Project 3729

Adult White Sturgeon Monitoring - Nechako River 2006.

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Prepared for:

Alcan Primary Metal
158 West Stewart St
Vanderhoof, B.C.

Prepared by:

Ryan Liebe, R.P.Bio
Project Manager/Biologist
Triton Environmental

Greg Sykes, R.P. Bio.
Biologist
Triton Environmental

Rachel Manson, B.Sc.
Biologist
Triton Environmental

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

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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 2006), as well as a species listed as endangered on 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) 2004). At present the reasons for the recruitment failure is unknown.

Extensive radio tagging programs has allowed for the tracking of adult white sturgeon movements in the Nechako River. In recent years, Golder Associates (2006) completed a tagging program in the fall of 2005 in which 27 sturgeon were implanted with internal radio transmitters. In the spring of 2006 (concurrent to the monitoring project reported here) a study was initiated by the Nechako/Upper Fraser White Sturgeon Technical Working Group (NUF-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). A total of two ripe females and four mature males were removed from the Nechako River during the 2006 spawning period and held at a facility in Prince George, and numerous other fish were implanted with radio transmitters. This effort, in addition to previous work by Golder and Associates, the BC Ministry of Environment, and the Carrier Sekani Tribal Council (CSTC), brought the total number of active tags in adult fish to approximately 70 by the fall of 2006.

Radio tagging efforts, and work completed by Triton Environmental Consultants Ltd. (Triton) in 2004 and 2005 formed the basis for the monitoring and sampling plan for 2006. In particular, a previously identified spawning area in the vicinity of Vanderhoof (Triton 2004) was the focus for the work in 2006. In addition, the physical conditions in the river around the time of the congregation in 2004 (*i.e.* water temperature and discharge) were examined to identify the critical monitoring period for 2006. Using the information on timing and location of the 2004 congregation (no congregation was detected in 2005), the 2006 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 (Alan Primary Metal 2006).

This report outlines the methods used to monitor white sturgeon spawning in the Nechako River in 2006, presents the results of field activities undertaken in May and June of 2006, 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, FLOW AND TURBIDITY MONITORING

Monitoring of the Water Survey of Canada (WSC) station at the Vanderhoof 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, three Onset StowAway® TidbiT™ temperature loggers were installed in the vicinity of where the congregation was identified in 2004 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 borrowed for the project, one from the University of Northern British Columbia and the other from the Department of Fisheries and Oceans in Prince George.

Telemetry overflights of the Nechako River between the Stuart and Nautley rivers were conducted between the 11th of May and the 6th of June in order to determine the presence or absence and movement patterns of tagged fish in the study area (Figure 1).

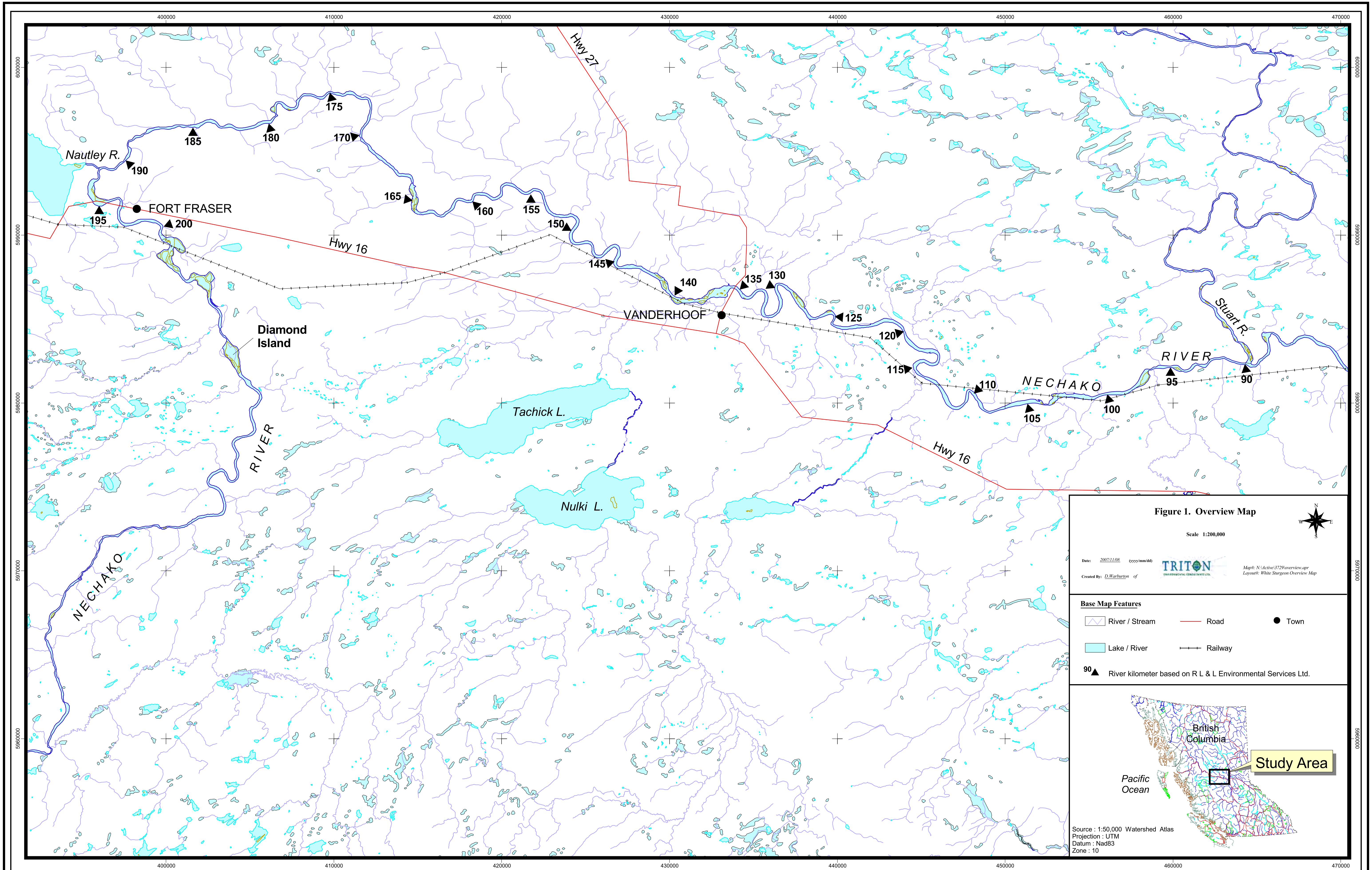


Figure 1. Overview Map

Scale 1:200,000

Telemetry flights originated from the Vanderhoof airport and were flown over the Nechako River from Vanderhoof downstream to the Stuart River confluence, then from the Stuart River confluence upstream to the confluence of the Nautley River, and finally back downstream to Vanderhoof. This flight pattern resulted in two complete passes of the study area on each flight. Both passes of the telemetry flights were flown at a height of 180 – 240 m above the river.

In addition to the telemetry flights noted above, three additional extended telemetry flights were completed on the 13th and 27th of June, and the 10th of August. During these flights the study area was extended to include the remainder of the Nechako River downstream to Prince George, and the Stuart River upstream to Stuart Lake. The extended flights also included sections of the Fraser River from Prince George downstream to Red Rock, and from Prince George upstream to the confluence of the Fraser and Willow rivers.

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 risk of missing a tag during scan time, the active 10 frequencies (149.800, 149.700, 149.770, 149.480, 149.320, 148.420, 148.400, 148.320, 148.380, 149.44) 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 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.

In the event that a tag was located but a code was not received, or if there was more than one signal received for a given frequency at one time, the receiver was paused on that frequency to enable codes to be generated for the signals being received. Additionally, during these events the aircraft circled the area in question until all codes were received.

2.2.1.1 Telemetry Base stations

A telemetry base station was established by Triton downstream of the Vanderhoof bridge on May 10th, 2006, to detect fish passage close to the location where the congregation of sturgeon was located in 2004 (Triton 2004). Ms. Deirdre Goodwin, a homeowner just downstream of the Vanderhoof bridge, provided access to her property to establish the base station. At the request of the NWSRI, the base station was left operating beyond the study period to assist with the tracking of juveniles that were tagged as part of a concurrent project.

2.3 LOW LEVEL OVERFLIGHTS

As water temperature approached conditions similar to those observed during the 2004 spawning congregation, low level observation flights were initiated. Observations were made through the photo hole in the floor of a Cessna 182, flown by Eric Steir of Guardian Aerospace based out of the Vanderhoof airport. 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 Vanderhoof bridge. Flights were generally 0.5 hours in length which allowed 6-8 passes through the identified spawning grounds.

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; and Paragamian *et al*. 2001). 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 generally deployed in sets of two with one buoy line attached to the upstream mat which allowed for retrieval of the gear. 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. Mats were checked and cleaned at 2 – 7 day intervals.

Additionally, previously fabricated egg tubes (Triton 2005) were deployed to increase the sampling intensity for eggs. Egg tubes were constructed of 0.75 m long 0.15 m diameter PVC pipe wrapped with furnace filter material as described in Firehammer and Scarnecchia (2005). A railway angle bar was attached to each tube as an anchor. Egg tubes were checked at 2 – 7 day intervals in conjunction with checking the egg mats.

2.5 HABITAT ANALYSIS

Analysis of habitat conditions was completed in the vicinity of where congregating fish were observed and at the egg mat and egg tube sites. Water depth, water velocity, and substrate composition was collected across habitat transects of the river (Figure 7).

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, without having the substrate interfere with the measurement (typically 10 cm above bed height). Depths and velocities were collected at regular intervals (approximately 10 m) along the transect.

Substrates were described based on visual observations according to 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 OBSERVATION TOWERS

Two observation towers were constructed in the vicinity of the known spawning area at the same time as the initial egg mat/tube deployment (*i.e.* prior to the congregation). The observation towers were similar to those used to monitor chinook (*Oncorhynchus tshawytscha*) redd residency time in the Nechako River. The towers were approximately 6 m high, and were constructed of scaffolding (Plate 3). The top platform included handrails, and the towers were secured according to manufacturers specifications. Wood bases were constructed to minimize toe scour, and orange flagging was attached to the guy wires to ensure the structures did not pose a navigational hazard.

2.7 PREDICTIVE MODEL

The need to understand the underlying mechanism of white sturgeon spawning migrations has been identified as a research goal for white sturgeon management and recovery programs from other systems such as the Kootenai and Columbia Rivers (Paragamian *et al.* 2001). Given the apparently short window during which spawning occurs in the Nechako, being able to accurately predict when migration to the spawning area will occur is critical to being able to study and understand the causes of recruitment failure post-spawning. Identifying the environmental cue or suite of cues for the onset of spawning is critical to the maintenance or enhancement of in-river conditions (*e.g* flow regimes) that do not adversely affect the onset of spawning. The goal of the present study was therefore to assess which environmental variables were best able to predict migration to the spawning area based on telemetry data gathered in 2004 and 2006.

An Information Theoretic Model Comparison (ITMC) approach was used to complete the analysis. This technique, which is growing in popularity in ecology, and in particular wildlife research, 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).

The telemetry data used in the development of the predictive model for this study were collected from May 2004 and 2006. The data from 2004 includes 14 white sturgeon (4 female, 10 male) that were tagged in 2001 (n = 13) and 2002 (n = 1). Due to the limited lifespan of those radio tags, no telemetry data was available for 2005. However, a tagging program was competed early in 2006 and as a result telemetry data from 14 fish (2 females, 12 males) was available for this analysis. Both years of the study involved the installation of a base-station immediately downstream of the spawning area (rkm 135.5) as well as frequent overflights of the study area.

Telemetry data collected from 1999 to 2003 were not used in the development of the predictive model due to the lack of continuous data required to accurately interpret (code) sturgeon movements. Particularly limiting was the lack of telemetry data from around the spawning area (rkm 136-140), which was not identified until 2004 (Triton 2004). Without this data it was impossible to confirm a spawning migration since it could not be determined with any certainty the destination of the fish when they left the overwintering hole.

2.7.1 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 136-140 spawning area). Based on these classifications, telemetry data was analysed and movements during the spawning period (May to June) were summarized and coded. The result of the analysis was 185 records (63 = "0"; 122 = "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). A small sample unbiased AIC (AIC_c) value was therefore calculated from each of the candidate models using the value of the –2 log-likelihood (-2LL) output from the logistic regression analysis. Akaike's weights (AIC_w), provides a relative weight of evidence for each model and can be interpreted as the approximate probability that a given model is the best for the observed data (Johnson and Omland 2004). AIC_w was used to assess the relative strength of each model (Anderson *et al*. 2000). AIC_{Diff} was calculated as the difference in AIC_c score for a given model with the lowest AIC_c score (Model Rank #1). However, if this value was small (*i.e*. < 2), further analysis was necessary to select the best model. Predictive ability (assessment of how well model predicts migration) and parsimony (selection of the simplest model) were then considered. Predictive ability was of particular importance given the goal of using the model for future research programs and management decisions, and as a result this was given a higher priority than selecting the simplest model.

The most basic predictive assessment techniques are based on classification of model outputs using a probability threshold. For example, in a situation where the calculated probability of migration based on the model is 0.47, a threshold probability cut-off of 0.5 (where values greater than 0.5 are interpreted as "1" or migration, and values less than 0.5 as "0" or non-migration) would result in a prediction of non-migration. However, if the probability cut-off level were changed to 0.4 the same model would predict migration. Therefore, if the assessment of the models predictive ability is based on an arbitrary probability threshold, the true predictive ability of the model is questionable (Boyce *et al.* 2002). The best means of avoiding this problem is to make use of a Receiver Operating Characteristic (ROC) curve. This analysis evaluates the proportion of correctly and incorrectly classified predictions over a continuous range of threshold probability cut-off levels (Pearce and Ferrier 2000). A curve is produced that compares the proportion of false-positive predictions with the proportion of false negative predictions at each threshold probability cut-off level. The area under the curve (AUC) is then calculated as a means of assessing the models overall predictive ability. 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).

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 AUC of the ROC graph produced when the predicted output of each model based on the 2004/2006 data was compared with the actual sturgeon migration data. Lastly, multicollinearity and analysis of residuals were completed for the "best" model to assess its statistical fit. All statistics for the study were calculated using Stata (version 9.2).

2.7.2 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.[*]

Physical data on river conditions including river flow (m^3/sec) and temperature (˚C), was gathered for the same period for 2002-2006 from the Water Survey of Canada (WSC) station (Station #08JC001) located at the bridge crossing of the Nechako at Vanderhoof which is in the vicinity of the spawning area. A substantial amount of research has been completed on the effect of both of these variables on the life histories of fish and in particular as cues for migration timing. In addition, several studies of the spawning behaviour of other populations of white sturgeon (*e.g.* Parsley *et al.* 1993; Paragamian and Kruse 2001) in regards to flow and temperature have been completed. Therefore, it reasonable to hypothesize that the Nechako population of white sturgeon have evolved to respond to changes in these variables. 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 at a particular time (in this case the date the river was free of ice) and were used to assess if fish were responding to a long-term temperature trend.

[*] Flow values are calculated using a formula based on river stage data that is logged at the WSC station hourly and on velocity measurements collected manually at the station at regular intervals throughout the year.

In addition, photoperiod is known to be a controlling factor for many physiological and behavioural changes in other fish species (*e.g.* salmonid smolt migration) and was therefore included in the analysis. Lastly, combinations of several of the parameters were included due to the likelihood that multiple cues could be involved.

Before combined models 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 statistics* for each of the parameters in the model. A tolerance statistic is equivalent to $1-R^2$ and values less than 0.1 suggest strong collinearity (Menard 2001). Due to collinearity issues surrounding maximum daily temperature and mean daily temperature, no models were tested that included both of these 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. This resulted in the development of 14 candidate models as outlined in Table 2.

2.7.3 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.

Table 2. Candidate models and associated rationale for selection.

Model #	Parameters Included	Rationale
1	Avg. Temp	Assess role of daily mean temperature.
2	Max Temp	Assess role of daily maximum temperature.
3	ATU	Assess role of cumulative temperature from ice-off, which may be a threshold cue.
4	Flow	Assess role of daily flow.
5	Photoperiod	Assess role of increasing day length.
6	Avg. Temp + Photoperiod	Assess combined role of daily mean temperature and increasing day length.
7	Avg. Temp + ATU	Assess combined role of daily mean temperature and cumulative temperature.
8	Avg. Temp + Flow	Assess combined role of daily mean temperature and daily mean flow.
9	Max Temp + ATU	Assess combined role of maximum daily temperature and cumulative temperature.
10	ATU + Photoperiod	Assess combined role of cumulative temperature and increasing day length.
11	Max Temp + Flow	Assess combined role of maximum daily temperature and mean daily flow.
12	ATU + Flow	Assess combined role of cumulative temperature and mean daily flow.
13	ATU + Photoperiod + Flow	Assess combined role of cumulative temperature, increasing day length and mean daily flow.
14	ATU + Photoperiod + Flow + Avg. Temp	Assess combined role of cumulative temperature, increasing day length, mean daily flow and mean daily temperature.

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

River discharge at the Vanderhoof bridge during the monitoring period began at a peak of 210 m^3/s with a rapid decline to 81 m^3/s in early April. However, the peak is erroneous and is the result of ice cover affecting the pressure transducer at the WSC station. The base flow of 81 m^3/s observed on April 8 likely indicates ice-free conditions at the station, with the discharge representative of typical spring flows. Discharge remained relatively steady until the end of April when it began to slowly increase, peaking on June 6th at 124 m^3/s. The remainder of June showed a decreasing trend until the end of the study period (Figure 2).

Mean daily water temperature at the Vanderhoof bridge during the monitoring period ranged from 0.8°C on April 1st to a high of 20.3°C on June 27th. The maximum daily water temperature ranged from 9.0°C on May 1st (maximum daily temperature was not obtained for April) to a high of 22.4°C on June 26. Daily mean and maximum daily water temperatures first approached conditions observed during the 2004 spawning congregation (13-15°C) during the middle of May (Figure 2). Detailed flow and temperature data can be found in Appendix 1.

3.2 RADIO TELEMETRY

A total of 13 telemetry flights were conducted between the 11th of May, 2006 and the 10th of August, 2006. There was an average of 20 active tags recorded during each flight, with the highest number of tags (32) being recorded during the extended telemetry survey conducted on June 13th. All but one of the fish located during the tracking were recorded between km 90 (approximately Stuart River confluence) and the Vanderhoof bridge (km 136), prior to the 19th of May. The exception to this (149.700 Code 26), was recorded at km 158 upstream of the bridge during the first telemetry flight (May 11), where it remained until June 27th, when it moved to downstream of the Vanderhoof bridge for a short period of time. Detailed results from the telemetry flights are provided in Table 7 which can be found in Appendix 2.

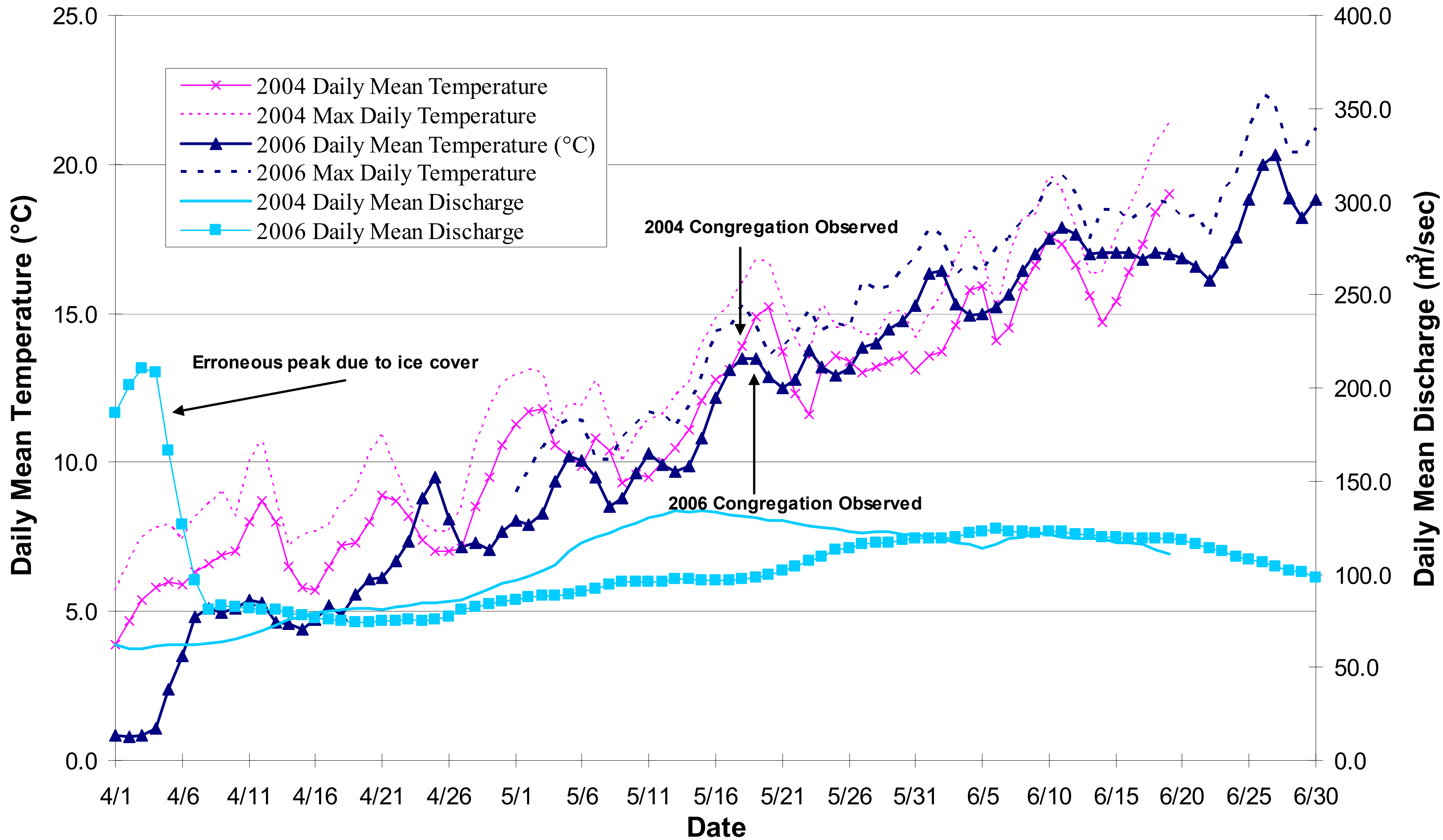


Figure 2. Daily mean and maximum temperature (primary y axis), and daily mean discharge (secondary y axis) at the Vanderhoof bridge (Water Survey of Canada station 08JC001) for April 1 to June 30, 2004 and 2006.

On the 18th of May (the day before the spawning event; see section 3.5 for a description of the congregation first observed on May 19th) the following ten fish were recorded within four kilometres of the Vanderhoof bridge during the telemetry flight: 149.800 codes 38, 40, 42, 45, 49, 52, 55, 59; 149.700 codes 27 and 25. The number of fish in the vicinity of the bridge decreased to six by the 22nd of May but increased to eleven fish on the 25th of May. However, this increase was due to the release of four male sturgeon at the Vanderhoof bridge boat launch on the 24th of May. The four males were initially captured as part of a brood stock program undertaken by the NUF-TWG.

Telemetry flights after the spawning event (May 28th -August 10th) showed that most of the fish located around the Vanderhoof bridge during the spawning event traveled downstream to between river kilometers 125 and 108, with the exception of 149.800-56 which was recorded at river kilometer 32 on August 10th. Detailed telemetry results for individual fish showing migrations during the study period are provided in Appendix 2 (Figures 12 - 31).

3.3 TELEMETRY BASE STATION

The Vanderhoof base station was installed on May 10th, 2006. The station was downloaded regularly (*e.g.* every day or couple of days) for the months of May and June and was downloaded periodically from July-October. Appendix 1 details the fish recorded by the base station. On certain days there could be as many as 13 fish located downstream of the base station, however, only a total of eight different fish (149.800-46, 51, 57, 59; 149.700-33, 40; 148.38-1, 4) were confirmed to have traveled past (*i.e.* upstream of) the base station. Most of these movements occurred on separate occasions, with some of the fish (*i.e.* 149.800 codes 46, 51, 59, 57) making numerous upstream movements between May and October.

