30-May	149.700	41
31-May	148.420	15
31-May	149.700	41
1-June	148.420	15
	149.700	39
2-June	148.320	20
	148.420	15
3-June	148.420	15
	149.700	41
4-June	All frequencies	NSD
5-June	148.320	26
6-June	149.800	50
7-June	All frequencies	NSD
8-June	All frequencies	NSD
9-June	All frequencies	NSD
10-June	All frequencies	NSD
11-June	All frequencies	NSD
12-June	All frequencies	NSD
13-June	All frequencies	NSD
14-June	All frequencies	NSD
15-June	All frequencies	NSD
16-June	All frequencies	NSD
17-June	All frequencies	NSD
18-June	All frequencies	NSD
19-June	All frequencies	NSD
20-June	All frequencies	NSD
21-June	All frequencies	NSD
22-June	All frequencies	NSD
23-June	All frequencies	NSD

Notes: All frequencies (MHz): 148.320, 148.380, 148.400, 148.420, 149.440, 149.700, and 149.800.
NSD: No Sturgeon Detected.

Table 7. Detailed telemetry data from the Burrard Avenue bridge base station.

Date (2008)	Frequency (MHz)	Code(s) detected
13-May	All frequencies	NSD
14-May	148.320	21
	148.420	15
15-May	148.320	19
16-May	148.420	15
17-May	148.320	18
18-May	149.700	39
19-May	149.700	41
	149.800	47
20-May	148.320	20
	149.700	26, 38, 41
	149.800	45
21-May	149.700	41
22-May	149.700	41
	149.800	46
23-May	148.320	20
	149.700	39, 41
24-May	148.320	22
	148.420	15,
	149.700	28, 41
25-May	148.320	19
	149.700	41
26-May	148.320	20
	149.700	25, 41
27-May	148.320	20, 21
	149.700	25, 41
28-May	148.320	20, 21, 22
	148.420	15
	149.700	25, 41
29-May	148.320	21, 22
	148.400	9
	149.700	25, 40, 41
	149.800	46
30-May	148.320	21
	149.700	40
31-May	148.320	21
	149.700	26, 41

Notes: "All frequencies (MHz)" : 148.320, 148.380, 148.400, 148.420, 149.440, 149.700, 149.800. "NSD" stands for No Sturgeon Detected

Date (2008)	Frequency (MHz)	Code(s) detected
1-June	148.320	20
	149.800	46
2-June	148.320	21
	148.400	9
3-June	148.320	27
	149.800	46
4-June	148.320	27, 28
	149.800	46
5-June	148.320	29
6-June	148.320	20, 22, 24
	149.700	24
	149.800	30, 46, 48
7-June	149.700	24
8-June	149.800	50
9-June	All frequencies	NSD
10-June	All frequencies	NSD
11-June	All frequencies	NSD
12-June	All frequencies	NSD
13-June	All frequencies	NSD
14-June	All frequencies	NSD
15-June	All frequencies	NSD
17-June	149.700	17
18-June	149.700	24
19-June	149.700	24
20-June	All frequencies	NSD
21-June	149.700	25
	19.800	46
22-June	148.320	1
23-June	149.700	25

Notes: "All frequencies (MHz)" : 148.320, 148.380, 148.400, 148.420, 149.440, 149.700, 149.800. "NSD" stands for No Sturgeon Detected.

Table 8. Detailed telemetry data from the telemetry flights in May, 2008.