During the congregation event on May 19th (see section 3.5 for a description of the congregation), 12 fish (2 females: 148.380 code 1 and 149.800 code 54; 7 males: 149.700 codes 27, 40, 42, 38, and 149.800 codes 55, 49, 59, 50, 51; and 1 unknown sex 149.800 code 56) were recorded by the base station at the Vanderhoof bridge. On the 20th of May, an additional fish was recorded by the base station (148.420 code 14), bringing the total number of tagged fish in the area to 13. Two tagged fish were recorded on the upstream antenna during the spawning period from the 18^{th} and 23^{rd} of May. Although it cannot be confirmed that these 2 fish and the remaining 11 fish were part of the congregation, it is likely that they were due to their close proximity (*i.e.* several hundred meters) to the congregation.

Of the tagged fish recorded to be in the area of the congregation, three of the males and one of the females were classified as ripe, three of the males were known to be in an early reproductive state, while the others were classified as late reproductive or maturing. The remaining females were classified as either previtellogenic or early vitellogenic (MOE 2004, 2006).

3.4 LOW LEVEL OVERFLIGHTS

A total of 9 low level overflights were completed between May 16^{th} and June 9^{th}. Average viewing conditions were such that deployed egg mats in 2.0 m of water could be seen from the air. Ducks and pieces of wood were easily observable, as were the bottom substrates across most of the side-channels. The bottom of the channel upstream of the islands and the deep channel immediately downstream of the confluence of Stoney Creek were not visible (they were also not visible in 2004 or 2005). Approximately 80% of the bottom substrates could be seen between the Vanderhoof bridge and the upstream end of the 2004 spawning location.

Sturgeon were first observed during the 08:00 flight of Friday morning (May 19). At that time 4 individual (*i.e.* not paired) fish were observed within 500 m downstream of the Vanderhoof bridge. An additional 6 or more fish were observed within 300 m upstream of the bridge, with 2 of the fish paired. Similar numbers were observed Friday evening, with a single fish observed just upstream of the Stoney Creek confluence. The Saturday morning flight had similar results to Friday evening, with 2 pairs observed 100 m upstream of the temporary hatchery pumps. The results from the observation flight completed Sunday morning at 8:40 am were similar to that of the previous days with 11 fish upstream and 3 fish downstream of the bridge, with 2 pairs of fish noted upstream of the bridge.

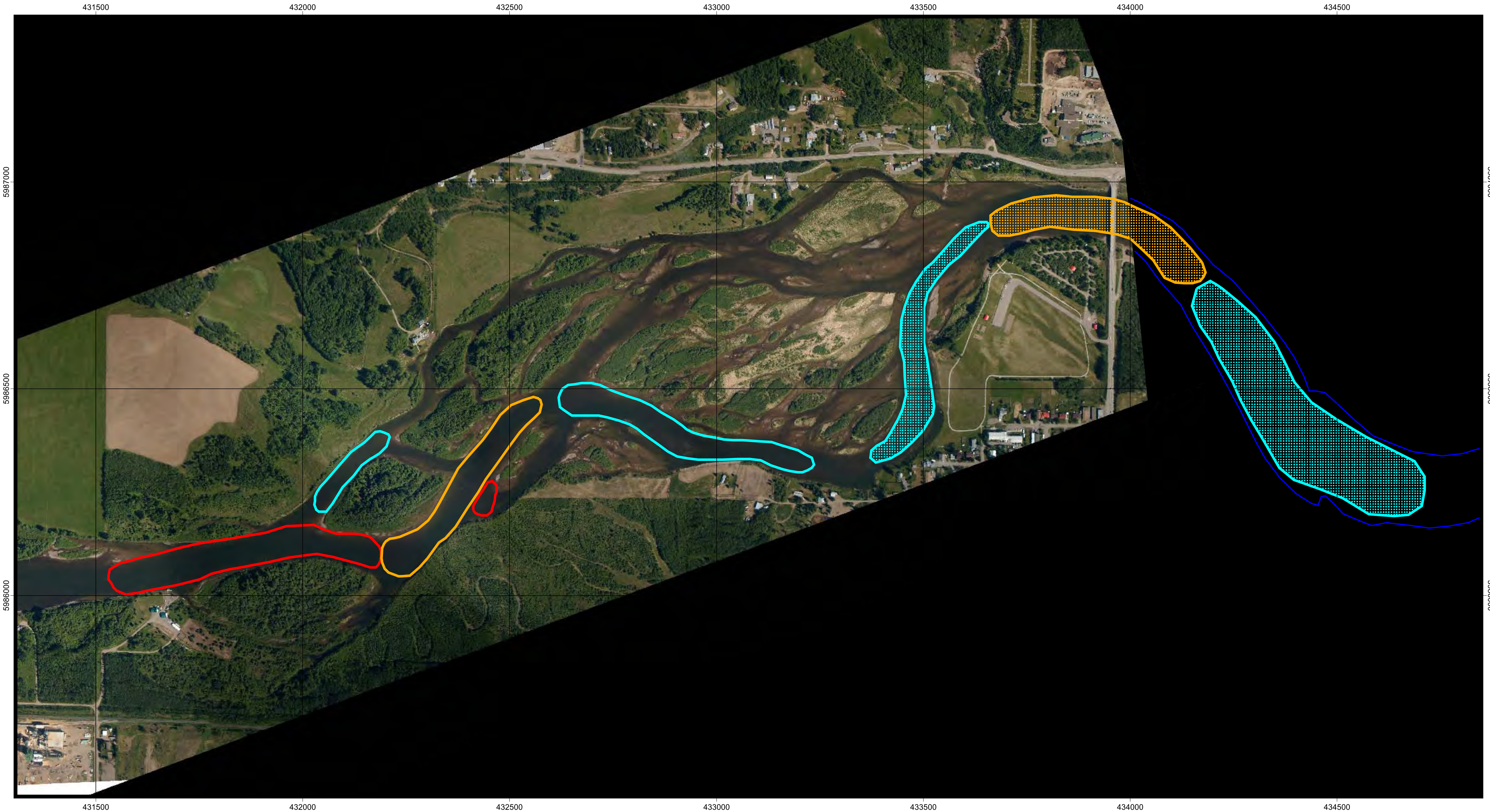
Only one fish was observed downstream of the bridge during the flight on Monday morning and no fish were observed in the area during a flight completed on the morning of May 23rd.

3.5 SPAWNING ASSESSMENT

The congregation of sturgeon was first observed during the overview flight on the morning of May 19. A total of 10 sturgeon were counted from the fixed wing plane on the 19th, with the highest number of fish (14) being record on the 21st. The observations from the overflights on the 19th-21st of May were consistent in the fact that on each occasion only 2 sets of pairs were noted above the bridge with all other fish spotted being singles (Figure 3). Although gamete release was never visually observed the presence of viable eggs on downstream egg mats (see section 3.6) indicates that gamete release and fertilization did occur.

Although not observed by Triton staff, visual observations of sturgeon breeching and rolling just upstream of the Vanderhoof bridge were noted by Mike Keehn (Freshwater Fisheries Society), who was working in the area at the time of the spawning event.

During the congregation event on May 19-21st, three tagged females (Figure 4) and nine tagged males (Figure 5) were recorded to be within the vicinity of the spawning site. Although it cannot be confirmed that they were part of the congregation, it is likely that they were due to their close proximity to the congregation and spawning grounds. Similar to 2004, several male sturgeon moved back and forth within the area between km 116 and the Vanderhoof bridge (km 136) prior to the congregation.



LEGEND

2005 Congregation Locations
- Numerous Fish, Multiple Pairings
- Occasional Single Fish
- Several Fish, Some Paired

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

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NECHAKO RIVER STURGEON PROJECT 2006

Figure 3.
Sturgeon Congregation Location

N W E S

100 0 100 200 300 400 Meters

Scale: *1:8,000*

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#: 3729\apr\Congregation Locations.apr Layout#: Figure 3.	2006/11/14

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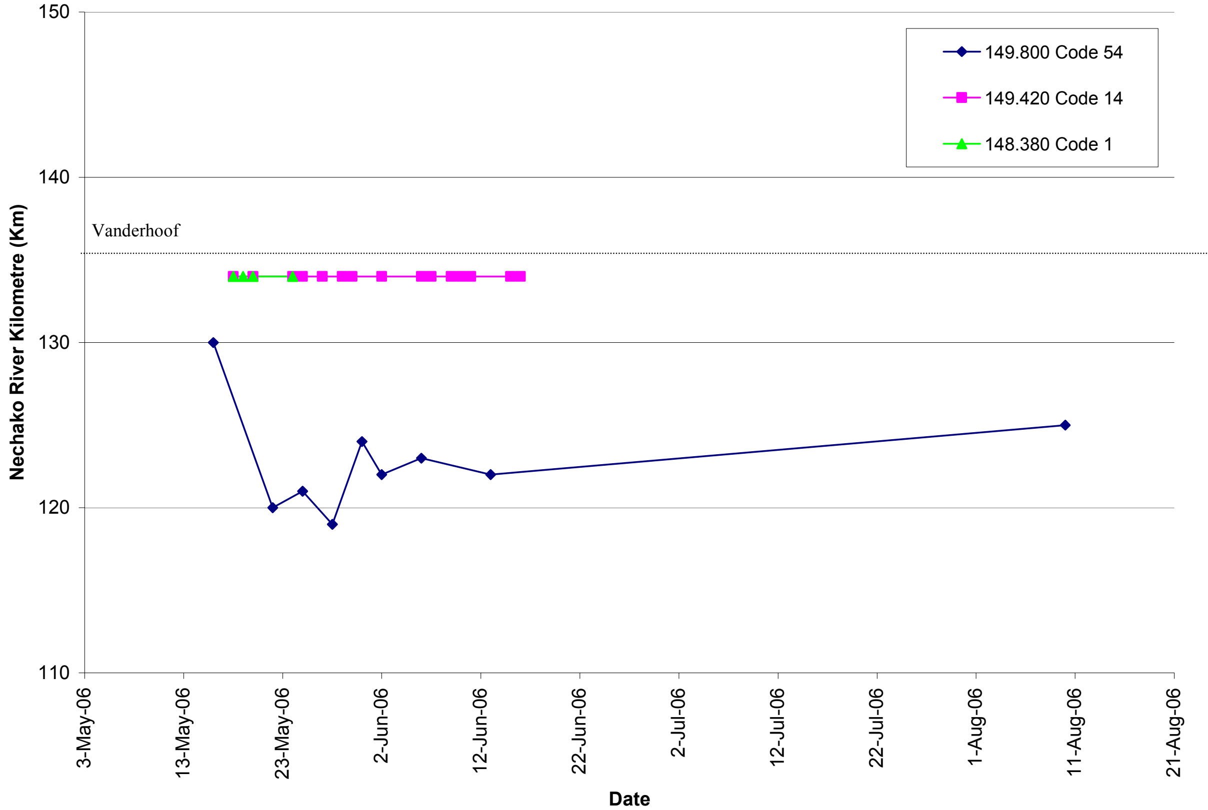


Figure 4. Detailed movements of tagged female sturgeon around the time of the congregation.

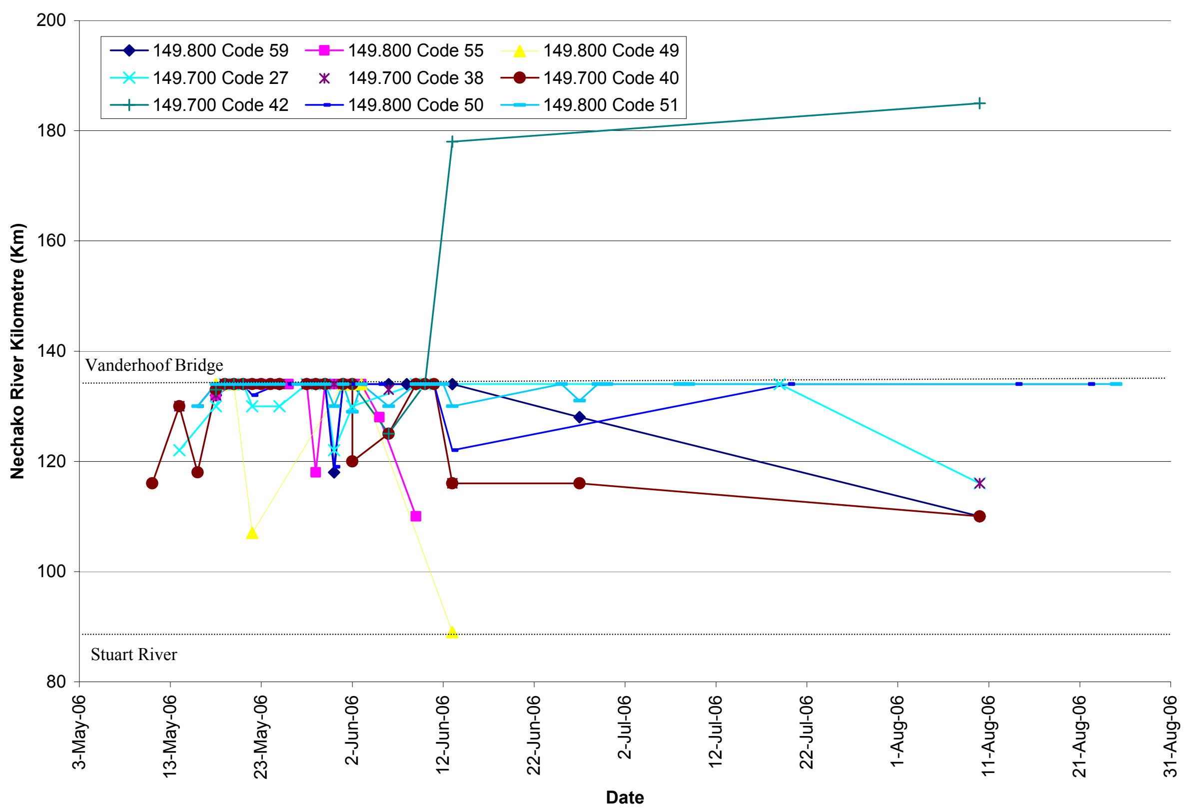


Figure 5. Detailed movements of tagged male sturgeon around the time of the congregation.

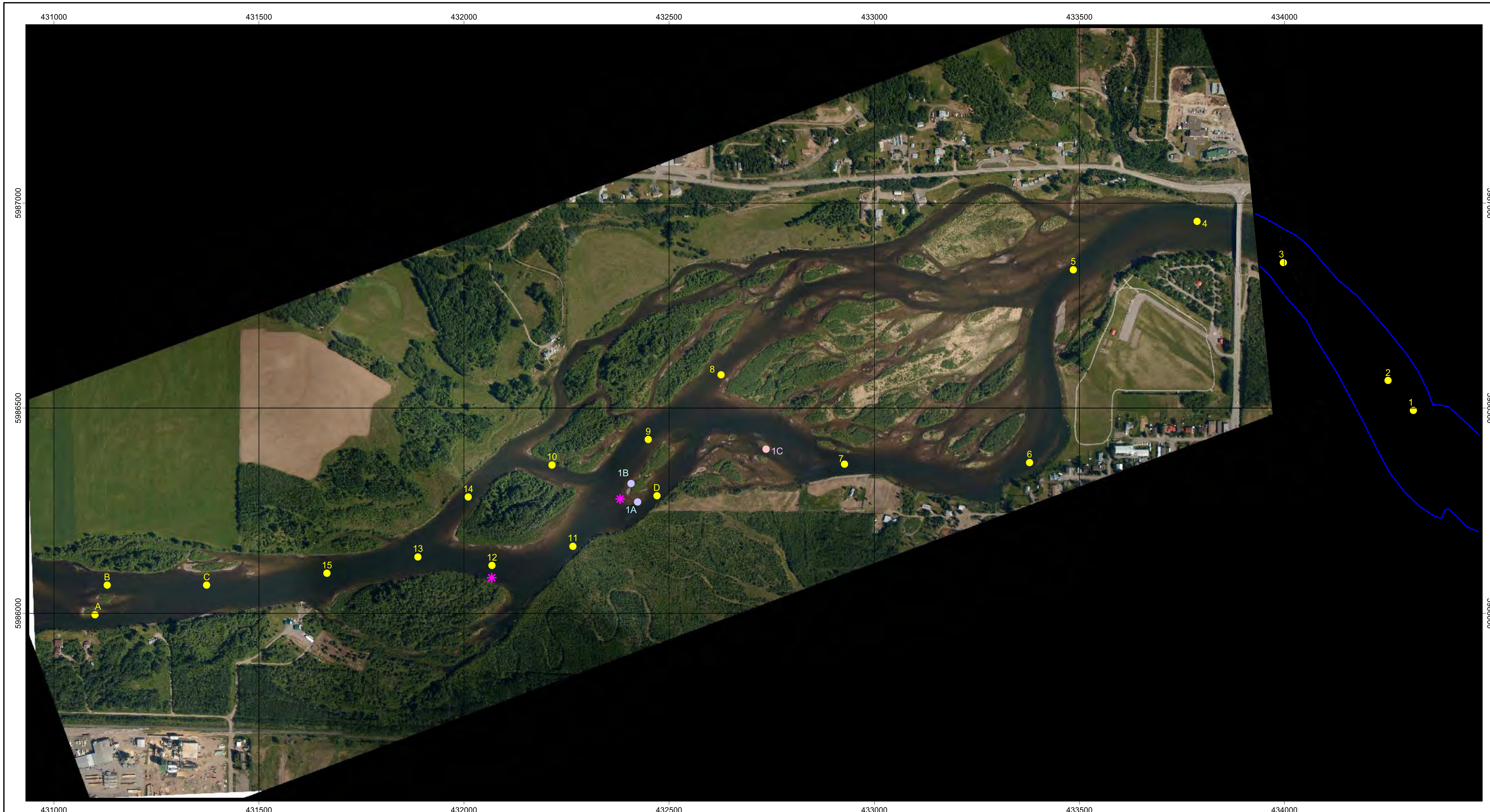
The duration of spawning activity is difficult to estimate. Telemetry data indicates fish were in the vicinity of the spawning grounds from mid-May until the second week of June (approximately June 6 – 12th), a period of several weeks. However, based on the low level overflights, the period of congregation and pairing appeared to be less than 72 hours (the morning of Friday May 19 to the morning of Monday May 22). The protracted spawning period observed from the low level overflights is supported by the egg mat data, where eggs were first captured on May 20. Although numerous eggs were captured on May 26, they appeared to be drifting as they were covered in sediment and most were observed to be coated with fungus. It therefore appears that eggs captured on May 26 and later were from a spawning event that occurred earlier (*i.e.* from the 19 – 22nd of May).

3.6 SAMPLING FOR EGGS

3.6.1 EGG MATS

CSTC and Triton egg mats were deployed in groups of four on May 18 (Figure 6). A total of 60 egg mats (42 m^2) were deployed from May 18 to June 6, at depths ranging from 0.5 to 2.0 m, and velocities ranging from 0.60 to 1.57 m/s. Mats were set for a combined total of 27,269 hours. A total of 207 sturgeon eggs were captured, all of which were collected from egg mats set downstream of Stoney Creek, with the exception of 2 eggs, which were collected from the mats set furthest upstream (site 15; Figure 6). Starting from Stoney Creek and heading downstream, the following number of eggs were capture on egg mat sites #6 to #1 respectively: 25, 7, 35, 106, 3, 29 (Figure 6). The largest number of eggs (n = 106) were captured at egg mat site #3 located directly downstream of the Vanderhoof bridge. The catch per unit effort (CPUE) for the egg mats ranged from 0.0 - 0.10 eggs/hour/m^2.

Reconnaissance from low level observation flights on the 19th and 20th indicated that fish were holding between Stoney Creek and a couple of hundred meters downstream of the Vanderhoof bridge (further downstream than the 2004 congregation). As a result the upstream most egg mats (sites A-C; Figure 6) were re-deployed downstream of Stoney Creek to increase the density of mats where the sturgeon were observed.



LEGEND

- Egg Mats (Group of 4)
- Egg Tubes (Group of 3)
- Egg Tubes (Group of 4)
- Observation Tower Location

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

NECHAKO RIVER STURGEON PROJECT 2006

Figure 6.
Sampling Site Location

N W E S

100 0 100 200 300 400 Meters

Scale: *1:9,000*

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#: 3729\apr\Fig6.apr Layout#: Fig6.	2006/11/14

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The majority of the eggs collected were found in close proximity to one another on the mats and were still quite adhesive. However, on more than one occasion the eggs were noted to be covered in fine sediments, suggesting they had been drifting. Additionally, many of the eggs collected during the later checks (May 26) were found to be damaged or covered in fungus suggesting they had been in the river for multiple days.

3.6.2 EGG TUBES

A total of 11 egg tubes (3.3 m^2) were deployed from May 18 to June 6, at depths ranging from 0.4 to 0.7 m, and velocities ranging from 0.68 to 1.1 m/s (Figure 6). Egg tubes were set for a combined total of 4,998 hours. No sturgeon eggs were captured on the egg tubes.

3.6.3 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 3 ruptured eggs, were transferred to Mike Keehn (Freshwater Fisheries Society) for inspection. Eggs were turned over to Mike Keehn immediately after the egg mats had been checked (*i.e.* within a couple of hours of collection). Mike confirmed that the eggs were from white sturgeon, and any eggs that appeared viable were incubated in the temporary hatchery at Vanderhoof. The subsequent hatching of the eggs and rearing of juvenile sturgeon proved a natural spawning event occurred in 2006 that produced viable eggs.

Of the over 200 eggs turned over to the Freshwater Fisheries Society temporary hatchery, approximately 20 were considered viable. A total of 9 of these eggs hatched, with the progeny raised to a size of approximately 10 cm and released back into the Nechako River in the fall of 2006.

3.7 OBSERVATION TOWERS

Two observation towers were installed on the 18th of May, 2006 within the area of the 2004 spawning congregation (Figure 6). The first tower was installed at the top of the first island located directly downstream of the main channel in which spawning was observed in 2004. The second tower was located on the right bank of the river just off the island paralleling the main channel in which spawning was observed in 2004. On three separate occasions the towers were climbed and observations were made regarding the visibility from each tower (Plate 4). On each occasions it was noted that visibility using polarized glasses was good for 30-40 m out from the tower and that within this area fish would only be seen clearly if they were in the shallows (1.0 m or less) or close to the waters surface.

3.8 HABITAT DOCUMENTATION

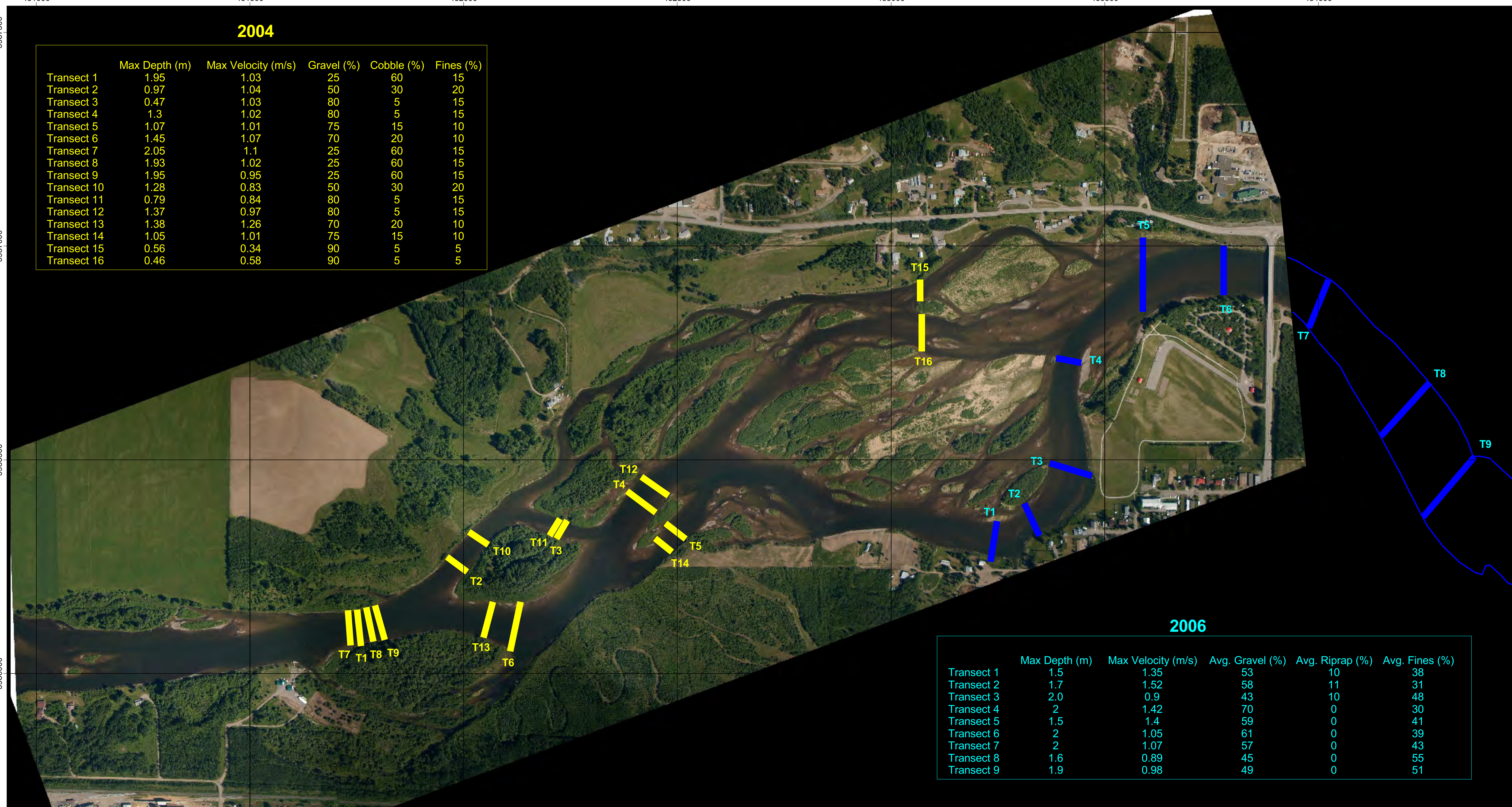
A total of nine transects were completed in order to gather habitat data for the spawning area. The transects were located in the main channels and side channels where sturgeon were observed to be congregating, as well as in channels upstream and downstream of that area. Figure 7 shows the location of each of the transects. Detailed channel profiles and water velocities for the transects can be found in Appendix 3.

Water Velocity

Water velocities were collected from each of the 9 transects (7 - 9 stations each). Although six of the nine transects had a least one velocity measurement greater than 1.0 m/s, the majority of the velocities (78%) collected along the transects were less than 1.0 m/s. The highest water velocity recorded along any of the transects was 1.5 m/s, which was recorded in Transect 2 which was located immediately downstream of Stoney Creek at a portion of the channel constricted by riprap.

Substrate

The results of the substrate analysis (Figure 7) showed that the study area is primarily dominated by a mix of gravel and fine substrates. Gravel was the dominant substrate at transects located where sturgeon were observed to be congregating. Fine substrates were abundant at sites located closer to and downstream of the Vanderhoof bridge but were also prevalent within back channel habitats throughout the study area.



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

N W E S

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

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

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3.9 PREDICTIVE MODEL

The results of the model selection analysis are presented in Table 3. The models are presented in order of ascending rank based on AIC_c scores.

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

Model	Rank	# of Parameters[1]	AIC_c	AIC_{Diff}	AIC_w
ATU + Photo + Flow	1	4	197.899	0.00	0.506
ATU + Photo + Flow + Avg Temp	2	5	197.947	0.05	0.494
Avg Temp + Photo	3	3	225.812	27.91	0.000
Avg Temp	4	2	225.818	27.92	0.000
Max Temp	5	2	225.818	27.92	0.000
ATU + Avg Temp	6	3	227.137	29.24	0.000
ATU + Photo	7	3	227.339	29.44	0.000
Avg Temp + Flow	8	3	227.636	29.74	0.000
Photo	9	2	229.829	31.93	0.000
Max temp + Flow	10	3	235.713	37.81	0.000
ATU + Max Temp	11	3	235.862	37.96	0.000
ATU	12	2	239.205	41.31	0.000
Flow	13	2	240.812	42.91	0.000
ATU + Flow	14	3	241.214	43.32	0.000

[1] Includes an intercept term for each model.

Based on the similarities of AIC_c scores for the top 2 models (AIC_{diff} = 0.05), it was necessary to assess the predictive ability of each in order to identify the best model. A ROC analysis for each was completed and it was found that the model ranked #1 (ATU + Photoperiod + Flow) had a marginally better predictive ability (correct 81% of the time) then did the model ranked #2 (correct 80% of the time). In addition, since model rank #1 was the more parsimonious, relying on 4 parameters (with the intercept term) as opposed to 5 (model rank #2), it was selected as the best model to explain white sturgeon spawning migration given the data.

The coefficients generated from the best model (ATU + Photoperiod + Flow) are provided in Table 4. All three parameters have a significant effect on the regression equation based on the calculated z-statistic ($p<0.05$) supporting their inclusion in the model. ATU was the only parameter (other than the intercept) with a negative coefficient.

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
ATU	-0.06077	0.0121	-5.02	< 0.001	-0.0845	-0.0371
Photoperiod	17.1955	3.3907	5.07	< 0.001	10.5498	23.8411
Flow	0.1767	0.0362	4.88	< 0.001	0.1058	0.2476
Intercept	-274.5238	54.0753	-5.08	< 0.001	-380.5094	-168.5383

3.9.1 PREDICTIVE ABILITY

Predicted probabilities of migration for 2004 and 2006 were generated using the coefficients from the best model. Standardized residuals were also calculated and were found to have a mean of -0.09 and a standard deviation of 1.6, which was reasonably close to the expected values of 0 and 1, respectively. However, it was found that 20% of the residuals were either greater than 2 or less than -2, although only 4% were greater than 3. A comparison of the observed and predicted probability of migration from 2004 and 2006 are shown in Figure 8 and Figure 9, respectively.

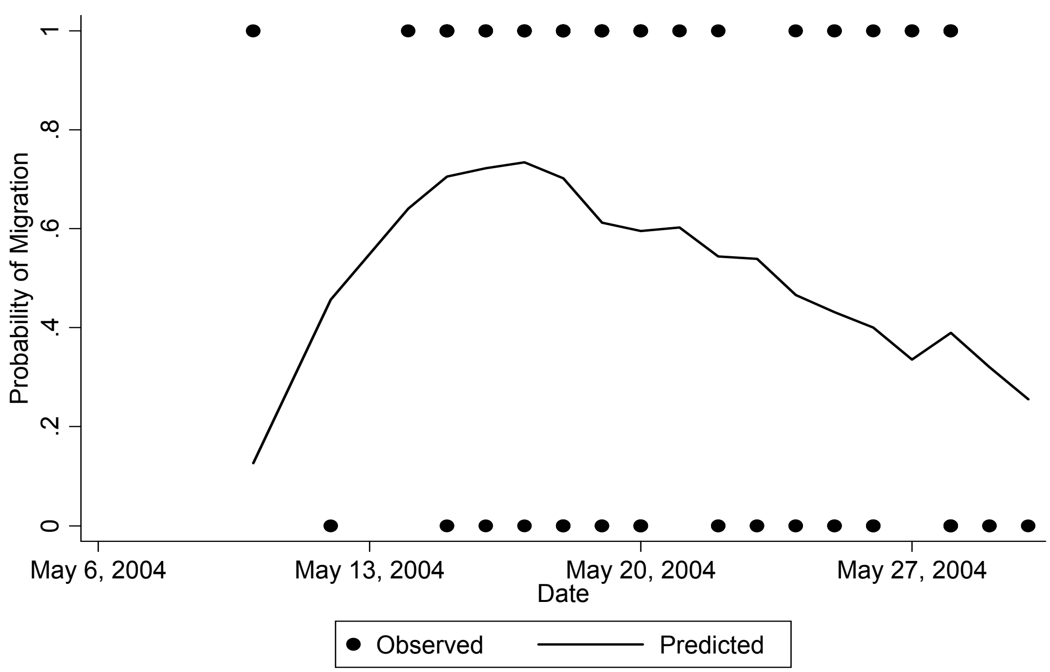


Figure 8. Predicted and observed probability of white sturgeon migration to the spawning area based on "best" model for 2004.

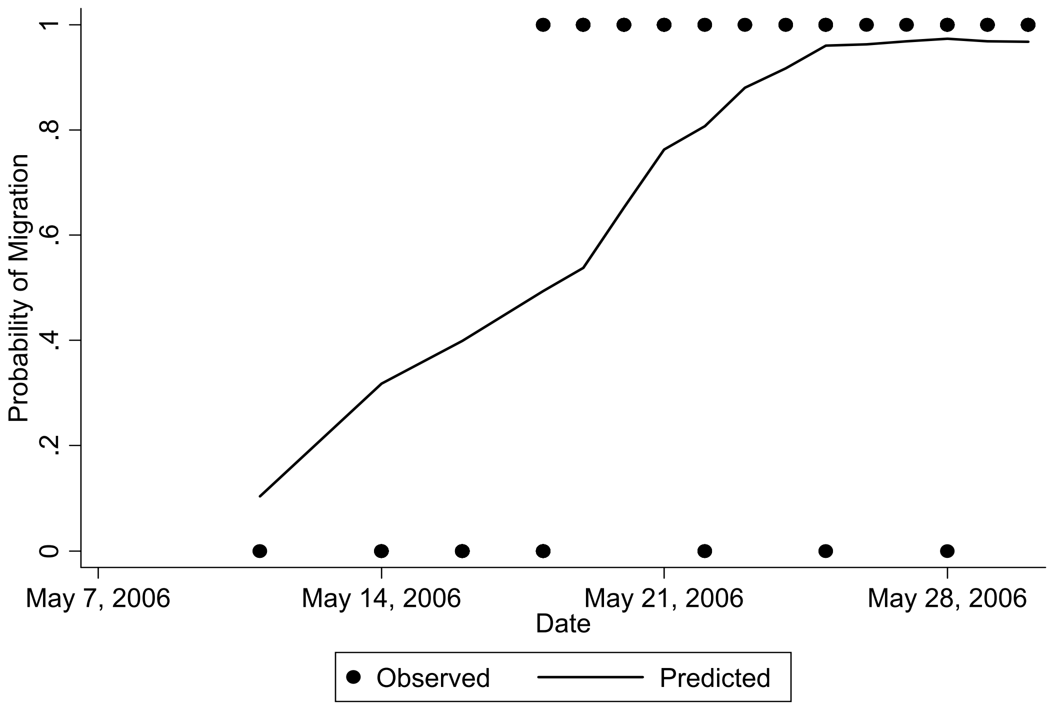


Figure 9. Predicted and observed probability of white sturgeon migration to the spawning area based on "best" model for 2006.

4 DISCUSSION

The 2006 study has again confirmed that natural spawning events occur in the Nechako River and that viable progeny (to the larval stage) can be produced. At a macrohabitat level, the observed location of the 2006 congregation indicates a fidelity to the vicinity of the Vanderhoof bridge, the same general location where the 2004 congregation was observed. However, the apparent downstream movement of the congregation (compared to 2004; Figure 3) indicates that mesohabitat or microhabitat selection varies, and allows for the comparison of habitat conditions between the 2004 and 2006 sites.

4.1 SPAWNING CONGREGATION

Although difficult to conclusively determine, the duration of actual spawning activity in 2006 (*i.e.* estimated to be approximately three days) appeared to be longer than previously documented (*i.e.* an estimate of 36 hours in 2004; Triton 2004). 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 for 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).

4.2 HABITAT

Figure 7 summarizes habitat parameters in the vicinity of the 2004 and 2006 spawning congregations. The maximum depth of transects in 2006 was generally greater than in 2004 (average maximum depth of 1.8 m versus 1.3 m in 2004), which can partially be explained by the difference in discharge at the time measurements were taken. In 2006 river discharge was 114 m^3/sec versus 104 m^3/sec at the time the 2004 measurements were taken, which corresponds to an elevation difference of approximately 0.1 m at the Vanderhoof bridge WSC station. The difference in average maximum depth is more reflective of the fact that a proportion of the 2004 habitat transects were located across shallower side-channel habitat within the braided portion of the river upstream of the Vanderhoof bridge. All of the 2006 habitat transects were located at the downstream end of the braided section of river, and occurred across the entire main channel of the Nechako River where it would be expected that maximum depths would be greater.

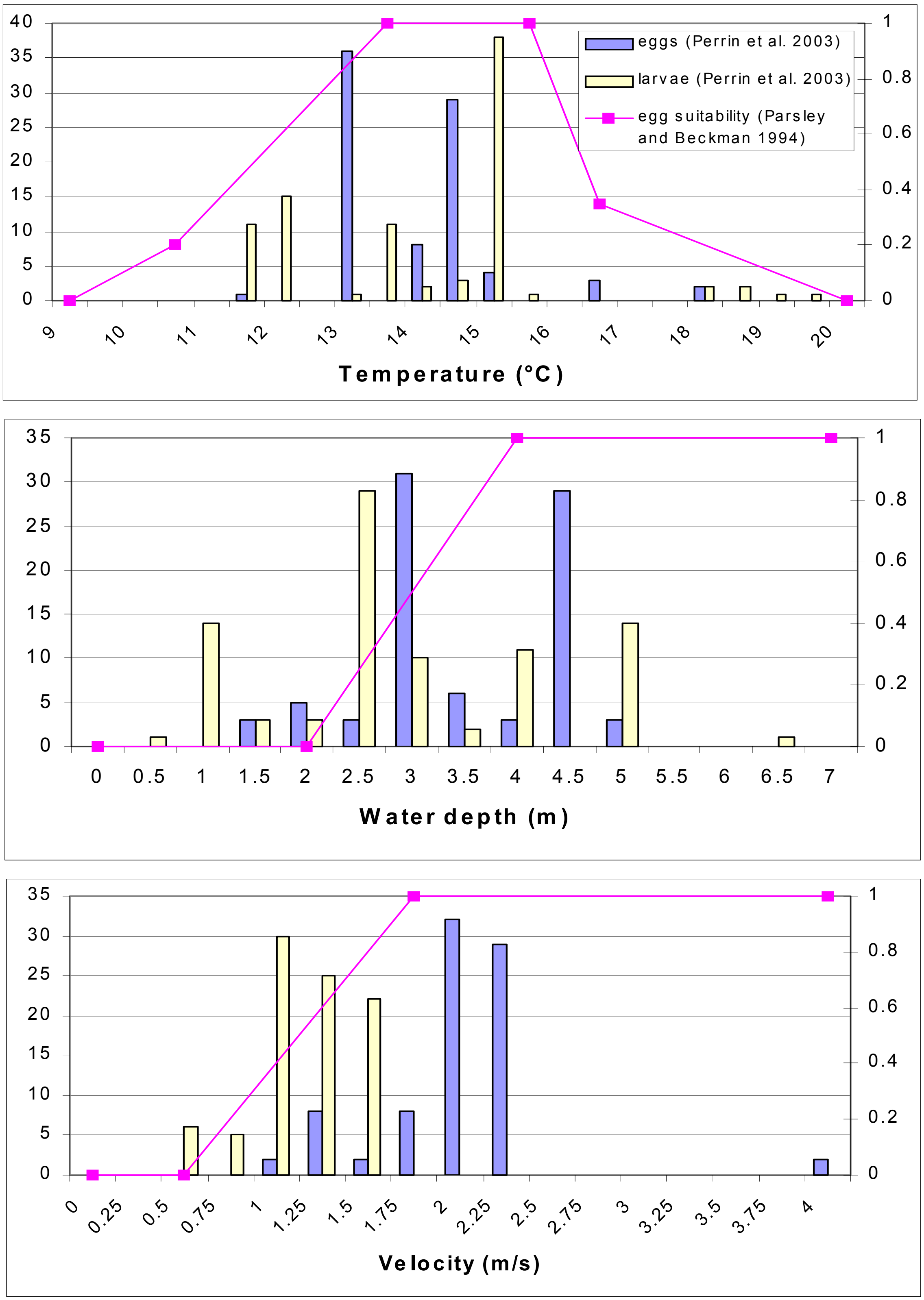
Maximum transect velocities were generally greater in 2006 compared to 2004 (average maximum velocity of 1.2 m/s in 2006 compared to 0.9 m/s in 2004). Similar to maximum depth, the difference between 2004 and 2006 maximum velocities is more reflective of transect location, with several of the 2004 habitat transects occurring across side-channel habitat within the braided portion of the river. All of the 2006 habitat transects were located at the downstream end of the braided section of river, and occurred across the entire main channel of the Nechako River where it would be expected that maximum velocities would be greater. Based on depth and velocity, both the 2004 and 2006 transects were completed in a similar mesohabitat type, which is best described as shallow river habitat.

Substrate size was noticeably different between the 2004 and 2006 habitat transects, with 2006 sites comprised of a higher proportion of fines and smaller gravels. All of the 2006 transects were downstream of areas where cobble dominates the channel substrates. In summary, habitats in the vicinity of the 2006 congregation were of comparable depth and velocity, but were comprised of smaller substrates when compared to habitats in the vicinity of the 2004 congregation.

Similar to observations during the 2004 congregation (Triton 2004), depth and velocity preference for Nechako sturgeon spawning habitat depart from literature values. As was noted in 2004, again the mean maximum depth of 1.8 m from habitat transects in the vicinity of the congregation is below documented values in Columbia studies, where the lower range of spawning suitability (0) was limited at 2 meters with a suitability of use of 1 noted at 4 meter depth and deeper (Parsley and Beckman 1994; Figure 10). Spawning depths in the Fraser River (based on egg capture data) indicated that water depths averaged 2.9 meters, which are noted as being less than found in other regulated rivers (Perrin *et al.* 2003).

Maximum velocities recorded at habitat transects in the vicinity of the congregation ranged from 0.89 to 1.52 m/s, and the maximum velocity measured at egg mat locations was 1.57 m/s. These velocities were reflective of the lower to mid range of habitat preference for Columbia River (Parsley and Beckman 1994), and lower than values measured in the Fraser River (average 1.8 m/sec, based on egg capture locations, Perrin *et al.* 2003).

Figure 10. Water temperature, depth (primary y axis) and near-bed velocity (secondary y axis) at sites where sturgeon eggs and larvae were collected in the Fraser River (Perrin *et al*. 2003), and suitability of use conditions for spawning in the Columbia River (Parsley and Beckman 1994). Figure taken from Perrin *et al*. 2003.



4.3 OBSERVATION AND SAMPLING TECHNIQUES

The effectiveness of observation towers was investigated during the 2006 program. Visibility was estimated to be approximately 40 m in any direction which is equivalent to a maximum visible area of 5,000 m^2. Visibility was best where water depth was less than 1 m, and the maximum viewable depth was estimated at 2 m. Realistically, the effective viewable area is only a proportion of the maximum as there are few (if any) locations where a tower could be installed 40 m (or more) from the shore to ensure habitat useable to sturgeon surrounded the tower. Additionally, at any given time of day glare along certain aspects reduces visibility.

It would take on the order of 20 observation towers to adequately cover the areas identified as having the highest density of fish during the 2004 or 2006 spawning congregations (approximately 1,500 m of river with towers every 80 m on alternating river margins). At a rental cost of approximately $750 for a month per tower (weekly cost is similar), and an installation time of 6 - 8 person hours per tower, the cost of installation would be prohibitive. More importantly, observation towers should only be considered effective where sturgeon congregate in shallow sections of the river. During future studies, if the spawning location and number of individuals appears appropriate for the use of observation towers, scaffolding can be obtained locally and the towers can be constructed within several hours if guy wires and bases for the scaffolding are stockpiled ahead of time.

Similar to 2004, egg mats proved effective at capturing eggs. However, they are more likely to catch drifting eggs that have detached from the channel substrate (as indicated by a sediment coating or fungus on the majority of eggs), as there is some degree of luck involved in having a mat located within the initial dispersal area of released eggs. Although the use of egg mats are effective at proving a spawning event occurred, it is unlikely that they would ever play a substantial role towards achieving the goals of the Nechako white sturgeon breeding program. For example, intensive egg mat sampling in 2006 resulted in the release of 9 juveniles. Even by doubling or tripling the egg mat effort, it would seem that a target of 100 juveniles would be optimistic. As the breeding program has a release target on the order of 12,000 juvenile fish (NWSRI 2005), 100 juveniles would only comprise a small portion of the target. As such, the use of egg mats to collect naturally fertilized eggs for incubation should only be considered supplementary to the capture of brood stock.

It would appear that the capture of viable eggs occurred within a short period of time (approximately 4 days), compared to the total length of time that the mats were deployed and catching eggs. In order to support the breeding program, there could be an increase in the number of egg mats used, with deployment concentrated at specific locations where pairing sturgeon are observed during low level overflights.

Egg collection locations give an indication of egg dispersal mechanics. Eggs were first collected at sites 2 – 6, which corresponds to the general location where paired adults were observed during low level overflights. The downstream most egg mats (site #1) only appeared to capture drifting eggs, several days after the estimated period of spawning. This would indicate a short (*e.g.* several hundred meters) dispersal of viable eggs, with longer drifts limited to non-viable eggs which were either never attached, or became detached from channel substrates.

The location of captured eggs also gives an indication as to the linear extent of spawning activity. The capture of two eggs on one of the upstream most egg mats (site 15) was upstream of visually observed sturgeon. This indicates the potential for low level observations flights to miss fish (a definite possibility in deeper sections of the river like in the vicinity of site 15), or alternatively that short term (*e.g.* overnight) forays away from the main congregation can occur. Both explanations are plausible.

The initial deployment and the duration that the egg mats were set were based on observations of fish activity (either visually or by telemetry) and river conditions (*i.e.* temperature). In 2006, the decision was made to pull the egg mats (and essentially end the field portion of the program) on June 6, after most fish from the May 19-21st spawning congregation had dispersed, fish were no longer being seen during the low level overflights, and only one ruptured egg was captured on the egg mats retrieved on June 6 after a 7-day set. However, subsequent observations by Mike Keehn (Freshwater Fisheries Society of BC) from the temporary hatchery upstream of the Vanderhoof bridge included 16 fish on June 9th, and 25-30 fish on June 10th. The observed fish were very active, however it could not be confirmed whether spawning was occurring as no egg mats were in place to collect eggs, and no overflights were being conducted to make any visually observations of pairing or gamete release. The potential exists that a second spawning event or prolonged spawning period occurred, something that could be investigated during future monitoring programs.

As a final note regarding egg mats, the capture of numerous eggs in 2006 adds support to the lack of a spawning event (or very limited spawning event) in the vicinity of the Vanderhoof bridge in 2005 as 31,847 hours of egg mats over a period of one month did not result in the capture of any eggs (viable or otherwise).

4.4 PREDICTIVE MODEL

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 model that was selected as "best" in the present study involves a combination of temperature experience (ATU), daily flow and photoperiod. These factors when considered together do a far better job explaining the observed white sturgeon migration patterns than each parameter individually, as was made apparent by comparing AIC_c scores (Table 3). The combination of these parameters is not unexpected given that in the spring when white sturgeon are spawning, each of those variables are changing at the same time and it is reasonable to expect that sturgeon would have evolved to respond to all three environmental cues as opposed to just one. Despite that the role of each parameter individually in the life histories of many species of fish has been well studied and the benefits and costs associated with spawning during optimal and sub-optimal conditions, further supports the inclusion of each parameter in the model.