Frequency - Code	Sex	06-May-08	13-May-08	16-May-08	18-May-08	21-May-08	23-May-08	26-May-08	29-May-08
148.320-10	M		95						
148.320-12		110		94	90	89	89	89	
148.320-14		90	89	92	104				
148.320-15	F			63					
148.320-17	F	110	110		108	109	109	110	110
148.320-19	F			136	136	136	136		
148.320-20	F	116	117	120	129				136
148.320-21	M					135	135	135	135
148.320-22	F							135	135
148.320-23	F						135	135	135
148.380-2		120	112	117		102	116	115	
148.400-6	F			30					
148.400-9								109	
149.700-20	M	116		110	110	110		122	120
149.700-21	M		109	108	109	109	108	108	116
149.700-23	F		126	126	127	127	111	111	108
149.700-24	M		109	120		129	120	125	124
149.700-25	M	129	129		129		136	136	136
149.700-26	F	150	155	158	155	123	94	95	93
149.700-28	F		116	117	117	118	133	125	116
149.700-29	M			108					
149.700-30	M	95			101	105	105	103	
149.700-31	F	95	99	105	103	97	96	96	102
149.700-32	M	120		117	120		117	116	117
149.700-33	M		116	117	117	105	105	103	105
149.700-34	M			118	110		111	111	111
149.700-35	F			60		110			
149.700-36	M		114	111	113	105	105	103	105
149.700-37	F	93	92	94					
149.700-38	M	129	129		129	150	150		190
149.700-39	M		89			133	136		
149.700-40	M			125	113	132	133	116	
149.700-41	M	114		108	136	136	136	136	136
149.700-42	M	178	172	170	172	175	175		
149.700-46	F				128			134	
149.700-47				108	122				180
149.800-45	M			134	135	120			
149.800-46	98					136	136		136
149.800-47	M	122	118	119	98	128		124	129
149.800-50	M	125							
149.800-51	M	116	155	160	160	168	168		190
149.800-52	M		120		122				126
149.800-53	F		97	103	100	102	102	104	103
149.800-54	F			127	128	123	124		126
149.800-55	M	116	118						
149.800-56	M	89		80	89				
149.800-57	F	125	127	129	128	128	128	128	133
149.800-58	M	100		75					
149.800-59	M		107	109	106	110	110	110	

Table 9. Detailed telemetry data from the telemetry flights in June, July, August, 2008.

Frequency - Code	Sex	1-Jun-08	2-Jun-08	3-Jun-08	4-Jun-08	6-Jun-08	10-Jun-08	13-Jun-08	19-Jun-08	23-Jun-08	15-Jul-08	15-Aug-08
148.320-2											20	
148.320-12												116
148.320-15	F							129		55		54
148.320-16	M					40				43	43	42
148.320-17	F		109	110		110	110	110	110	110		
148.320-19	F						168	161	175	176	170	73
148.320-20	F	137	137	138	136	136					90	80
148.320-21	M	134	130	133	133	133	133		124	124		134
148.320-22	F	136	135	135	133	136	101					
148.320-23	F		135	135	133	135	123		111			
148.320-24	F				136	136	131	133	133	133		
148.320-26	M					139	140	141	175	179		
148.320-27	F				135		110	112				
148.320-28	F					136	128		108	90		
148.320-29						116	108					
148.380-2								131			103	
148.400-9						134						
148.400-8	M										50	
148.420-13	M					28						
149.700-20	M		107	107		106	104	102	103	103	109	108
149.700-21	M		116	115		115		129	128	110	110	111
149.700-23	F		107	107		109	107	105	106	105		125
149.700-24	M	128	129	129			129	134	135		135	
149.700-25	M		134		137	137	137		135	135	135	
149.700-26	F	140	160	160		160	147	150	160	160	156	
149.700-28	F					111	112	110	110			
149.700-29	M					75						75
149.700-30	M					80				81	105	110
149.700-31	F		98	98		98	100	97	103	101	116	67
149.700-32	M		118	118		119		116	116	117	106	74
149.700-33	M		103	104			116		103		105	103
149.700-34	M		113	112		111	112	110	110	111	110	
149.700-36	M		103	104		105	104	99	95	91	102	
149.700-37	F					43				33	27	23
149.700-38	M			190								
149.700-39	M		129									
149.700-40	M	128	107	111		70				67	92	110
149.700-41	M	138	138	138	137	109	109	93	92		85	
149.700-42	M			175		182	182	161	175	179		
149.700-47						80					125	93
149.800-45	M									25	27	28
149.800-46	98								134			
149.800-47	M		123	124		123	123	121	122	120		115
149.800-48	M				137		133			131		
149.800-50	M					137	127	131	122		125	
149.800-51	M			189				163	190	190		
149.800-52	M	133	133	130			134		121	120		128
149.800-53	F		104	104		103	104	100,101	100	100		102
149.800-54	F		123			126		129,126	122	125		
149.800-55	M											127
149.800-56	M					28					25	
149.800-57	F	126	128	128		134	127	126	126	125	117	125
149.800-58	M									71		115
149.800-59	M			109					110			

Appendix 3

Egg Mat Field Survey Data

Table 9. Substrate mat (egg mat) details.