As a direct result of being obligate ectotherms, temperature is considered by many to be the primary abiotic factor influencing the life histories and distribution of fish (Moyle and Cech 2004; Wooton 1992). Everything from metabolism and growth, to physiology, reproduction and behavior is impacted and in many cases controlled by temperature. In the case of white sturgeon, rising water temperatures in the spring likely increase swimming ability, making migrations less energetically demanding, and influence gamete production prior to spawning. Once spawning is complete, temperature impacts 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. The fact the model selected ATU, which is a measure of temperature experience, over either daily mean temperature or daily maximum temperature suggests that in regards to migration, it is not a threshold temperature that the fish are responding to but rather a trend over time.

Flow is also 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 to prevent desiccation. 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. Alternatively, high levels of turbidity associated with increased flows can provide cover for dispersing larvae and may help to limit predation. Lastly, photoperiod is known to play a critical 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. Therefore, while increasing photoperiod and flow have a positive influence on the probability of migration, increasing ATU has a negative influence. However, this should not be interpreted to mean that higher flow and lower ATU 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 ATU, a potential explanation is that more of the data points included in the analysis were from 2006 which was a cooler year than 2004. As a result, the coefficients generated reflect the fact that there are more records of fish in the spawning area when the water was cooler. As with any modeling analysis, it is important to remember that the value of the coefficients generated and their corresponding sign will change depending on what data is included during model generation. Similarly, the data used to generate the model also limits what the resulting model can be used for. For example, since the goal of this model was to predict the onset of migration, only data from May was included and as a result the model could not be expected to reliably predict when fish would return to the overwintering holes.

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 analyses completed show that while all parameters included in the model have a significant effect on the regression equation, the predictive ability of the selected model was only reasonable (correct 81% of the time based on the ROC analysis). Similarly, the analysis of the standardized residuals showed that 20% of the time the residuals were either greater than 2 or less than -2. A general rule is that for a good fit, less than 5% of the residuals should be in that range. The rationale for the lower than expected predictive ability and high number of outlier residuals is that the dataset is simply not complete enough for a more precise analysis. It is important to remember that this analysis is based on data from only two migration events and a total of 185 records, which is a relatively small dataset. As with any statistical analysis, the larger the dataset the more precise the results. Therefore, were the data more continuous (*i.e.* data was available from more fish and on more days), it is likely that the model's predictive ability would improve. In addition, differences in migration patterns between the two years included in the study also limited the models predictive ability. In 2004, once spawning occurred, fish appeared to leave the spawning area within a few days (it should be noted that few radio tagged fish were part of the 2004 congregation). However, in 2006, fish tended to remain in the area for several weeks afterward. This conflicting data makes it difficult for the model to accurately predict the observed patterns and results in a lower predictive ability and greater number of outlying residuals. Despite these deficiencies in the dataset, the predicted results do follow the general trends observed in both years. In 2004, spawning occurred on May 18th and the predicted results show a peak in migration probability around that date followed by a decline towards the end of May (Figure 8). In 2006, the model was not able to identify the exact spawning period (May 19th) as some fish remained in the vicinity of the spawning area for the remainder of the month. As a result the predicted probability of migration does not reach a peak until approximately 1 week after spawning occurred (Figure 9).

4.4.1 Model Validation

A major criticism of ITMC method is that often the identified "best" model is not validated using independent datasets (Guthery *et al.* 2005). As a result, the ability of the model to perform in real-world applications is unknown. To that end, the developed model was used to predict sturgeon migration for 2003 when a congregation of white sturgeon was observed at the spawning area (rkm 136-140) on May 26th (Personal

Communication, Cory Williamson). Since no telemetry data from 2003 was used in the development of the model, this observation represents an opportunity to test the models performance using an independent dataset. The model was run and the predicted probabilities of migration are shown in Figure 11.

The results of the model validation show a peak in the probability of migration between May 18th and June 4th, approximately a week before and after the congregation was said to have occurred. This result seems reasonable based on the knowledge that male sturgeon in particular do tend to migrate earlier than females and may arrive at the spawning area several days before the spawning event. Likewise, fish can then remain in the vicinity of the spawning area fore several days or weeks after spawning (as was observed in 2006). The results of this validation do appear to support the model selected as being correct and confirm the potential usefulness of such a model to predict migration patterns. However, it would be beneficial to validate the model with an independent dataset that consists of continuous telemetry data which could be compared to the predicted results throughout the entire migration period. In addition, this would allow for a quantitative assessment of predictive ability using an analysis such as a ROC.

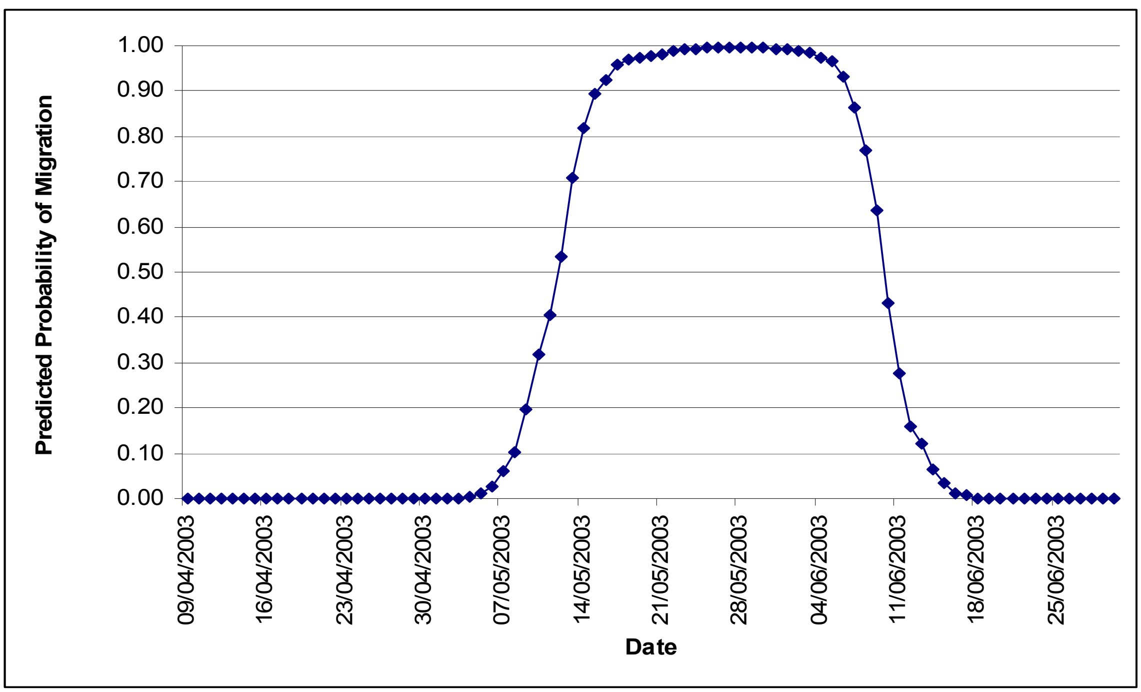


Figure 11. Predicted probability of white sturgeon spawning migration for 2003 using the selected model (ATU + Flow + Photoperiod).

4.4.2 Test Scenario – High Flow

In order to test the application of the model from a management standpoint, the model was used to predict the sturgeon migration pattern under a 'high-flow' scenario (*e.g.* forced spilling from the reservoir). Flow and temperature data from 2005 was used for the model inputs since flows that year where 3-4 times higher than normal due to forced spilling. No congregation was observed that year and as a result there is no way of assessing the accuracy of the predictions. However, the results should provide insight as to the potential changes to the migration pattern that may occur as a result of high flows in future years. The results are provided in Figure 12.

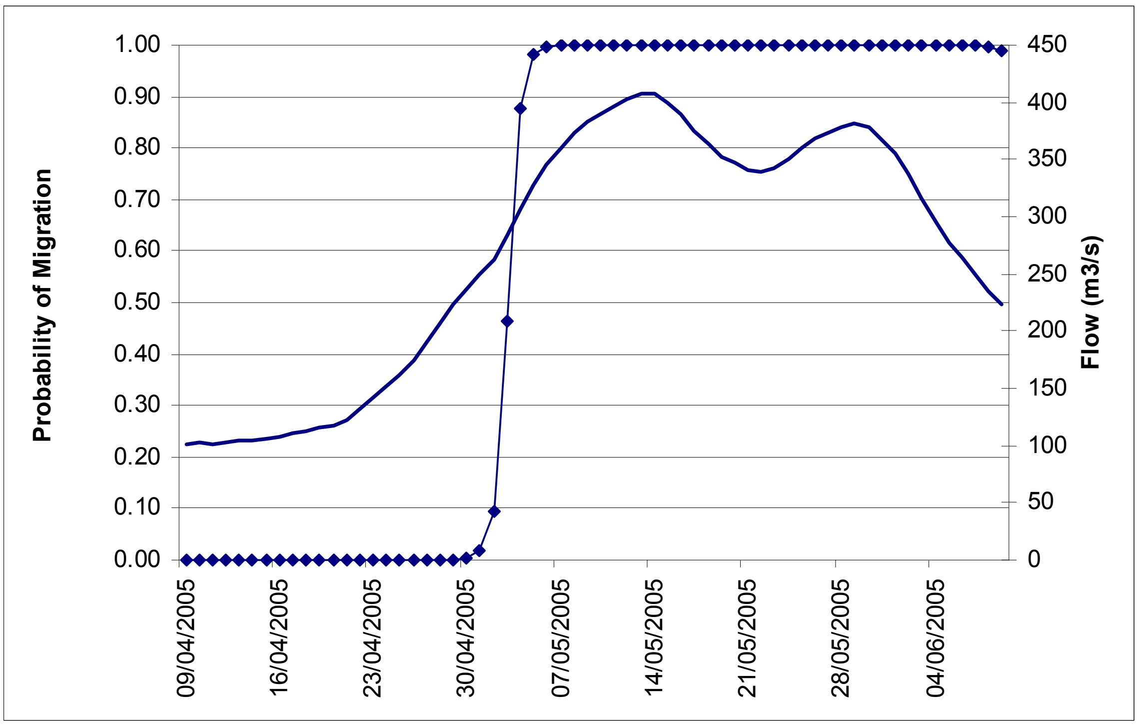


Figure 12. Predicted probability of white sturgeon spawning migration (♦) and flow (m^3/s) for a 'high-flow' year (2005), using the selected model (ATU + Flow + Photoperiod).

The model predicts that the probability of migration would increase rapidly in the first week of May. This is approximately 2-3 weeks earlier than migration typically occurs under normal flow conditions. However, since the flows in 2005 remained high throughout May, the probability of migration also remains high for an extended period of time. It is not until June when flows have begun to decrease that the model predicts a decline in the probability of migration. Therefore, while the increase in probability of migration is predicted to occur earlier under high-flow conditions, the decrease occurs at a similar time to normal flow conditions (see 2003 prediction, Figure 11), resulting in an extended migration window.

These results are to be expected given that the flow coefficient for the developed model had a positive value (Table 4), meaning there is a positive relationship between flow and migration. However, it is important to note that the model was developed without data from high-flow years. As a result, the value of the flow coefficients may not be appropriate when flow is 3-4 times higher than in the years used to develop the coefficient (2004/2006). This is because at extreme values, one parameter could come to dominate the model such that the values of the other parameters have little to no influence on the model output. In the test scenario the model is being dominated by the high flow values which explains the very rapid increase in migration probability in the first week of May as well as the extended period with a probability of migration of 1. In particular, there appears to be a threshold level around 300 m^3/s above which there will be a probability of migration of 1 regardless of the value of the other parameters. This is made apparent by the fact that when flows dropped for several days in mid-May there was no change in the predicted probability of migration since flows never dropped below 300 m^3/s. It was not until flows fell below that threshold level in early June that the probability of migration began to drop.

Therefore, while the general trend of migration occurring earlier seems reasonable to expect, the ability of the model to accurately predict specific dates will be limited due to the difference in magnitude of the flow values as compared to those used to develop the model. Inclusion of telemetry data from a high-flow year would likely alleviate this problem and produce model coefficients that are more robust for the range of flows possible for the system.

4.4.3 MANAGEMENT IMPLICATIONS

Although it is apparent that the developed model would benefit from additional years of data to further refine its predictive ability, the results generated are still considered useful from a management perspective. Based on the results, it seems likely that fluctuations in river temperature and flow away from what would be considered normal during the spawning period could have an adverse affect on both the timing and subsequent success of white sturgeon 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 such as the one developed could be used for this purpose by predicting white sturgeon migration patterns based on a series of hypothetical management strategies. However, that model would need to be developed with as complete a data set as possible and undergo rigorous testing and validation with additional independent datasets.

5 Recommendations for Future Work

Due to the limited number of pairings planned as part of the Nechako River white sturgeon breeding program, naturally spawned eggs will be important to the maintenance of genetic diversity within the population. As previously discussed, naturally spawned eggs captured on egg mats will never comprise a large portion of released juveniles. However, options to increase the chance of collecting viable eggs include:

1) Increasing the number of deployed egg mats.
2) The careful deployment of egg mats upon first observation of paired sturgeon.
3) Investigating the use of strategically located fyke nets to catch fertilized eggs before they attach to the substrate. At low flows (like those observed in 2004 and 2006) a row of fyke nets could be deployed across the majority of the river (*e.g.* the shallow glide upstream of the Vanderhoof bridge).

Another consideration for future work is that the first observation of pairing or congregating fish should be considered a spawning event. Any proposed activities contingent on the observation of a congregation should be initiated after the first pairings are observed. For example, in 2006 the limited number of fish observed and the limited number of pairings compared to 2004, resulted in the delay of some field activities (*e.g.* video recording of the congregation from a helicopter and relocation of the observation towers). Numbers of fish and intensity of pairing did not drastically increase in subsequent days (although it was expected that this would happen), and by the fourth day the congregation had dispersed, eliminating the potential to undertake some of the planned field activities.

5.1 RECOMMENDATIONS FOR MODELING

The results of the modeling analysis suggest that while the model will benefit from the inclusion of additional years of data, its general ability to predict migratory patterns that coincide with observed patterns and that are supported by the literature provides support for this analysis. As a result it is recommended that:

1. Additional year(s) of telemetry data should be included so as to provide a more extensive dataset for the analysis. This would help refine the predictive ability and reduce the number of outlier residuals, which are an artifact of the non-continuous data set, and provide a means of more rigorously testing and validating the developed model.
2. Future telemetry projects need to focus on the collection of more continuous data with the continued establishment of base-stations at both the spawning area (downstream and upstream) as well as at the overwintering holes. Regular telemetry overflights leading up to and during the potential spawning period (May) at regular intervals (*e.g.* every 2 days) should also be completed.
3. Once a more continuous and larger dataset is available, use of this technique 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.

Report reviewed and approved by:

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Ryan Liebe, B.Sc., R.P.Bio.
Triton Environmental Consultants Ltd.

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Personal Communication

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 Vanderhoof bridge (Water Survey of Canada station 08JC001) from April 1 to June 30, 2006.

Date	Daily Mean Temperature (°C)	Daily Maximum Temperature (°C)	Daily Mean Discharge (m^3/sec)
April 1	0.8		186.8
April 2	0.8		201.6
April 3	0.8		210.5
April 4	1.1		208.4
April 5	2.4		166.6
April 6	3.5		126.6
April 7	4.8		96.3
April 8	5.1		81.2
April 9	5.0		82.9
April 10	5.1		82.5
April 11	5.4		81.8
April 12	5.3		81.1
April 13	4.6		80.8
April 14	4.6		79.1
April 15	4.4		77.7
April 16	4.7		76.2
April 17	5.2		75.5
April 18	4.9		74.7
April 19	5.6		73.9
April 20	6.1		73.9
April 21	6.1		74.8
April 22	6.7		75.1
April 23	7.3		75.7
April 24	8.8		75.0
April 25	9.5		75.4
April 26	8.1		77.5
April 27	7.2		81.0
April 28	7.3		82.3
April 29	7.1		83.8
April 30	7.7		85.2
May 1	8.1	9.0	86.2
May 2	7.9	9.8	87.6
May 3	8.3	10.5	88.4
May 4	9.4	11.2	88.2
May 5	10.2	11.4	89.2
May 6	10.1	11.4	90.6
May 7	9.5	10.1	92.3
May 8	8.5	10.1	94.3
May 9	8.8	10.8	95.6
May 10	9.7	11.3	95.8
May 11	10.3	11.7	96.1
May 12	9.9	11.6	96.1
May 13	9.7	11.2	97.2
May 14	9.9	11.9	97.6

Date	Daily Mean Temperature (°C)	Daily Maximum Temperature (°C)	Daily Mean Discharge (m^3/sec)
May 15	10.8	12.9	97.0
May 16	12.2	14.4	96.8
May 17	13.1	14.5	96.6
May 18	13.5	15.3	97.4
May 19	13.5	14.6	98.2
May 20	12.9	13.6	99.5
May 21	12.5	13.9	102
May 22	12.8	14.3	104
May 23	13.8	15.1	107
May 24	13.2	14.4	109
May 25	12.9	14.7	113
May 26	13.1	14.5	114
May 27	13.8	16.1	116
May 28	14.0	15.8	117
May 29	14.5	15.9	117
May 30	14.7	16.5	118
May 31	15.3	16.8	119
June 1	16.4	17.9	119
June 2	16.4	17.6	119
June 3	15.3	16.3	120
June 4	15.0	16.6	122
June 5	15.0	16.4	123
June 6	15.2	17.2	124
June 7	15.6	17.5	123
June 8	16.5	18.1	123
June 9	17.0	18.5	122
June 10	17.5	19.3	123
June 11	17.9	19.6	123
June 12	17.6	19.0	121
June 13	17.0	17.5	121
June 14	17.1	18.5	120
June 15	17.1	18.5	120
June 16	17.0	18.1	119
June 17	16.8	18.4	119
June 18	17.1	18.8	119
June 19	17.0	18.7	119
June 20	16.8	18.2	118
June 21	16.6	18.3	116
June 22	16.1	17.6	114
June 23	16.7	19.0	112
June 24	17.6	19.7	109
June 25	18.8	21.2	108
June 26	20.0	22.4	106
June 27	20.3	22.0	104
June 28	18.9	20.4	102
June 29	18.2	20.4	101
June 30	18.8	21.2	98.5

Appendix 2

Telemetry Data

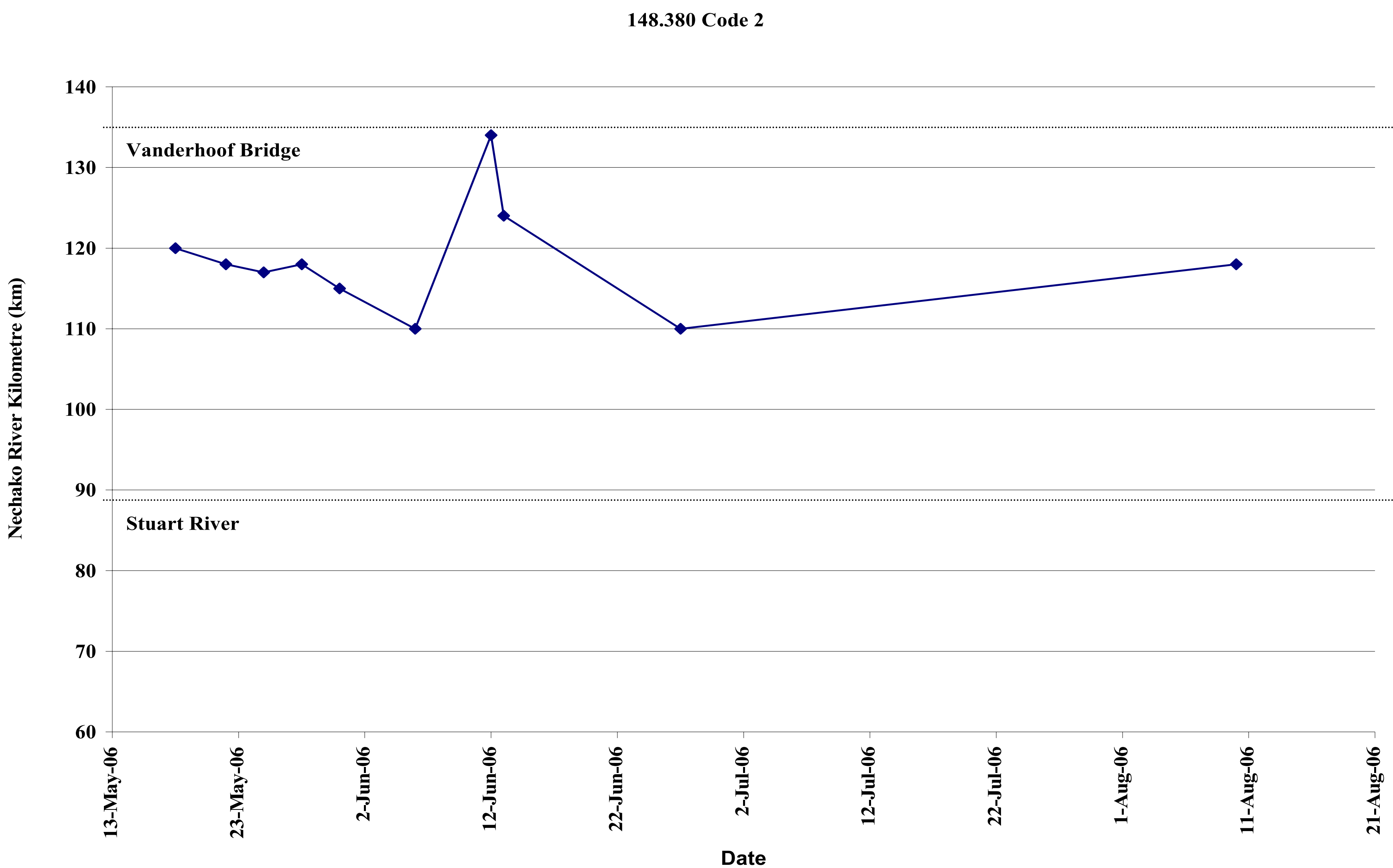


Figure 13. Detailed telemetry data for 148.390 Code 2.

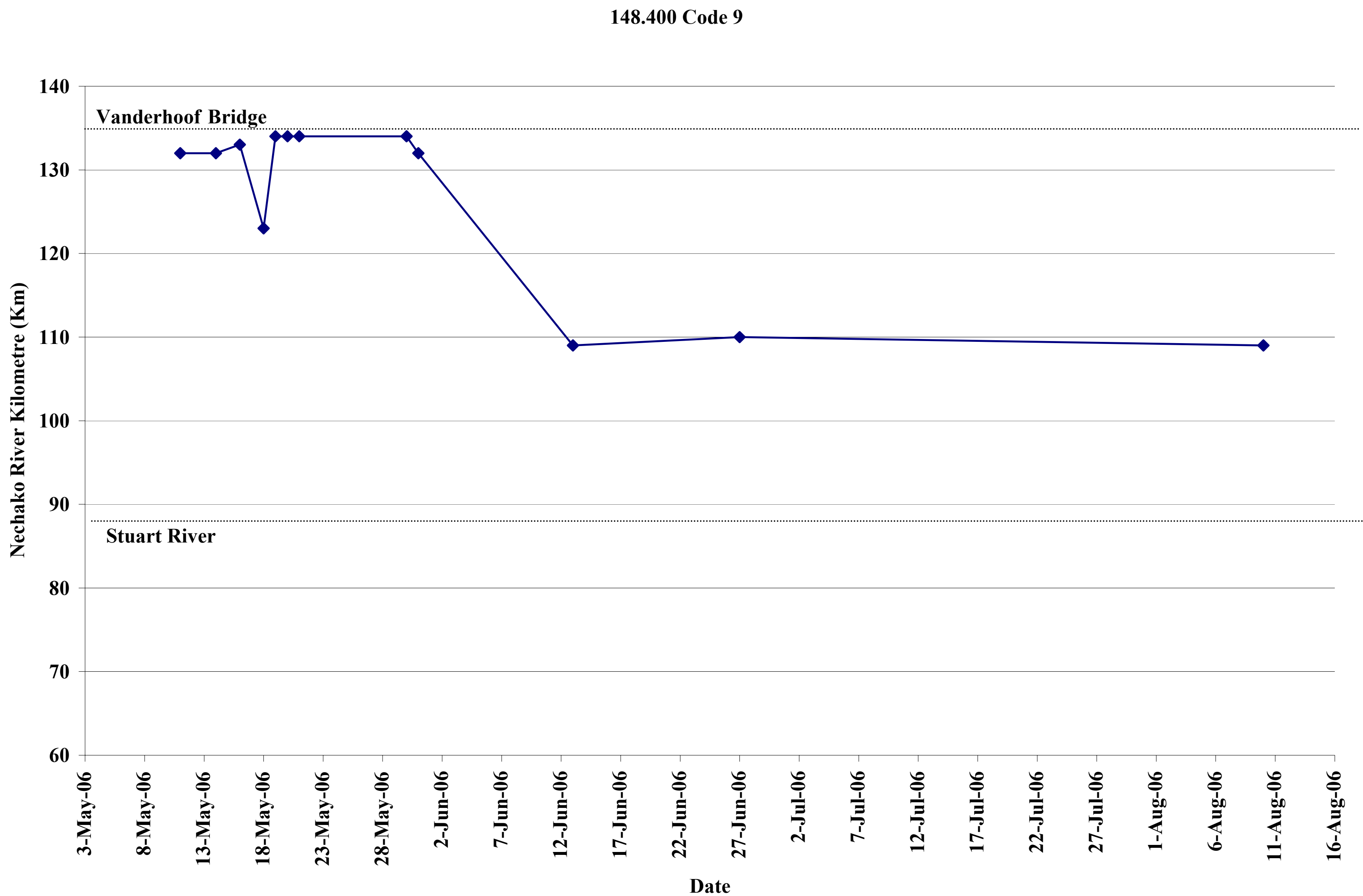


Figure 14. Detailed telemetry data for 148.400 Code 9.

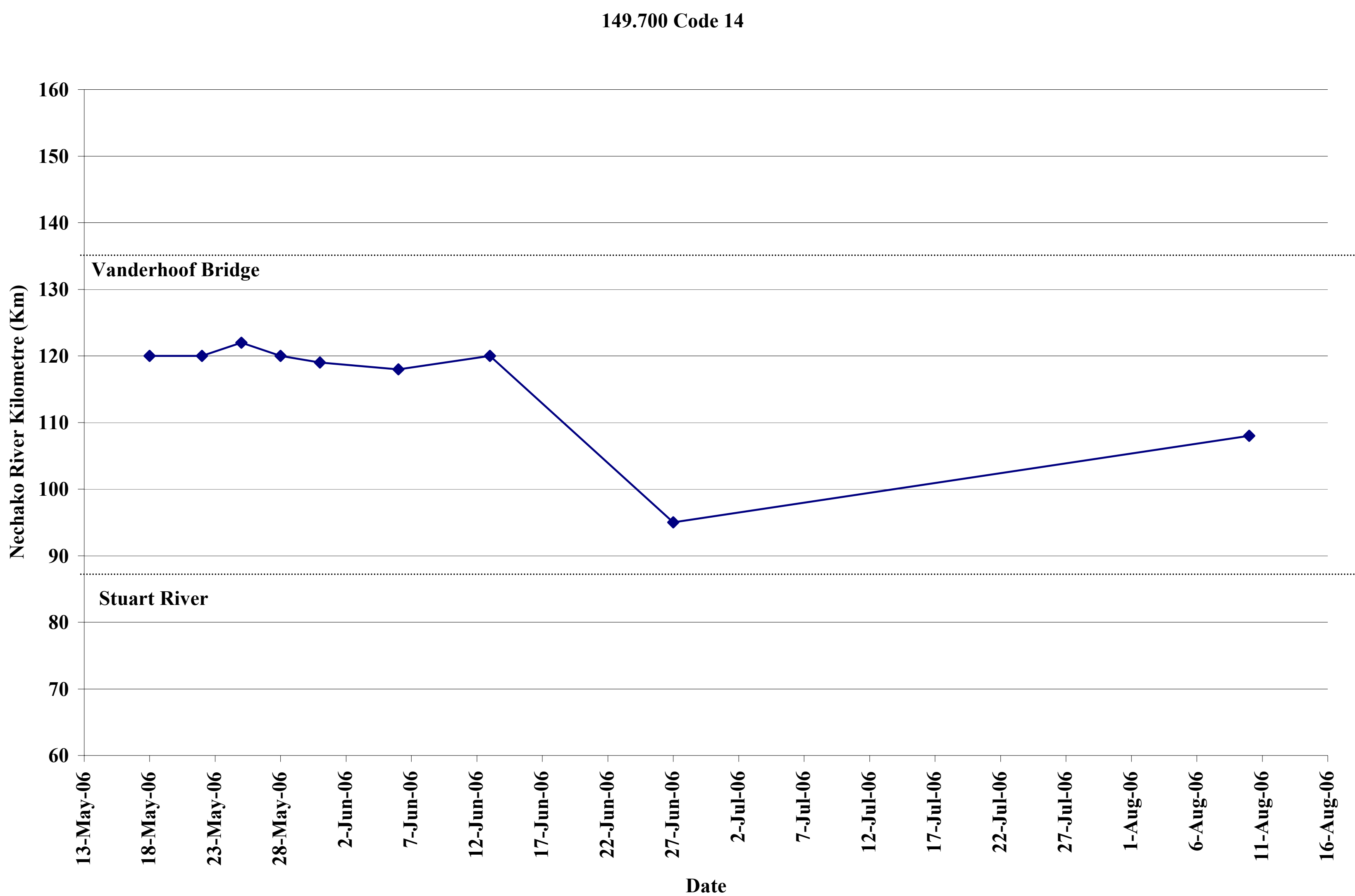


Figure 15. Detailed telemetry data for 149.700 Code 14.

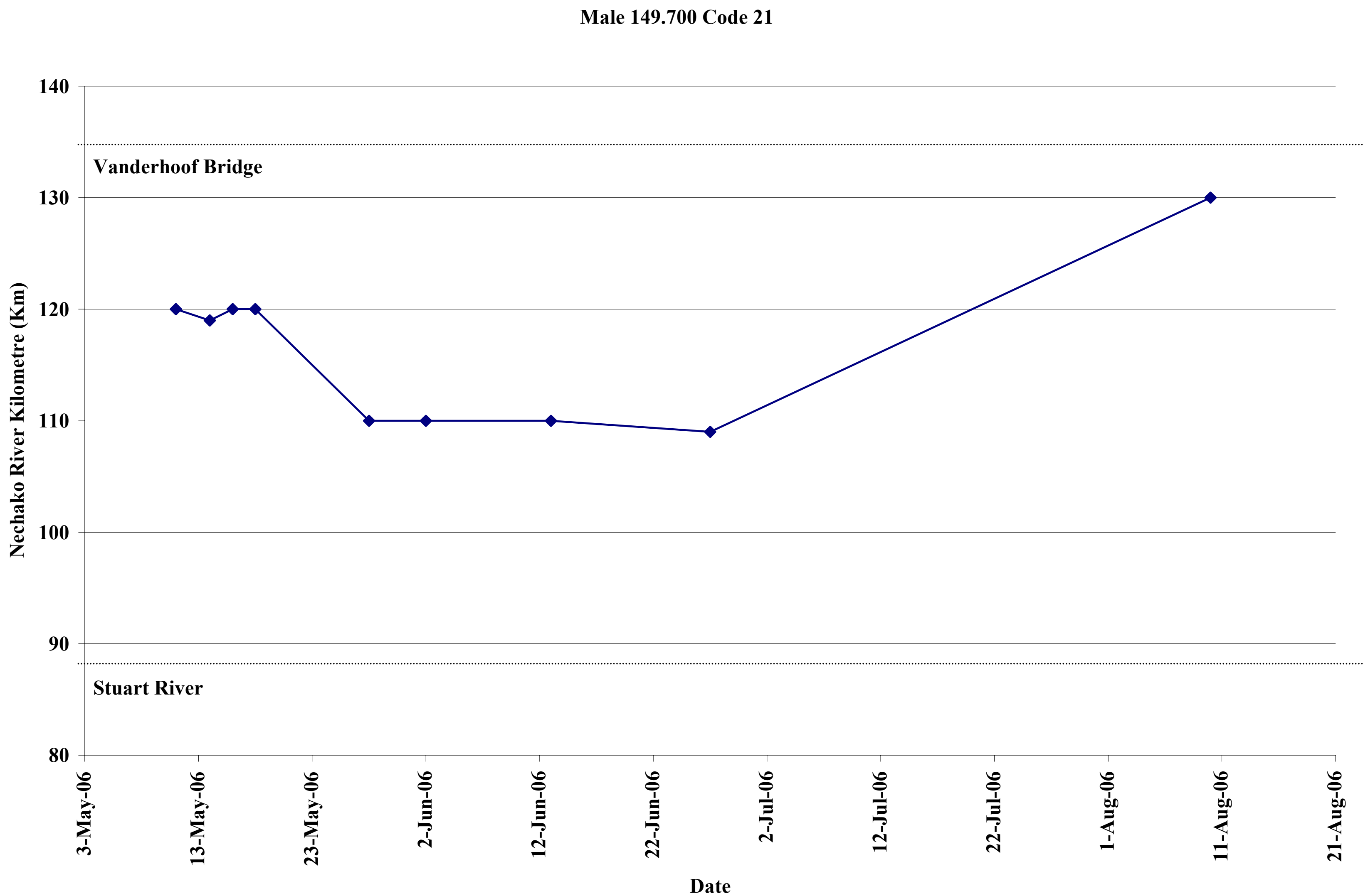
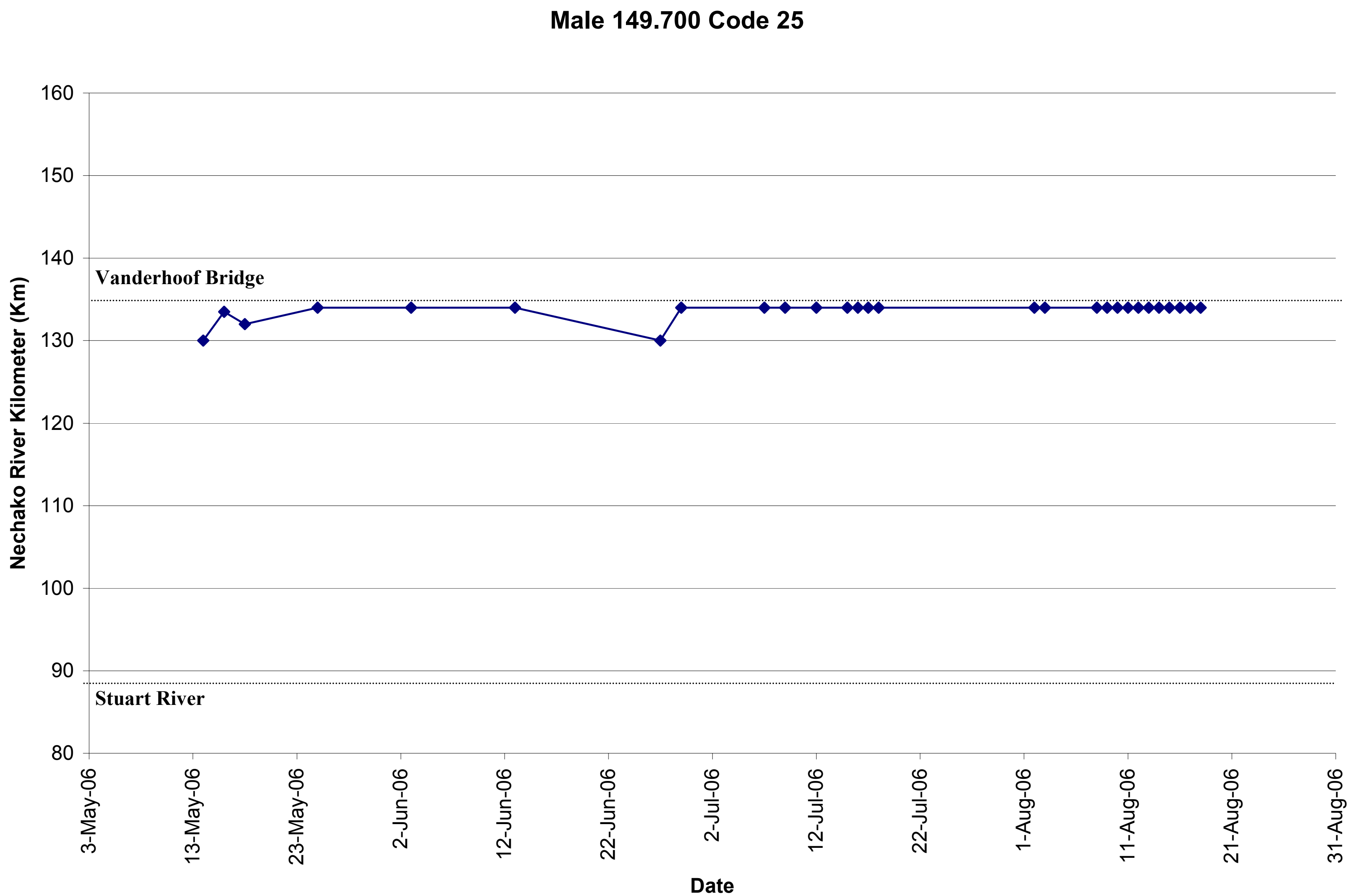


Figure 16. Detailed telemetry data for 149.700 Code 21.



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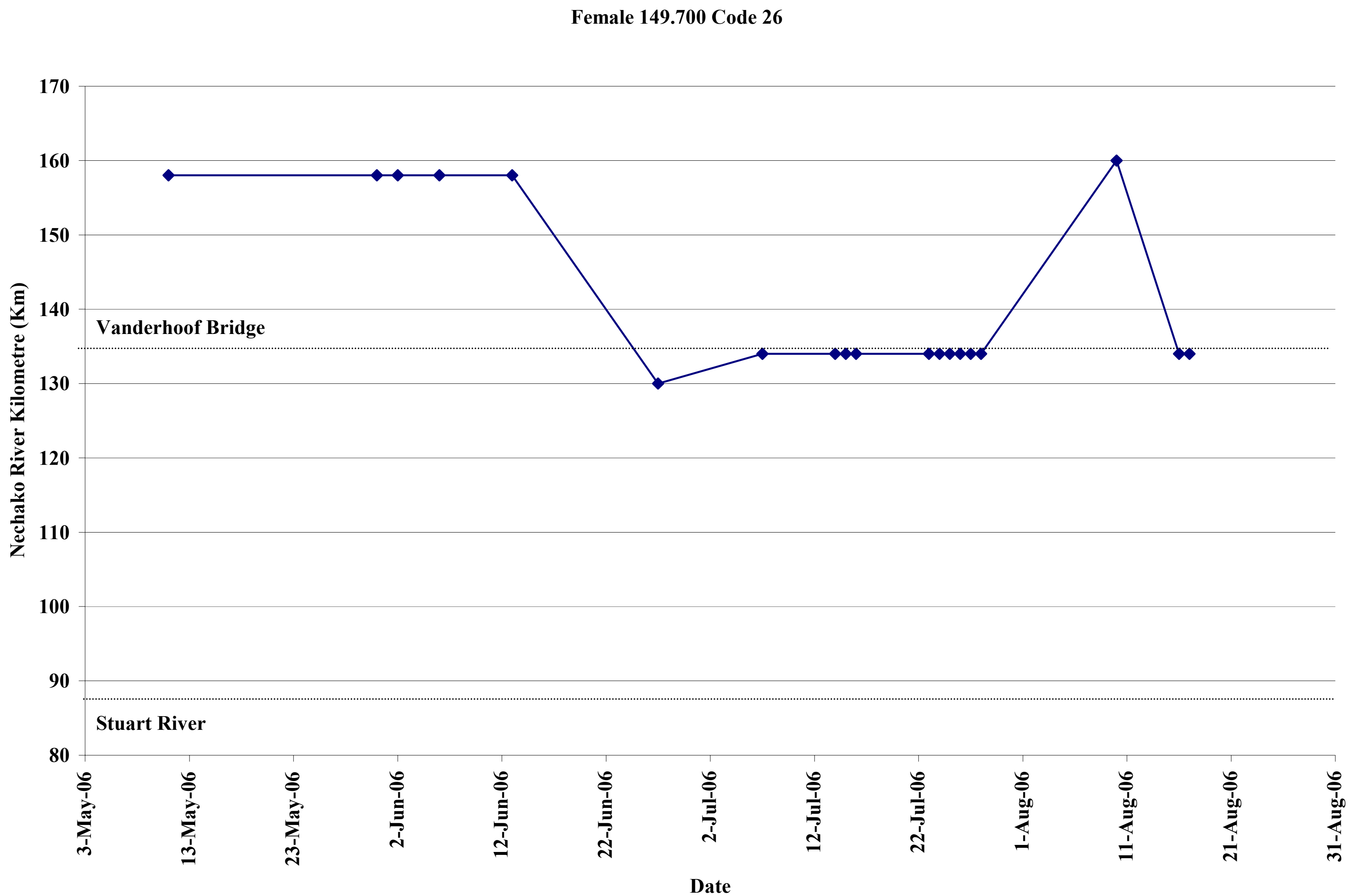


Figure 18. Detailed telemetry data for 149.700 Code 26.

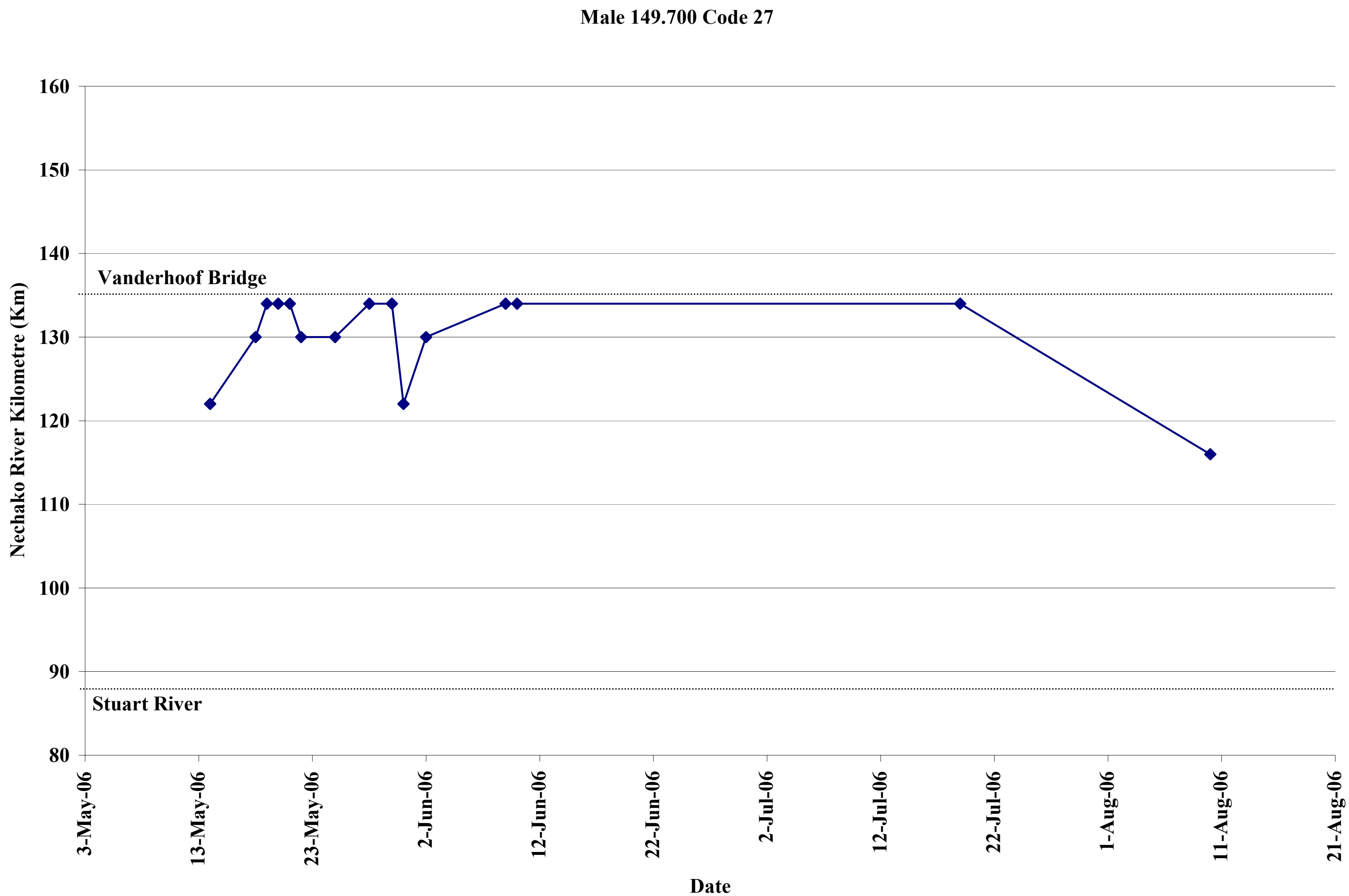


Figure 19. Detailed telemetry data for 149.700 Code 27.

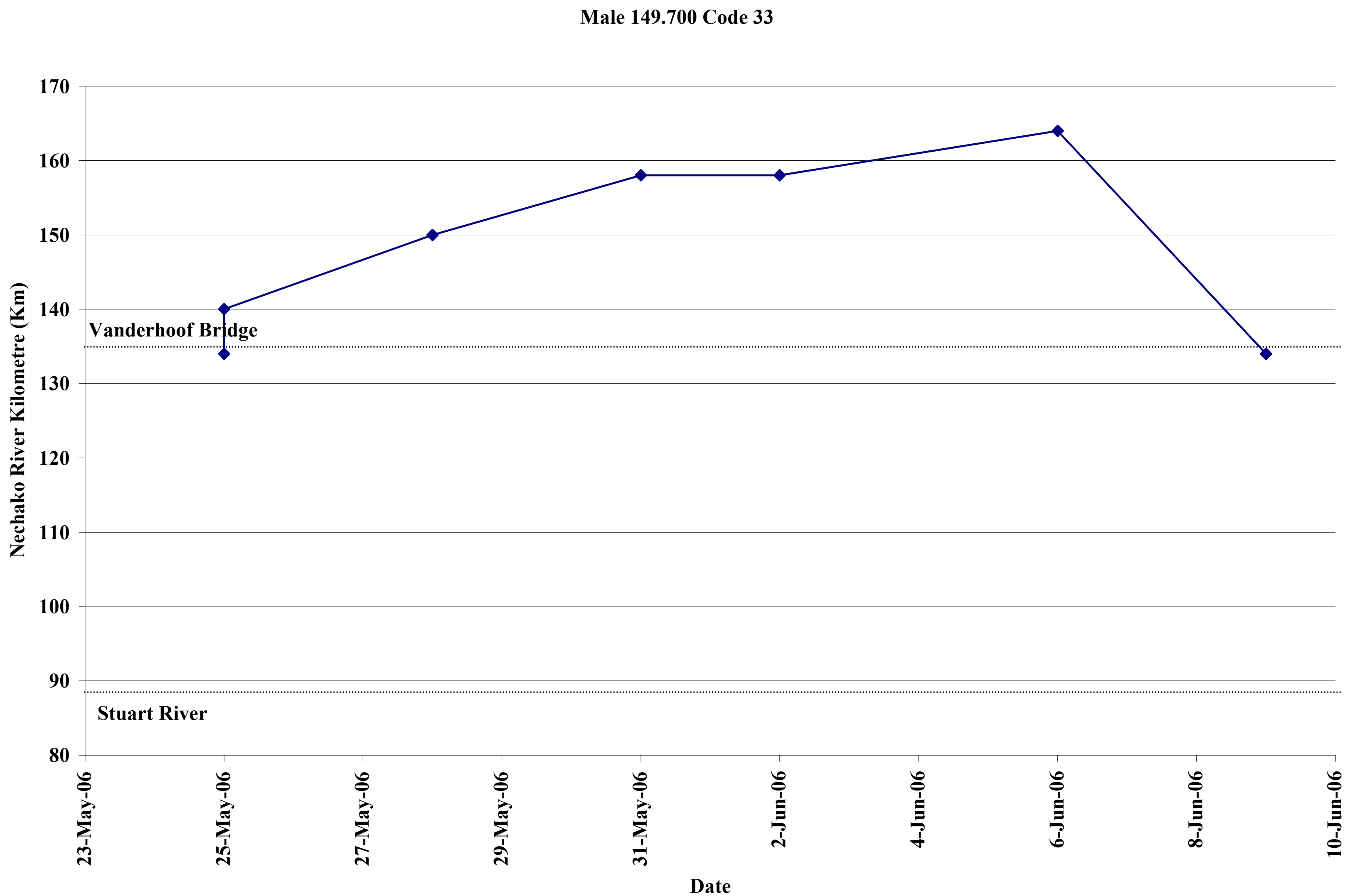


Figure 20. Detailed telemetry data for 149.700 Code 33.