Deployment						Retrieval			
Set #	Date	Time	UTM	Depth	Velocity	Date	Time	Eggs	Comment
1	26-May-08	14:00	10.431039.5986094	1.5	1.35	02-Jun-08	13:34	0	
2	26-May-08	14:00	10.431446.5986063	2	1.63	02-Jun-08	13:42	1	
3	26-May-08	14:00	10.431446.5986130	1.6	1.45	02-Jun-08	13:53	7	
4	26-May-08	14:00	10.432070.5986371	1.9	1.19	02-Jun-08	14:06	0	
5	26-May-08	14:00	10.432434.5986434	1.5	1.12	02-Jun-08	14:21	1	
6	26-May-08	14:00	10.433158.5986361	2.0/2.4	0.55	02-Jun-08	14:32	1	egg covered in sediment
7	26-May-08	14:00	10.433405.5986468	2.1/2.0	0.62	02-Jun-08	14:43	1	
8	26-May-08	14:00	10.433724.5986925	1.9	0.84	02-Jun-08	14:53	6	3 ruptured
9	26-May-08	14:00	10.434058.5986832	3.3/3.1	0.61	02-Jun-08	15:08	16	12 covered in sediment
10	26-May-08	14:00	10.434234.5986547	2.8/2.9	0.57	02-Jun-08	15:23	0	
1	02-Jun-08	13:34	10.431039.5986094	1.5	1.35	04-Jun-08	13:30	0	
2	02-Jun-08	13:42	10.431446.5986063	2	1.63	04-Jun-08	13:40	0	
3	02-Jun-08	13:53	10.431446.5986130	1.6	1.45	04-Jun-08	13:50	0	
4	02-Jun-08	14:06	10.432070.5986371	1.9	1.19	04-Jun-08	14:00	0	
5	02-Jun-08	14:21	10.432434.5986434	1.5	1.12	04-Jun-08	14:09	0	
6	02-Jun-08	14:32	10.433158.5986361	2.0/2.4	0.55	04-Jun-08	14:20	0	
7	02-Jun-08	14:43	10.433405.5986468	2.1/2.0	0.62	04-Jun-08	14:30	0	
8	02-Jun-08	14:53	10.433724.5986925	1.9	0.84	04-Jun-08	14:39	1	
9	02-Jun-08	15:08	10.434058.5986832	3.3/3.1	0.61	04-Jun-08	14:50	3	2 ruptured
10	02-Jun-08	15:23	10.434234.5986547	2.8/2.9	0.57	04-Jun-08	15:08	1	ruptured
1	04-Jun-08	13:30	10.431039.5986094	1.5	1.35	09-Jun-08	11:36	0	
2	04-Jun-08	13:40	10.431446.5986063	2	1.63	09-Jun-08	11:48	7	1 crushed
3	04-Jun-08	13:50	10.431446.5986130	1.6	1.45	09-Jun-08	12:00	0	
4	04-Jun-08	14:00	10.432070.5986371	1.9	1.19	09-Jun-08	12:10	11	2 fungus, 3 crushed
5	04-Jun-08	14:09	10.432434.5986434	1.5	1.12	09-Jun-08	12:25	0	
6	04-Jun-08	14:20	10.433158.5986361	2.0/2.4	0.55	09-Jun-08	12:36	0	
7	04-Jun-08	14:30	10.433405.5986468	2.1/2.0	0.62	09-Jun-08	12:48	0	
8	04-Jun-08	14:39	10.433724.5986925	1.9	0.84	09-Jun-08	12:56	0	
9	04-Jun-08	14:50	10.434058.5986832	3.3/3.1	0.61	09-Jun-08	13:08	0	
10	04-Jun-08	15:08	10.434234.5986547	2.8/2.9	0.57	09-Jun-08	13:13	0	
1	09-Jun-08	11:36	10.431039.5986094	1.5	1.35	16-Jun-08	10:20	0	
2	09-Jun-08	11:48	10.431446.5986063	2	1.63	16-Jun-08	10:22	0	
3	09-Jun-08	12:00	10.431446.5986130	1.6	1.45	16-Jun-08	10:40	0	
4	09-Jun-08	12:10	10.432070.5986371	1.9	1.19	16-Jun-08	11:00	0	
5	09-Jun-08	12:25	10.432434.5986434	1.5	1.12	16-Jun-08	11:15	0	
6	09-Jun-08	12:36	10.433158.5986361	2.0/2.4	0.55	16-Jun-08	11:25	0	
7	09-Jun-08	12:48	10.433405.5986468	2.1/2.0	0.62	16-Jun-08	11:33	0	
8	09-Jun-08	12:56	10.433724.5986925	1.9	0.84	16-Jun-08	11:45	0	
9	09-Jun-08	13:08	10.434058.5986832	3.3/3.1	0.61	16-Jun-08	11:54	0	
10	09-Jun-08	13:13	10.434234.5986547	2.8/2.9	0.57	16-Jun-08	12:00	0	