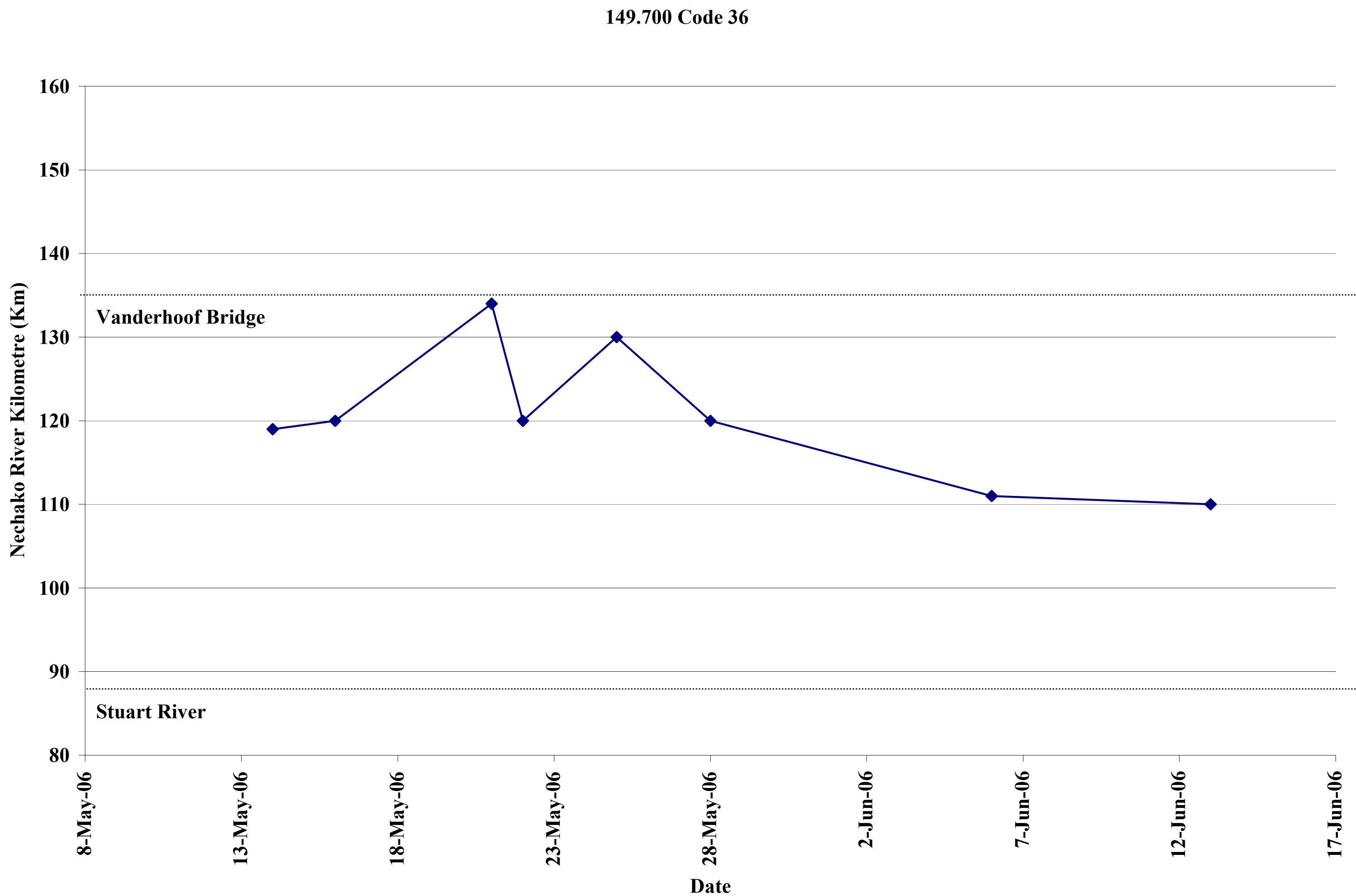
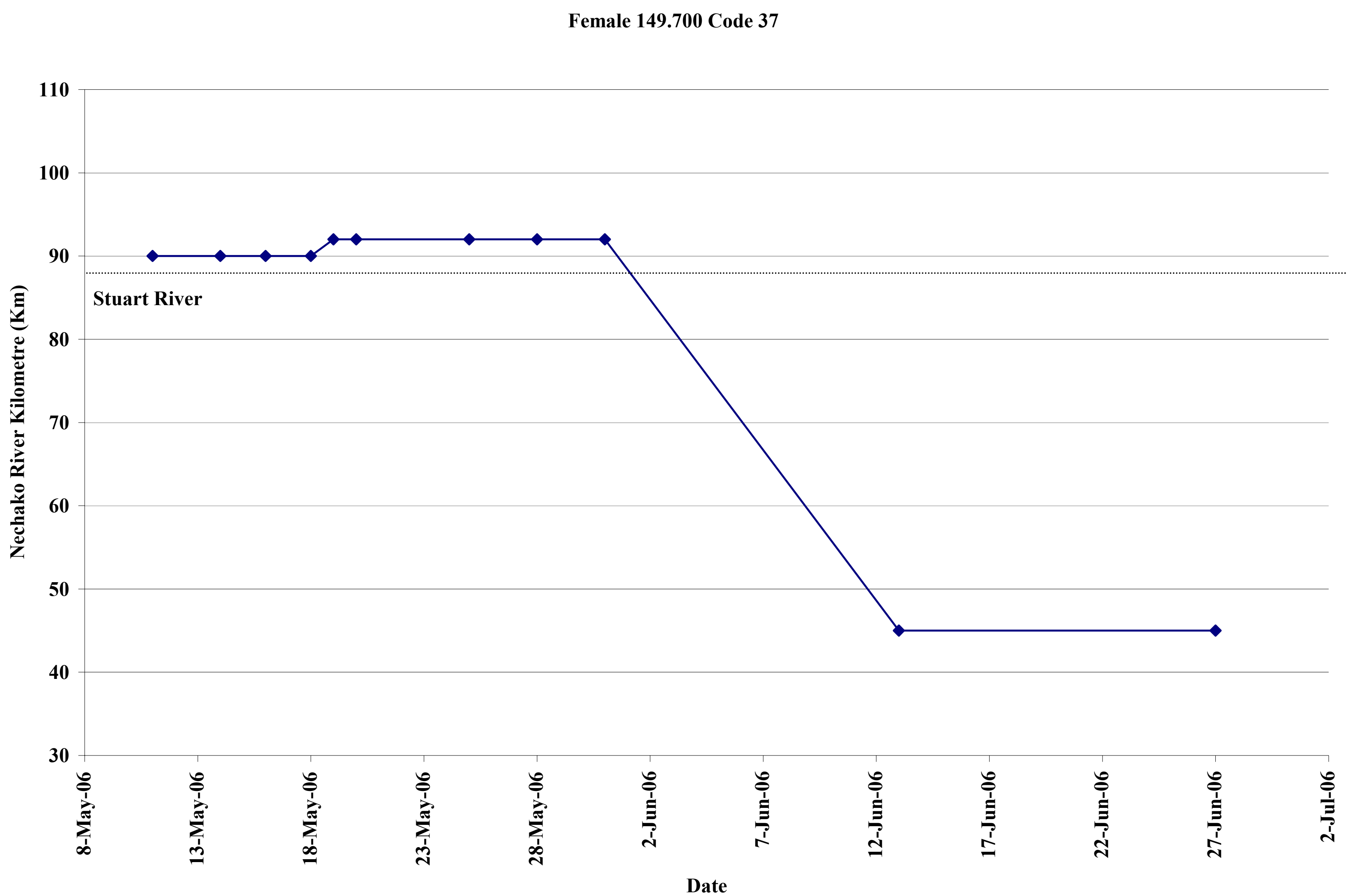


Figure 21. Detailed telemetry data for 149.700 Code 36.



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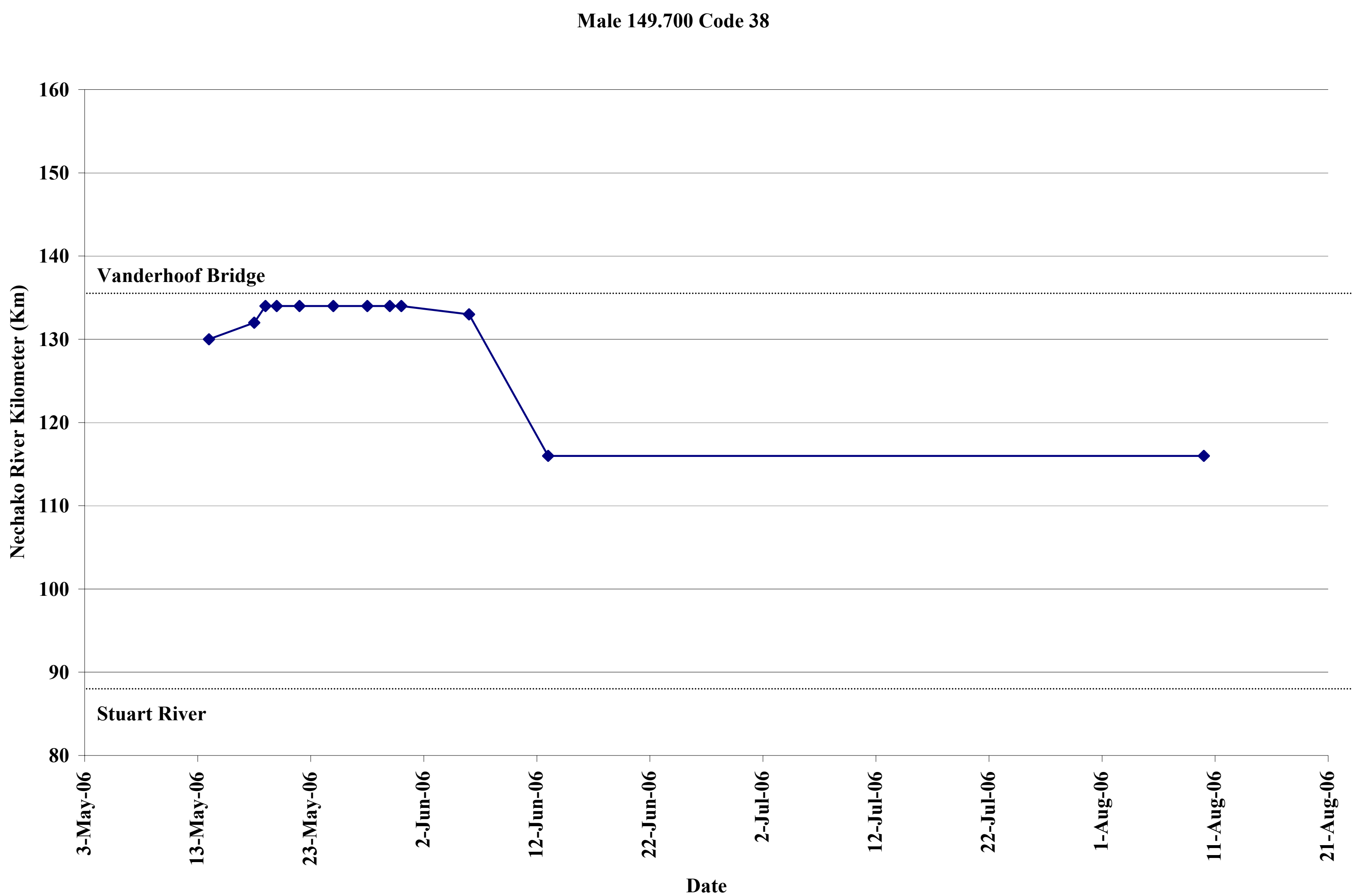

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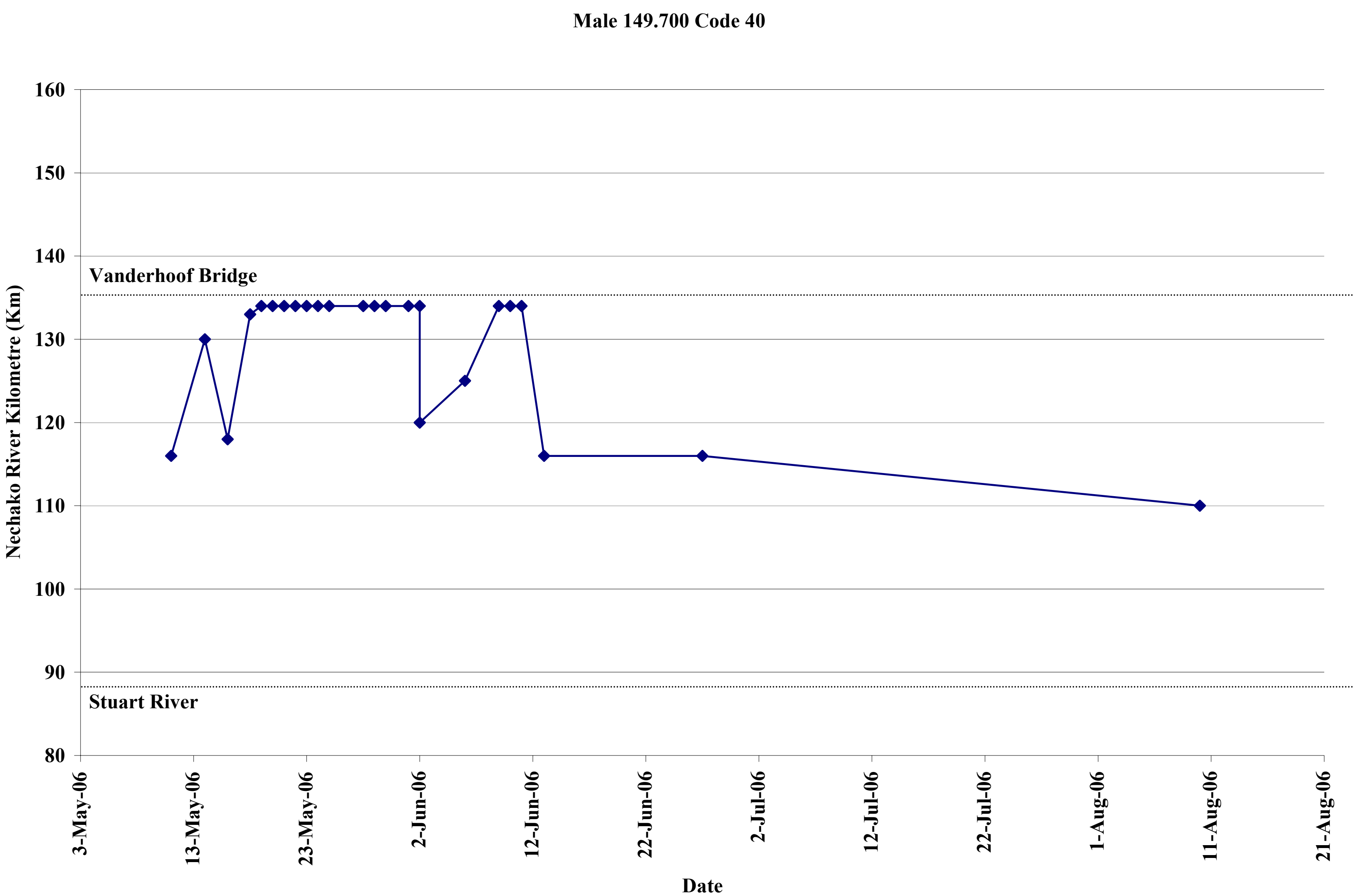

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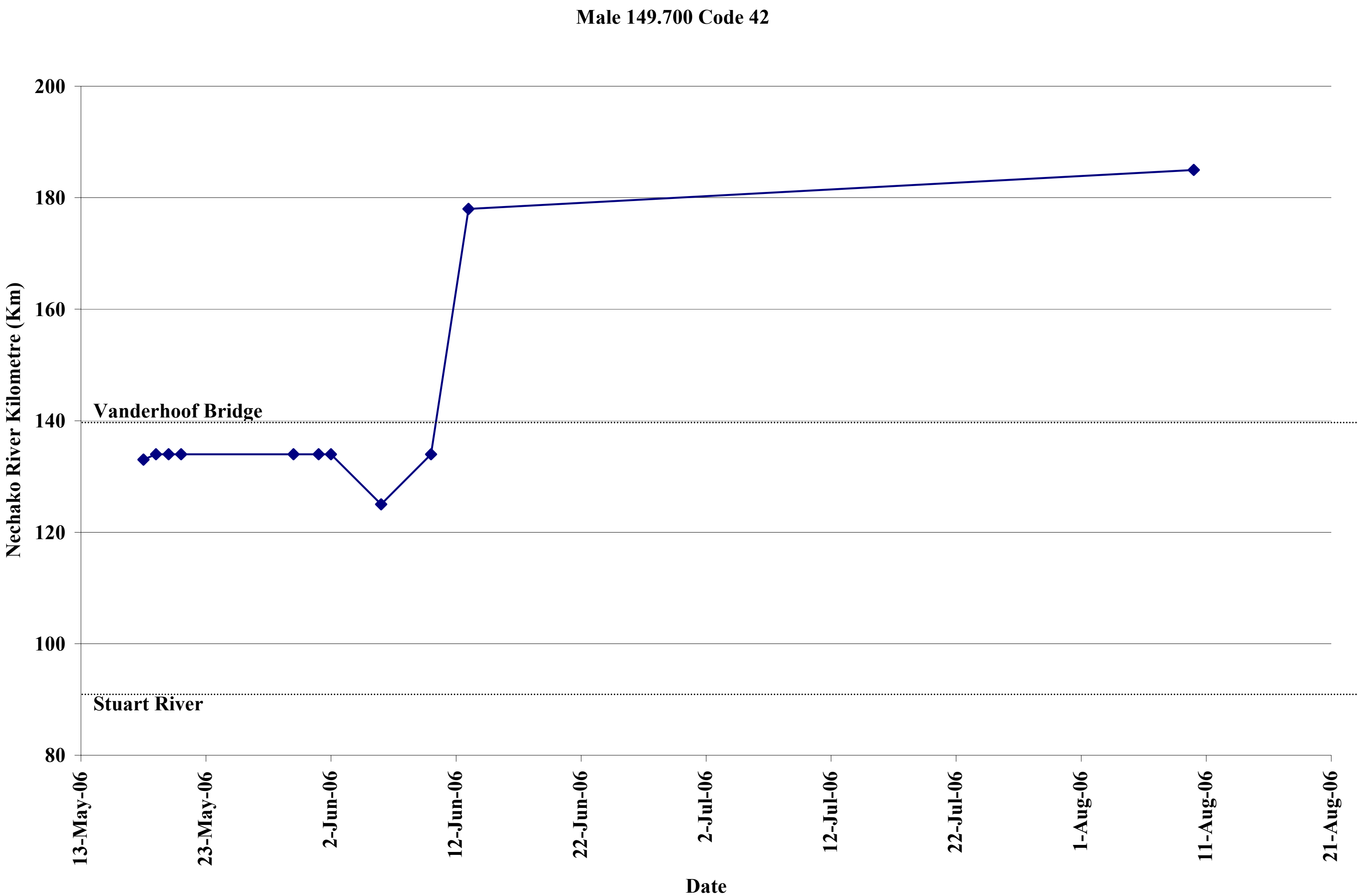

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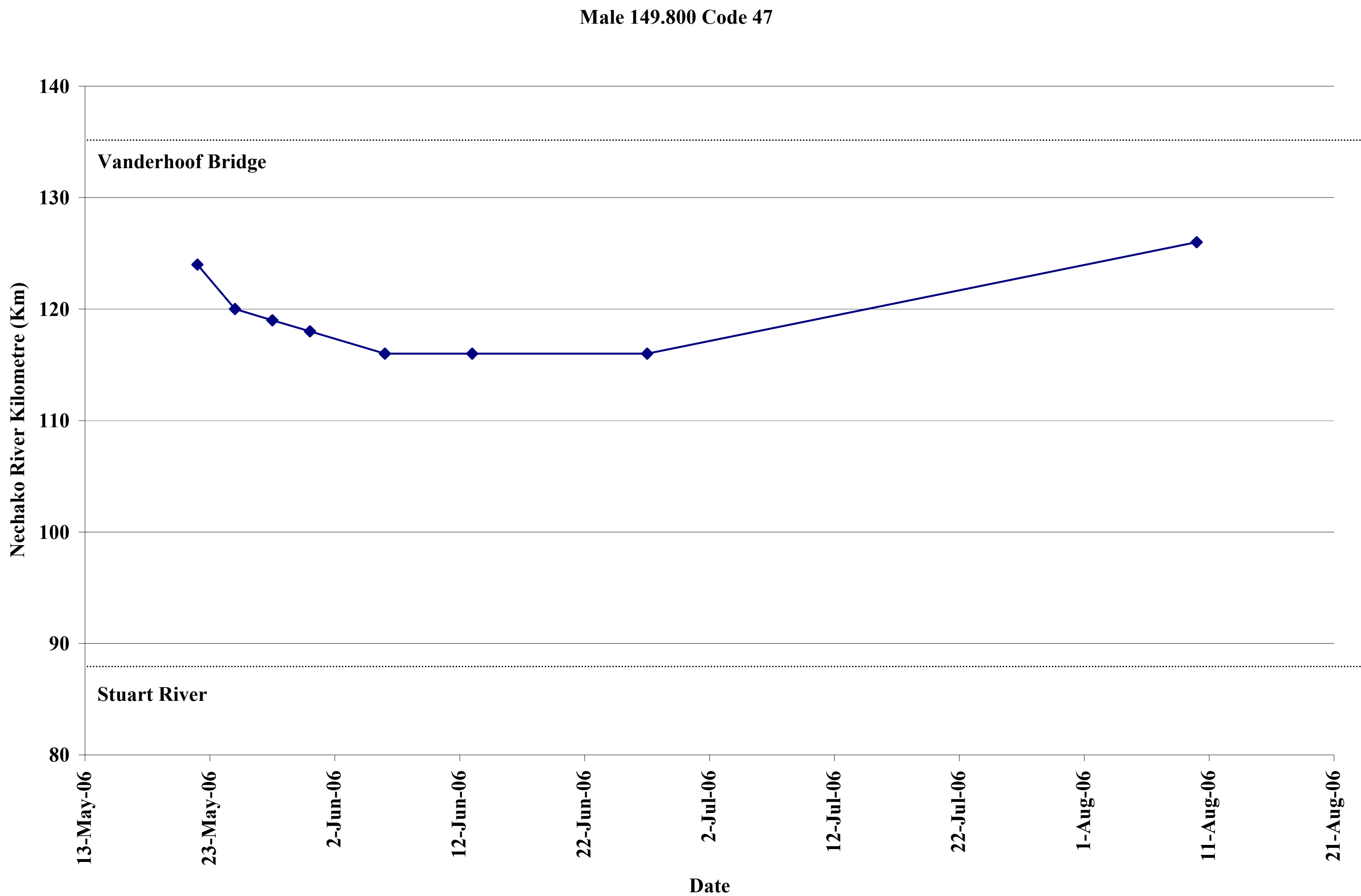

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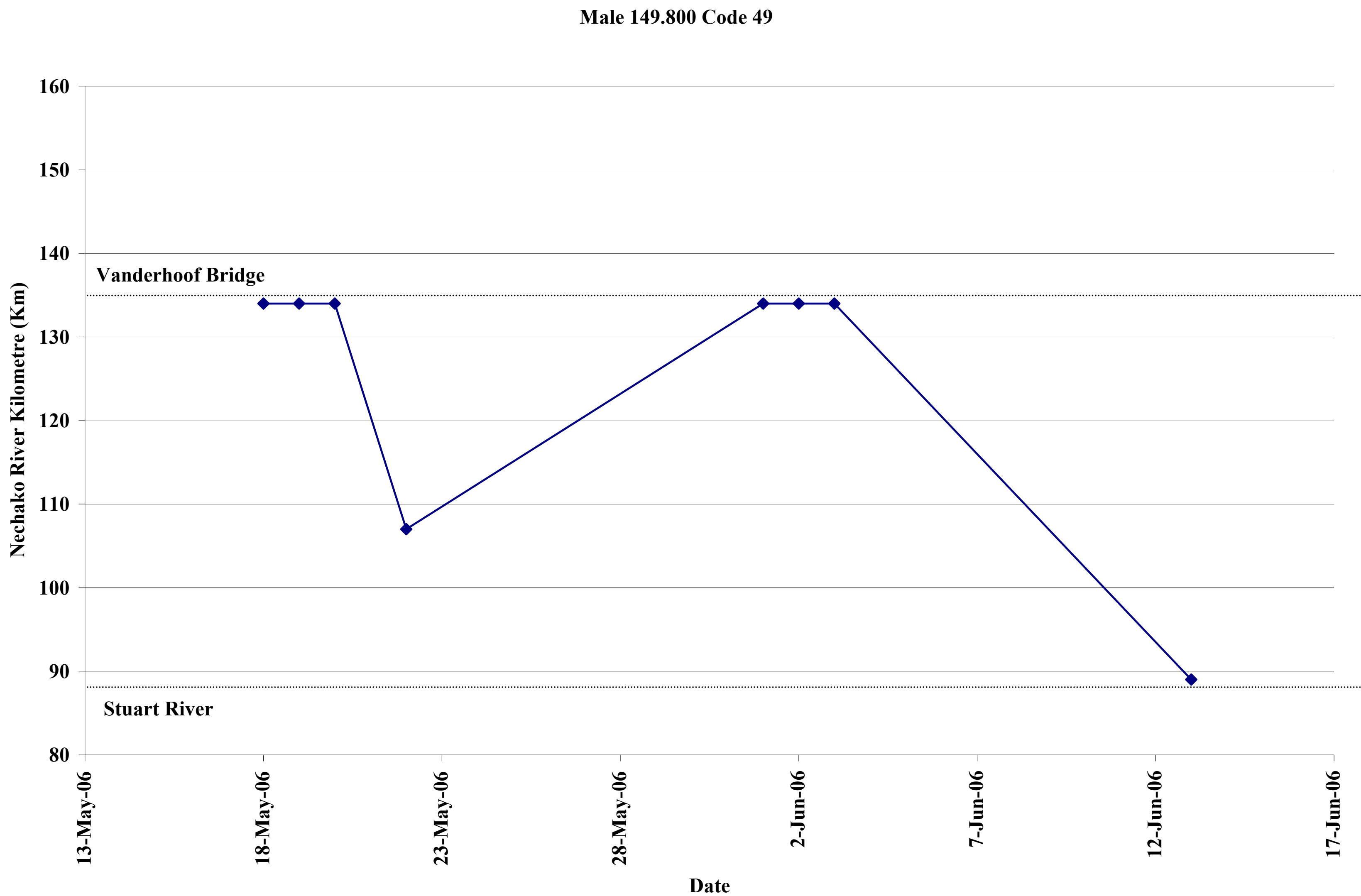

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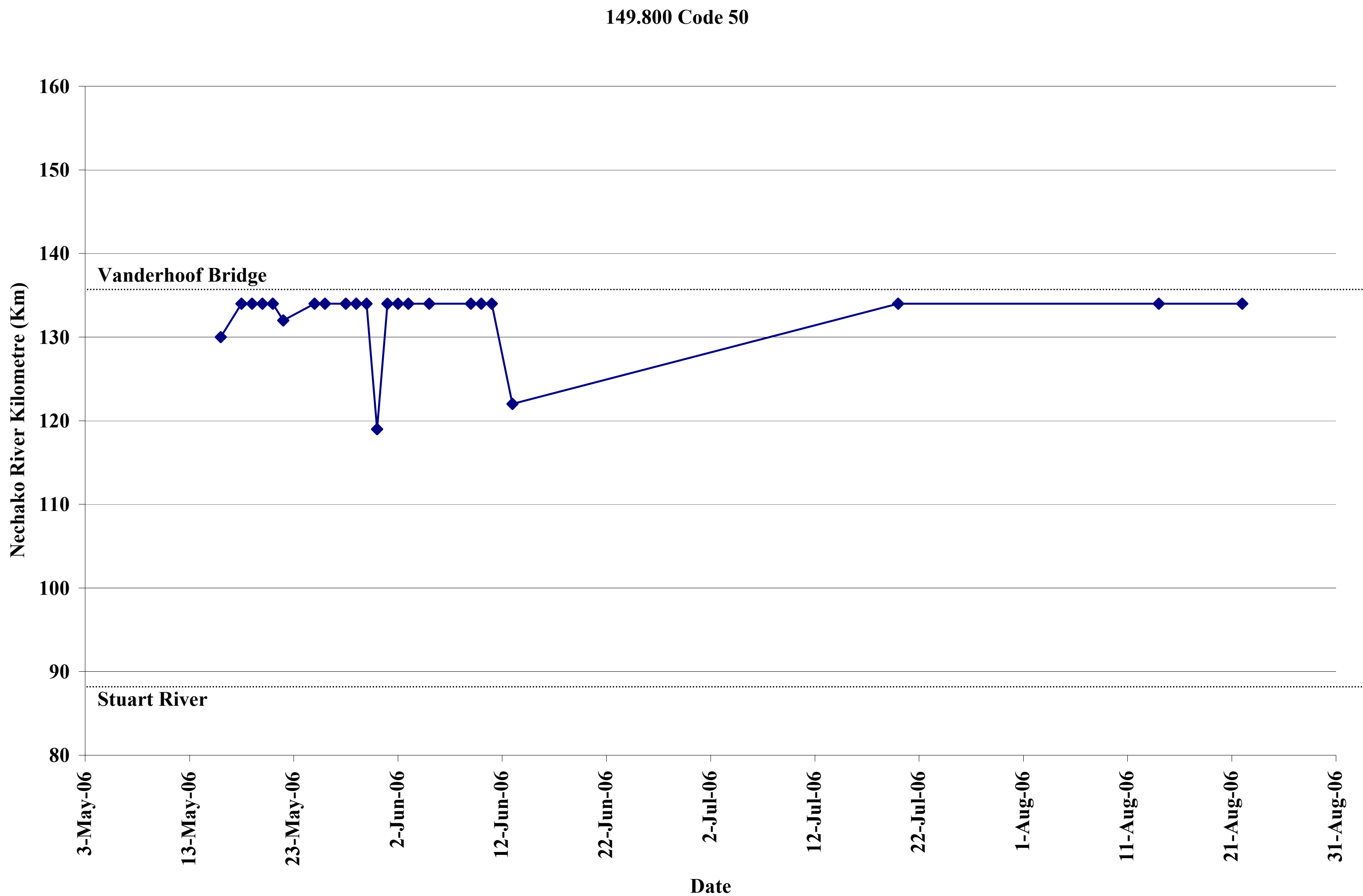

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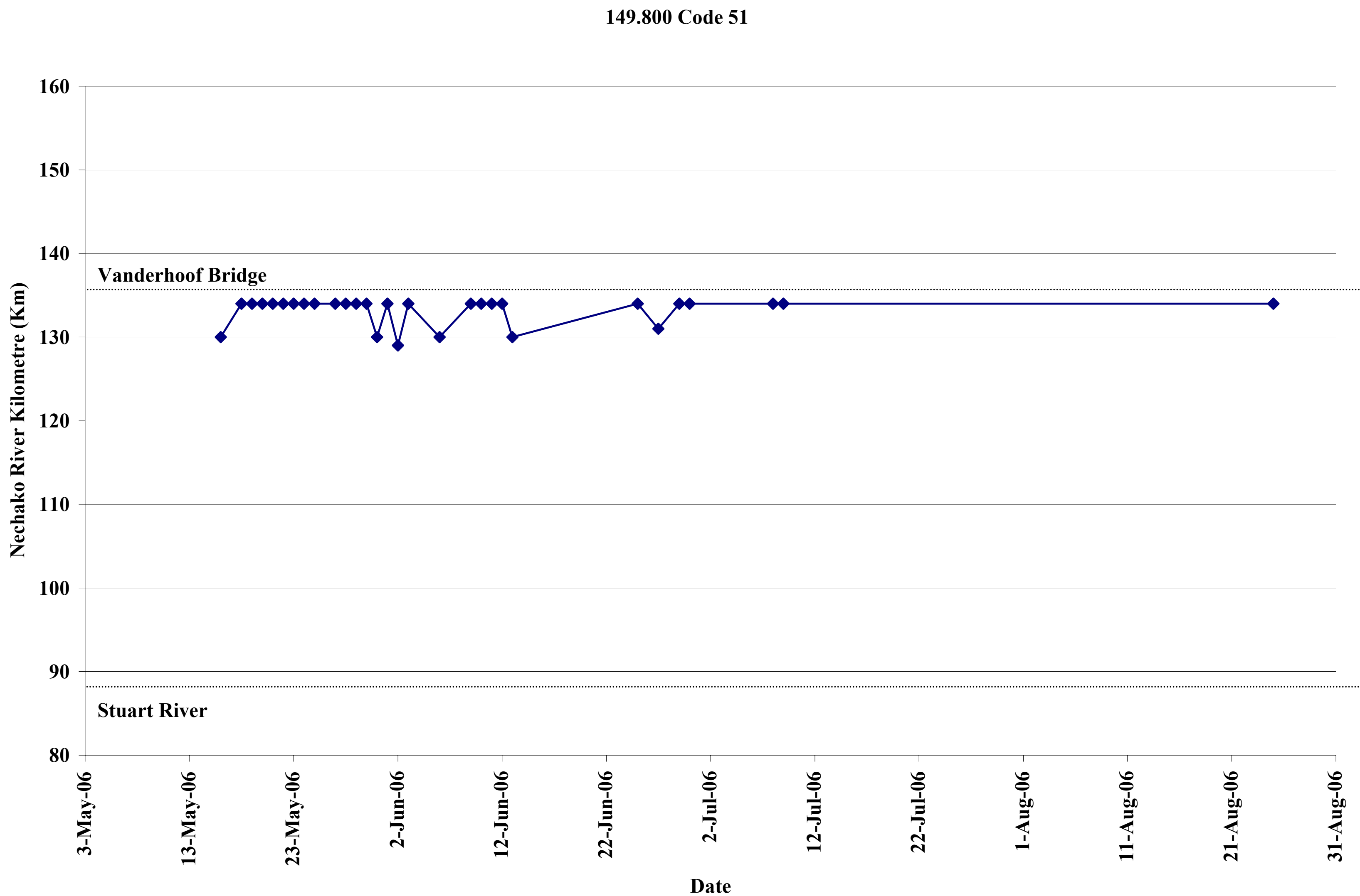

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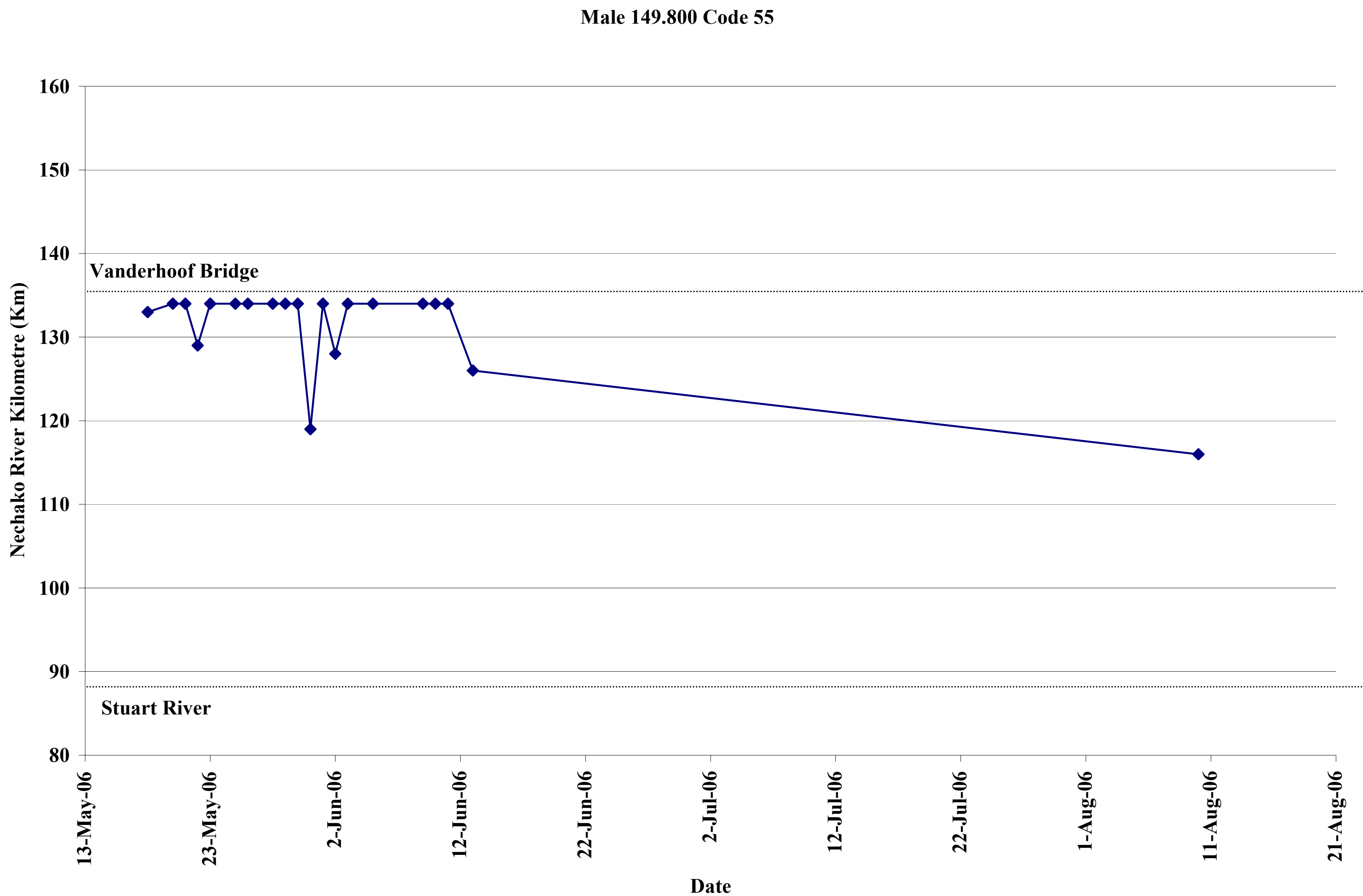

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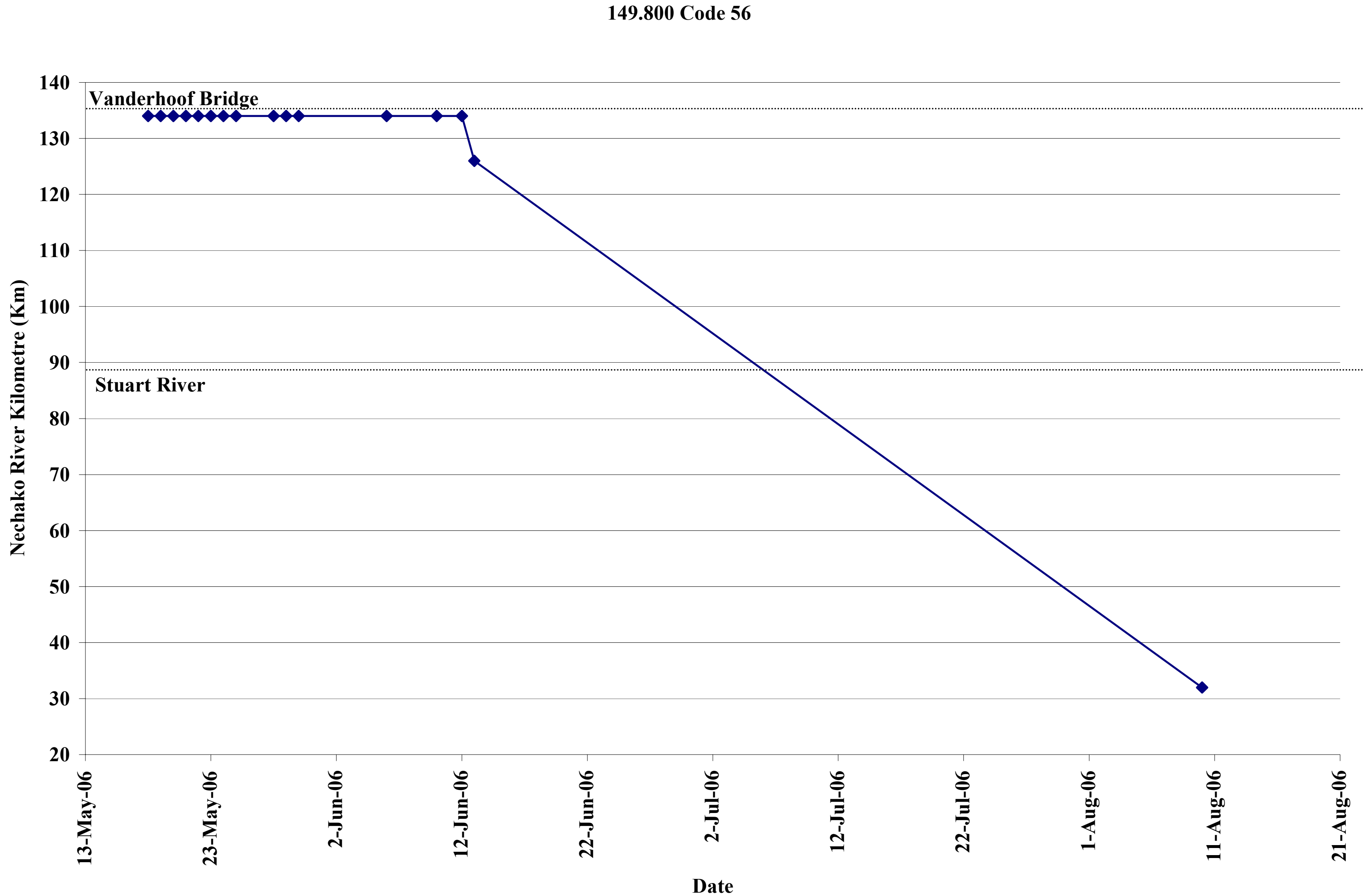

Figure 31. Detailed telemetry data for 149.800 Code 56.

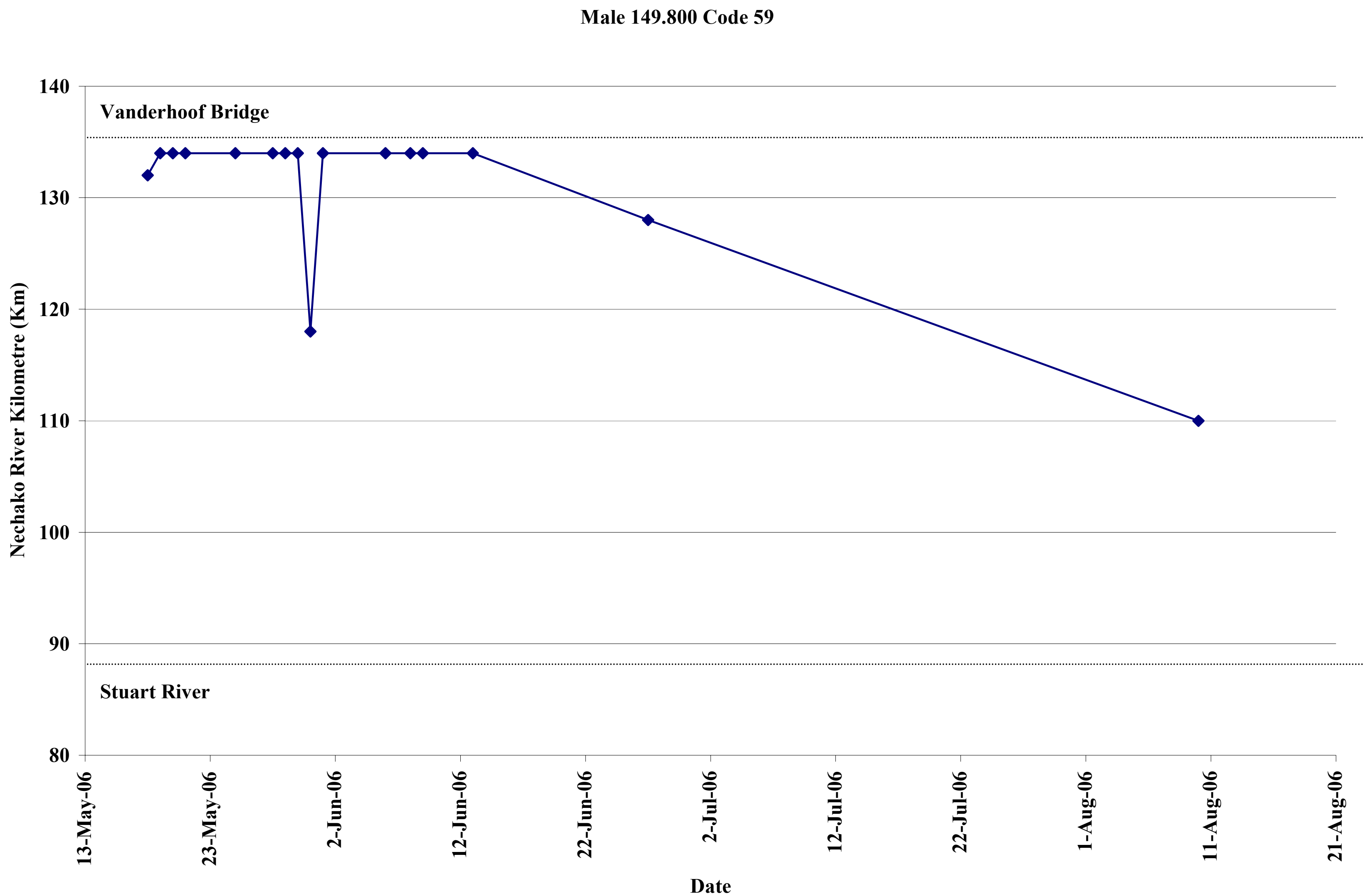

Figure 32. Detailed telemetry data for 149.800 Code 59.

Table 6. Detailed telemetry data from the Vanderhoof bridge base station.