Appendix 4

White Sturgeon Developmental Stage Description

Maturity Code	Sex	Description
1	Male	Non-reproductive, testes appear as thin strips with no pigmentation.
2	Male	Maturing; small testes, some folding may be apparent; translucent, smoky pigmentation.
3	Male	Early reproductive; large testes, folds beginning to form lobes; some pigmentation still present. Testes more white than cream coloured.
4	Male	Late reproductive; testes large, often filling posterior of body cavity; white with little or no pigmentation.
5	Male	Ripe; milt flowing; large white lobular testes; no pigmentation.
6	Male	Spent; testes pinkish-white, flaccid, and strongly lobed.
10	Male	General unknown maturity.
11	Female	Non-reproductive; ovaries small, folded with no visible oocytes; tissue color white to yellowish.
12	Female	Pre-vitellogenic, moderate size ovary with small eggs present (0.2 to 0.5 mm diameter) may have "salt and pepper" appearance.
13	Female	Early vitellogenic; large ovary varying in color from white to yellowish-cream to light grey; eggs 0.6 to 2.11 mm diameter.
14	Female	Late vitellogenic; ovaries large with pigmented oocytes still attached to ovarian tissue; eggs 2.2 to 2.9 mm in diameter; sometimes with "salt and pepper" appearance.
15	Female	Ripe; eggs fully pigmented and easily detached from ovarian tissue; eggs 3.0 to 3.4 m in diameter.
16	Female	Spent; ovaries are flaccid with some residual eggs.
17	Female	Pre-vitellogenic with attritic oocytes; small eggs (< 0.5 mm diameter) present; dark pigmented tissue present that may be reabsorbed eggs.
20	Female	General unknown maturity.
97	Unknown	Gonad not visible; juvenile based on size.
98	Unknown	Gonad not visible; adult based on size.

* Description of maturity state classifications adapted from Conte et al. (1988).

Appendix 5

Photograph Plates

Plate 1. Showing the downstream end of the spawning area with Burrard Avenue bridge in visible in the background.

Plate 2. Showing two pairs of egg mats deployed downstream of Stoney Creek.

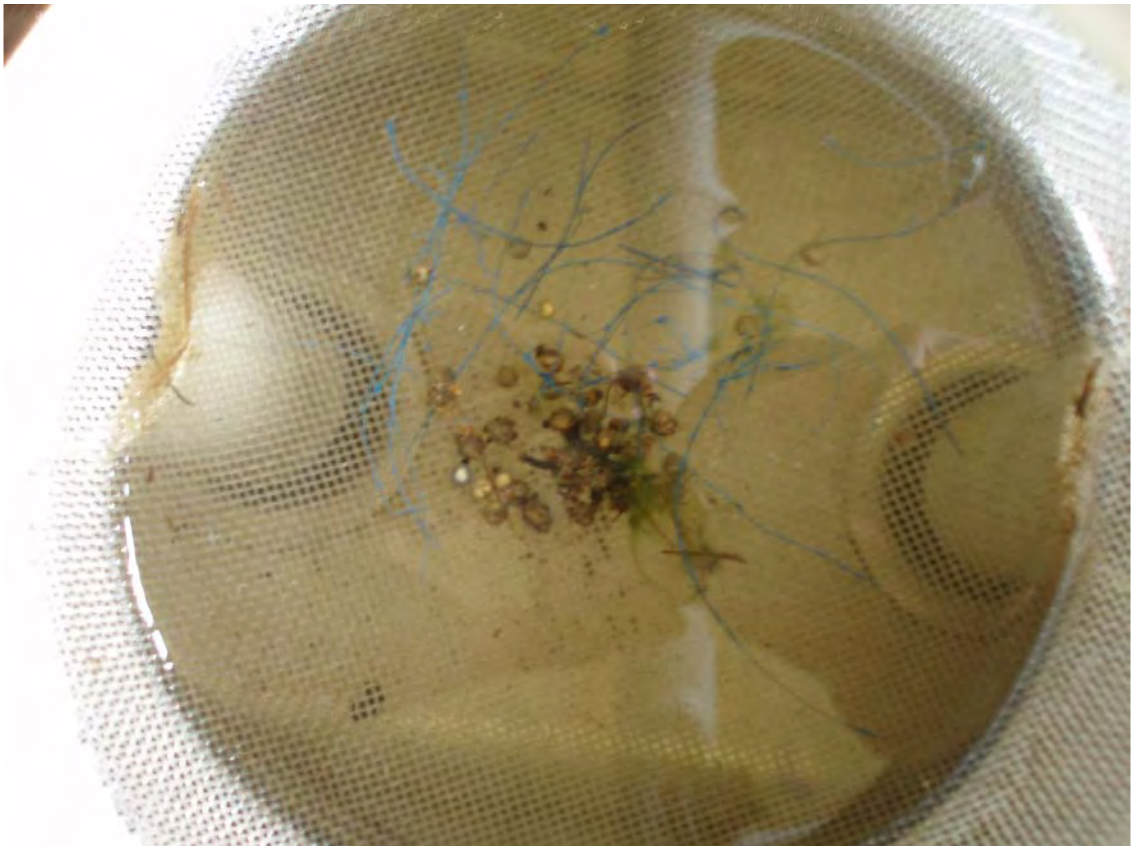


Plate 3. Showing the eggs collected on June 2nd following transfer the hatchery.

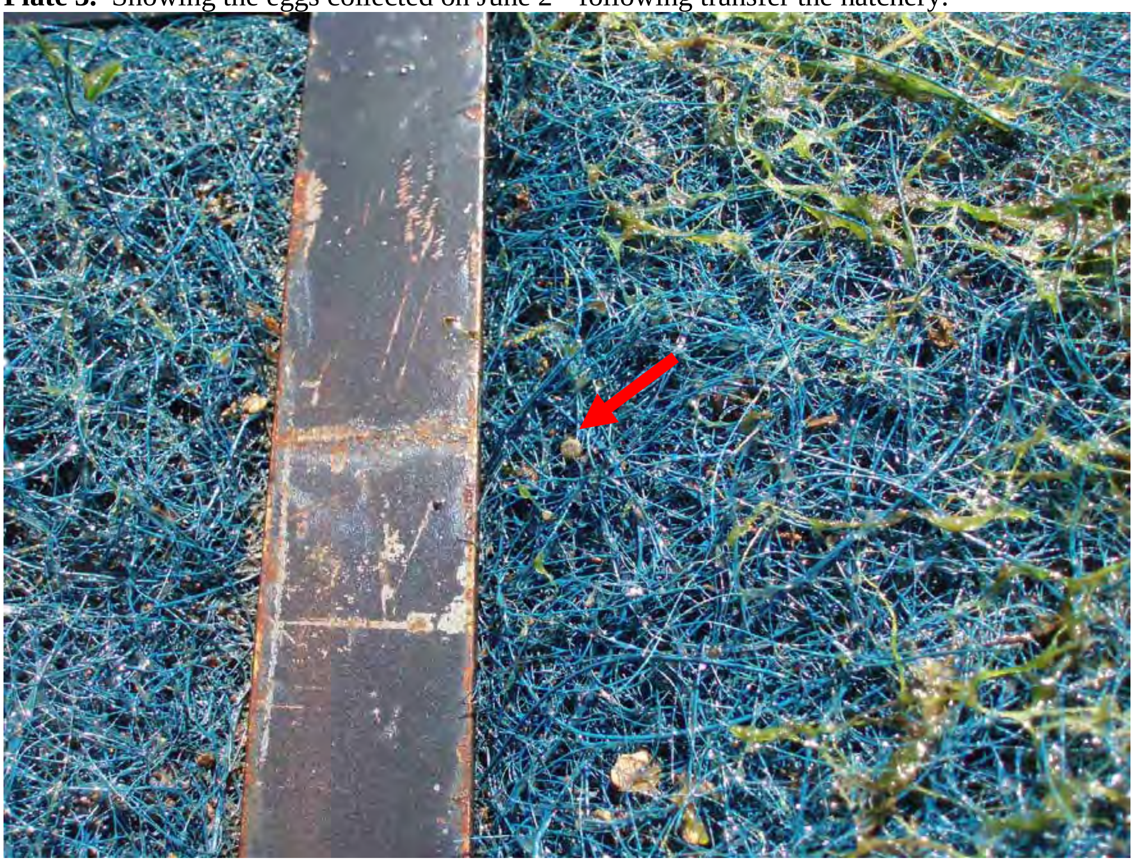


Plate 4. One sturgeon egg captured on the coarse material of an egg mat.