Date	Frequency	Codes-Downstream Antenna	Codes-Upstream Antenna
May 18	149.700	42,40	
	149.800	49, 50, 51, 55, 56	
	148.420	14	
	148.380	1, 4	1 (34 mins)
May 19	149.700	40, 42, 27, 38	
	149.800	49, 50, 51, 56, 59	
	148.380	1, 4	
	148.400	9	
May 20	149.700	38, 40, 27, 42	
	149.800	50, 51, 55, 56, 59, 49	59 (6 mins)
	148.380	1	
	148.400	9	
	148.420	14	
May 21	149.700	27, 40, 42, 36	
	149.800	50, 51, 55, 56, 59	
	148.400	9	
May 22	149.700	27, 40	
	149.800	50, 51, 55, 56	
	148.380	4	
May 23	149.700	40	
	149.800	51, 55, 56	
May 24	148.380	1	
	148.420	14	
	149.700	40	
	149.800	51	
May 25	149.700	41, 33	33
	149.800	50, 55, 56	
	148.420	14	
	148.380	4	
	148.320	2 (?)	
May 26	149.700	41	
	149.800	50, 55	
May 27	148.380	4	
	148.420	14	
	149.800	51	
May 29	148.380	4	
	148.420	14	
May 30	149.700	40	
	149.800	50, 51, 55, 56, 59	51 (6 min)
	148.380	4	
	148.400	9	
	148.420	14	
	149.700	27, 38, 40, 42	
	149.800	50, 51, 55, 56, 59	
June 1	148.380	4	
	149.700	40, 42	
	149.800	49, 50, 51, 55, 59	
June 2	148.380	4	
	148.420	14	
	149.700	40, 42	40 (10 min)
	149.800	49, 50, 51	
June 3	148.380	4	
	149.700	25	
	149.800	49, 50, 51, 55	
June 5	149.800	59, 50, 51, 55	
June 6	149.800	56	
	148.420	14	
June 7	148.420	14	
June 8	149.800	59	59 (23 hrs)
	148.380	4	4
June 9	149.700	40, 33, 27	
	149.800	51, 50, 55, 59	
	148.420	14	
June 10	149.800	50, 51, 55, 56, 59	51 (16min)
	148.420	14	
	149.700	40, 27, 42	
	148.380	4	
June 11	149.700	40	
	149.800	50, 51, 55	
	148.420	14	
	148.380	4	
June 12	149.800	51, 56	
	148.420	14	

Date	Frequency	Codes-Downstream Antenna	Codes-Upstream Antenna
	148.380	2	
June 15	148.420	14	
June 16	148.420	14	
June 24	149.800	46	46 (total of 40min)
June 25	149.800	46, 51	46 (total of 14min)
June 26	149.800	46	46 (13 min)
June 27	149.800	46	
June 28	149.800	46	46 (total of 8 min)
June 29	149.800	46, 51	51 (9 min)
	149.700	25	
June 30	149.800	46, 51	
July 6	149.800	46	
July 7	149.700	25, 26	
	149.800	46	
July 8	149.800	46, 51	
July 9	149.800	51, 46	
	149.700	25	
July 10	149.800	46	
July 12	149.800	46	
	149.700	25	
July 13	149.800	46	
July 14	149.700	26	
July 15	149.700	25, 26	
	149.800	46	
July 16	149.700	25, 26	
	149.800	46	
July 17	149.800	57, 46	57
	149.700	25	
July 18	149.800	46	
	149.700	25	
July 19	149.800	46	
	149.700	27	
July 20	149.800	50, 46	
July 21	149.800	46	
July 22	149.800	46	
July 23	149.800	46, 48	
	149.700	26	
July 24	149.800	46	
	149.700	26	
July 25	149.700	26	
July 26	149.700	26	
July 27	149.700	26	

Date	Frequency	Codes-Downstream Antenna	Codes-Upstream Antenna
	149.800	46	
July 28	149.800	46	
	149.700	26	
July 29	149.800	46	
July 30	149.800	46	46 (3 min)
July 31	149.800	46	
August 1	149.800	46	46 (3 min)
August 2	149.700	25	
August 3	149.700	25	
August 8	149.700	25	
August 9	149.700	25	
August 10	149.700	25	
August 11	149.700	25	
August 12	149.700	25	
August 13	149.700	25	
August 14	149.700	25	
	149.800	50	
August 15	149.700	25	
August 16	149.700	25, 26	
August 17	149.700	26, 25	
August 18	149.700	25	
August 22	149.800	50, 57	
August 25	149.800	51	51
October 3	149.800		57
October 4	149.800		57

Table 7. Detailed telemetry data from the telemetry flights.

Frequency	Code	Sex	May 11	May-14	May-16	May-18th	May 22nd	May-25	May-28	May-31	Jun-02	Jun-06	Jun-13	Jun-27	Aug-10
148.380	2	unknown				120	118	117	118	115		110	124	110	118
148.380	3	F												116	118
148.400	6	F											45	45	111
148.400	9	unknown	132	132	133	123				132			109	110	109
148.400	8	M													41
148.420	12	M											32	49	34
149.480	54	F	124		124	125								125	126
149.440	1	F (brood)											116	124	
149.440	10	F (brood)											110		98
149.700	14	unknown				120	120	122	120	119		118	120	95	108
149.700	15	M													110 (stuart)
149.700	20	M	110		110				110		105	108	109	109	110
149.700	21	M	120	119	120	120			110		110		110	109	130
149.700	22	Unknown					112	110							42 (stuart)
149.700	23	F											72	80	110
149.700	24	M	120	118	120	118		120	118	119				116	
149.700	25	M		130	133.5	132		134					134	133	
149.700	26	F	~158							158	158	158	158	130	160
149.700	27	M		122		130	130	130	134	122	130				116
149.700	28	F	116	120	112										
149.700	29	M		117											
149.700	30	M					105							85	
149.700	31	F		97	97	100		105		105		105	97		103
149.700	32	M												87	90
149.700	33	M						140	150	158	158	~164			
149.700	34	M		112	116					112	110		110		110
149.700	35	F	108	100	105		105								
149.700	36	Unknown		119	120		120	130	120			111	110		
149.700	37	F	90	90	90	90	92	92	92	92			45	45	
149.700	38	M		130		132	134	134	134	134		133	116		116
149.700	39	M											10 (stuart)		
149.700	40	M	116	130	118	133	134	134	134		120	125	116	116	110
149.700	41	M						134				108			
149.700	42	M				133						125	178		185
149.700	43	F													110
149.770	18	unknown	130						100	108					
149.770	26	unknown	120						125	120			120		
149.800	45	M				132							30	30	35
149.800	46	unknown			125		134		134			134	134	134	
149.800	47	M					124	120	119	118		116	116	116	126
149.800	48	M			133					131					
149.800	49	M				134	107				134		89		
149.800	50	M			130		132	134	134	119	134		122		
149.800	51	M			130			134	134	130	129	130	130	131	
149.800	52	M				132		121	122	122		122	120		
149.800	53	F					126		116	116					86
149.800	54	F			130		120	121	119	124	122	123	122		125
149.800	55	M				133	129	134	134	119	128		126		116
149.800	56	'06 tag					134	134	134				126		32
149.800	58	M												90	116
149.800	59	M				132		134	134	118		134	134	128	110

Appendix 3

Field Survey Data

Table 8. Substrate mat (egg mat) details.

Site	Date Set	Set Time	Date Retrieved	Retrieve Time	Length of Set (hours)	Easting	Northing	# of Mats in Group	Total Egg Mat Time (hours)	Total Area Sampled (m^2)	Depth (m)	Near bed velocity (m/s)	# of WSG eggs	CPUE (eggs/hour)	CPUE (eggs/hour/m^2)	Comment
A	18-May	11:00	20-May	15:01	52.0	431100	5985996	4	208.1	2.8	1.8	0.90	0	0.00	0.000	Moved downstream of bridge (renamed site 1)
B	18-May	11:15	20-May	15:10	51.9	431130	5986068	4	207.7	2.8	0.7	1.57	0	0.00	0.000	Moved downstream of bridge (renamed site 2)
C	18-May	11:30	20-May	15:17	51.8	431372	5986068	4	207.1	2.8	1.6	0.95	0	0.00	0.000	Moved downstream of bridge (renamed site 3)
4	18-May	14:32	20-May	16:37	50.1	433787	5986955	4	200.3	2.8	0.8	1.09	0	0.00	0.000	
D	18-May	13:15	20-May	16:09	50.9	432470	5986286	4	203.6	2.8	2	0.86	0	0.00	0.000	Moved upstream of bridge (renamed site 5)
6	18-May	14:30	20-May	16:26	49.9	433378	5986367	4	199.7	2.8	1.4	1.00	0	0.00	0.000	
7	18-May	14:15	20-May	16:25	50.2	432928	5986559	4	200.7	2.8	1.3	0.68	0	0.00	0.000	Sturgeon observed in the vicinity of the site.
8	18-May	13:45	20-May	16:18	50.6	432626	5986981	4	202.2	2.8	0.6	1.04	0	0.00	0.000	
9	18-May	13:30	20-May	16:15	50.8	432449	5986423	4	203.0	2.8	0.9	0.91	0	0.00	0.000	
10	18-May	13:10	20-May	16:04	50.9	432214	5986361	4	203.6	2.8	1.2	0.66	0	0.00	0.000	
11	18-May	12:30	20-May	15:48	51.3	432265	5986163	4	205.2	2.8	1.95	0.88	0	0.00	0.000	
12	18-May	12:15	20-May	15:42	51.5	432068	5986116	4	205.8	2.8	1.2	1.40	0	0.00	0.000	
13	18-May	11:50	20-May	15:28	51.6	431887	5986137	4	206.5	2.8	1.5	0.76	0	0.00	0.000	
14	18-May	12:00	20-May	15:35	51.6	432010	5986283	4	206.3	2.8	1.15	1.16	0	0.00	0.000	
15	18-May	11:40	20-May	15:22	51.7	431665	5986097	4	206.8	2.8	1.6	1.09	0	0.00	0.000	
1	20-May	16:50	23-May	8:33	63.7	434314	5986494	4	254.9	2.8	1.1	0.60	0	0.00	0.000	
2	20-May	16:42	23-May	8:38	63.9	434011	5986896	4	255.7	2.8	1.5	1.07	1	0.00	0.001	Egg collected from the downstream mat.
3	20-May	16:40	23-May	8:45	64.1	433997	4986855	4	256.3	2.8	1.7	0.68	0	0.00	0.000	
4	20-May	16:32	23-May	8:59	64.5	433787	5986955	4	257.8	2.8	0.8	1.09	4	0.02	0.006	Eggs on upstream mat.
5	20-May	16:28	23-May	9:18	64.8	433485	5986837	4	259.3	2.8	1.8	1.04	4	0.02	0.006	
6	20-May	16:27	23-May	9:30	65.1	433378	5986367	4	260.2	2.8	1.4	1.00	13	0.05	0.018	Site in vicinity of Stoney Creek.
7	20-May	16:26	23-May	10:15	65.8	432928	5986559	4	263.3	2.8	1.3	0.68	0	0.00	0.000	

Site	Date Set	Set Time	Date Retrieved	Retrieve Time	Length of Set (hours)	Easting	Northing	# of Mats in Group	Total Egg Mat Time (hours)	Total Area Sampled (m^2)	Depth (m)	Near bed velocity (m/s)	# of WSG eggs	CPUE (eggs/hour)	CPUE (eggs/hour/m^2)	Comment
8	20-May	16:20	23-May	10:21	66.0	432626	5986981	4	264.1	2.8	0.6	1.04	0	0.00	0.000	
9	20-May	16:17	23-May	10:28	66.2	432449	5986423	4	264.7	2.8	0.9	0.91	0	0.00	0.000	
10	20-May	15:57	23-May	10:37	66.7	432214	5986361	4	266.7	2.8	1.2	0.66	0	0.00	0.000	
11	20-May	15:51	23-May	10:42	66.9	432265	5986163	4	267.4	2.8	1.95	0.88	0	0.00	0.000	
12	20-May	15:45	23-May	10:51	67.1	432068	5986116	4	268.4	2.8	1.2	1.40	0	0.00	0.000	
13	20-May	15:30	23-May	10:56	67.4	431887	5986137	4	269.7	2.8	1.5	0.76	0	0.00	0.000	
14	20-May	15:37	23-May	11:05	67.5	432010	5986283	4	269.9	2.8	1.15	1.16	0	0.00	0.000	
15	20-May	15:24	23-May	11:25	68.0	431665	5986097	4	272.1	2.8	1.6	1.09	2	0.01	0.003	
1	23-May	8:36	26-May	15:20	78.7	434314	5986494	4	314.9	2.8	1.1	0.60	0	0.00	0.000	
2	23-May	8:42	26-May	15:27	78.8	434011	5986896	4	315.0	2.8	1.5	1.07	2	0.01	0.002	
3	23-May	8:52	26-May	15:32	78.7	433997	4986855	4	314.7	2.8	1.7	0.68	1	0.00	0.001	
4	23-May	9:10	26-May	15:45	78.6	433787	5986955	4	314.3	2.8	0.8	1.09	2	0.01	0.002	
5	23-May	9:24	26-May	15:50	78.4	433485	5986837	4	313.7	2.8	1.8	1.04	3	0.01	0.003	
6	23-May	9:45	26-May	16:05	78.3	433378	5986367	4	313.3	2.8	1.4	1.00	11	0.04	0.013	
12	23-May	10:54	26-May	16:48	77.9	432068	5986116	4	311.6	2.8	1.2	1.40	0	0.00	0.000	
13	23-May	11:00	26-May	16:37	77.6	431887	5986137	4	310.5	2.8	1.5	0.76	0	0.00	0.000	
14	23-May	11:12	26-May	16:30	77.3	432010	5986283	4	309.2	2.8	1.15	1.16	0	0.00	0.000	
15	23-May	11:30	26-May	16:25	76.9	431665	5986097	4	307.7	2.8	1.6	1.09	0	0.00	0.000	
1	26-May	15:25	30-May	9:30	90.1	434314	5986494	4	360.3	2.8	1.1	0.60	29	0.08	0.029	Eggs captured on downstream mat (2 ruptured).
2	26-May	15:30	30-May	9:50	90.3	434011	5986896	4	361.3	2.8	1.5	1.07	0	0.00	0.000	
3	26-May	15:37	30-May	9:55	90.3	433997	4986855	4	361.2	2.8	1.7	0.68	105	0.29	0.104	42 eggs on downstream mat, 63 eggs on upstream mat.
4	26-May	15:48	30-May	10:17	90.5	433787	5986955	4	361.9	2.8	0.8	1.09	29	0.08	0.029	All eggs on upstream mat.
5	26-May	16:00	30-May	10:20	90.3	433485	5986837	4	361.3	2.8	1.8	1.04	0	0.00	0.000	
6	26-May	16:10	30-May	10:30	90.3	433378	5986367	4	361.3	2.8	1.4	1.00	0	0.00	0.000	
7	23-May	10:17	30-May	10:37	168.3	432928	5986559	4	673.3	2.8	1.3	0.68	0	0.00	0.000	
8	23-May	10:25	30-May	10:44	168.3	432626	5986981	4	673.3	2.8	0.6	1.04	0	0.00	0.000	
9	23-May	10:34	30-May	10:50	168.3	432449	5986423	4	673.1	2.8	0.9	0.91	0	0.00	0.000	
10	23-May	10:40	30-May	11:00	168.3	432214	5986361	4	673.3	2.8	1.2	0.66	0	0.00	0.000	

Site	Date Set	Set Time	Date Retrieved	Retrieve Time	Length of Set (hours)	Easting	Northing	# of Mats in Group	Total Egg Mat Time (hours)	Total Area Sampled (m^2)	Depth (m)	Near bed velocity (m/s)	# of WSG eggs	CPUE (eggs/hour)	CPUE (eggs/hour/m^2)	Comment
11	23-May	10:47	30-May	11:05	168.3	432265	5986163	4	673.2	2.8	1.95	0.88	0	0.00	0.000	
12	26-May	16:52	30-May	11:15	90.4	432068	5986116	4	361.5	2.8	1.2	1.40	0	0.00	0.000	
13	26-May	16:42	30-May	11:18	90.6	431887	5986137	4	362.4	2.8	1.5	0.76	0	0.00	0.000	
14	26-May	16:35	30-May	11:24	90.8	432010	5986283	4	363.3	2.8	1.15	1.16	0	0.00	0.000	
15	26-May	16:29	30-May	11:30	91.0	431665	5986097	4	364.1	2.8	1.6	1.09	0	0.00	0.000	
1	30-May	9:38	06-Jun	9:58	168.3	434314	5986494	4	673.3	2.8	1.1	0.60	0	0.00	0.000	
2	30-May	9:54	06-Jun	10:11	168.3	434011	5986896	4	673.1	2.8	1.5	1.07	0	0.00	0.000	
3	30-May	10:05	06-Jun	10:14	168.2	433997	4986855	4	672.6	2.8	1.7	0.68	0	0.00	0.000	
4	30-May	10:19	06-Jun	10:17	168.0	433787	5986955	4	671.9	2.8	0.8	1.09	0	0.00	0.000	
5	30-May	10:27	06-Jun	10:24	168.0	433485	5986837	4	671.8	2.8	1.8	1.04	0	0.00	0.000	
6	30-May	10:35	06-Jun	11:58	169.4	433378	5986367	4	677.5	2.8	1.4	1.00	1	0.00	0.001	Egg ruptured.
7	30-May	10:42	06-Jun	11:52	169.2	432928	5986559	4	676.7	2.8	1.3	0.68	0	0.00	0.000	
8	30-May	10:49	06-Jun	11:40	168.9	432626	5986981	4	675.4	2.8	0.6	1.04	0	0.00	0.000	
9	30-May	10:58	06-Jun	11:34	168.6	432449	5986423	4	674.4	2.8	0.9	0.91	0	0.00	0.000	
10	30-May	11:04	06-Jun	11:06	168.0	432214	5986361	4	672.1	2.8	1.2	0.66	0	0.00	0.000	
11	30-May	11:11	06-Jun	10:35	167.4	432265	5986163	4	669.6	2.8	1.95	0.88	0	0.00	0.000	
12	30-May	11:17	06-Jun	10:40	167.4	432068	5986116	4	669.5	2.8	1.2	1.40	0	0.00	0.000	
13	30-May	11:23	06-Jun	10:44	167.4	431887	5986137	4	669.4	2.8	1.5	0.76	0	0.00	0.000	
14	30-May	11:28	06-Jun	11:06	167.6	432010	5986283	4	670.5	2.8	1.15	1.16	0	0.00	0.000	
15	30-May	11:37	06-Jun	10:52	167.3	431665	5986097	4	669.0	2.8	1.6	1.09	0	0.00	0.000	

Table 9. Egg tube details.

Site/ Group	Date Set	Set Time	Date Retrieved	Retrieve Time	Length of Set (hours)	Zone	Easting	Northing	# in Group	Total Egg Tube Time (hours)	Total Area Sample (m^2)	Depth (m)	Near bed velocity (m/s)	Number of WSG eggs	CPUE (eggs/hour)
1A	18-May-06	13:00	20-May-06	15:59	51.0	10	432423	5986271	4	203.9	1.2	0.4	0.89	0	0.00
1B	18-May-06	12:45	20-May-06	15:54	51.2	10	432407	5986316	4	204.6	1.2	0.7	0.68	0	0.00
1C	18-May-06	14:01	20-May-06	16:22	50.4	10	432736	5986400	3	151.1	0.9	0.5	1.10	0	0.00
1A	20-May-06	16:02	23-May-06	11:15	67.2	10	432423	5986271	4	268.9	1.2	0.4	0.89	0	0.00
1B	20-May-06	16:07	23-May-06	11:17	67.2	10	432407	5986316	4	268.7	1.2	0.7	0.68	0	0.00
1C	20-May-06	16:24	23-May-06	11:42	67.3	10	432736	5986400	3	201.9	0.9	0.5	1.10	0	0.00
1A	23-May-06	11:18	30-May-06	11:40	168.4	10	432423	5986271	4	673.5	1.2	0.4	0.89	0	0.00
1B	23-May-06	11:20	30-May-06	11:40	168.3	10	432407	5986316	4	673.3	1.2	0.7	0.68	0	0.00
1C	23-May-06	11:47	30-May-06	11:47	168.0	10	432736	5986400	3	504.0	0.9	0.5	1.10	0	0.00
1A	30-May-06	11:43	06-Jun-06	10:50	167.1	10	432423	5986271	4	668.5	1.2	0.4	0.89	0	0.00
1B	30-May-06	11:43	06-Jun-06	10:50	167.1	10	432407	5986316	4	668.5	1.2	0.7	0.68	0	0.00
1C	30-May-06	11:53	06-Jun-06	11:40	167.8	10	432736	5986400	3	503.4	0.9	0.5	1.10	0	0.00

Table 10. Detailed habitat transects. Velocities measured as follows: depths < 1.0 m @ 40%, and depths > 1.0 m @ 20% of depth. Measurements taken on May 26, 2006 (discharge of 114 m^3/sec).

Transect 1

Location: Upstream of Stoney Creek — **Secchi depth (m):** 1.0

UTM: 433233E 5986259N — **Channel Width (m):** 70

			Substrates (%)				
Station #	**Depth (m)**	**Velocity (m/s)**	**Fines**	**Gravel**	**Cobble**	**Boulder**	**Riprap**
1 (2 m from RM)	1.4	0.03	60	0	0	0	40
2	1.5	0.57	60	0	0	0	40
3	1.4	0.70	40	60	0	0	0
4	1.2	0.79	40	60	0	0	0
5	1.2	1.03	40	60	0	0	0
6	0.8	1.35	20	80	0	0	0
7	0.8	1.09	20	80	0	0	0
8 (5 m from LM)	0.5	1.03	20	80	0	0	0

Transect 2

Location: Downstream of Stoney Creek — **Secchi Depth (m):** 0.9

UTM: 433346E 5986320N

			Substrates (%)				
Station #	**Depth (m)**	**Velocity (m/s)**	**Fines**	**Gravel**	**Cobble**	**Boulder**	**Riprap**
1 (2 m from RM)	1.0	0.34	0	0	0	0	100
2	1.5	1.52	40	60	0	0	0
3	1.7	1.07	20	80	0	0	0
4	1.3	1.16	20	80	0	0	0
5	0.8	1.16	30	70	0	0	0
6	0.7	0.79	30	70	0	0	0
7	0.2	0.40	60	40	0	0	0
8	0.6	0.78	40	60	0	0	0
9 (3 m from LM)	0.5	0.77	40	60	0	0	0

Transect 3

Location: Downstream of Stoney Creek — **Secchi Depth (m):** 0.9

UTM: 433468E 5986464N

			Substrates (%)				
Station #	**Depth (m)**	**Velocity (m/s)**	**Fines**	**Gravel**	**Cobble**	**Boulder**	**Riprap**
1 (2 m from RM)	0.9	0.10	20	0	0	0	80
2	2.0	0.34	100	0	0	0	0
3	1.4	0.89	30	70	0	0	0
4	1.0	0.85	30	70	0	0	0
5	0.9	0.82	30	70	0	0	0
6	0.7	0.82	40	60	0	0	0
7	0.9	0.68	40	60	0	0	0
8 (2 m from LM)	1.1	0.52	90	10	0	0	0

Comment: Fines dominant for 20 m from left bank. Gravels are all small in diameter (< 2 cm).

Transect 4

Location: Downstream of Stoney Creek from the gravel bar to mid-channel island.

UTM: 433447E 5986727N **Secchi depth (m):** 1.0

			Substrates (%)				
Station #	**Depth (m)**	**Velocity (m/s)**	**Fines**	**Gravel**	**Cobble**	**Boulder**	**Riprap**
1 (50 m from RM)	0.3	0.59	20	80	0	0	0
2	0.8	0.97	20	80	0	0	0
3	1.4	1.05	20	80	0	0	0
4	1.7	1.42	20	80	0	0	0
5	2.0	0.97	20	80	0	0	0
6	2.0	0.86	20	80	0	0	0
7 (3 m from island)	1.2	1.07	20	80	0	0	0
8 (side channel)	0.6	0.60	100	0	0	0	0

Comment: Slow section on right bank not measured. Transect starts 50 m from shore. Most gravel < 1 cm in diameter.

Transect 5

Location: Upstream of the bridge, at observation tower.

UTM: 433588E 5986850N **Channel Width (m):** 120

			Substrates (%)				
Station #	**Depth (m)**	**Velocity (m/s)**	**Fines**	**Gravel**	**Cobble**	**Boulder**	**Riprap**
1 (2 m from RM)	0.4	0.33	30	70	0	0	0
2	0.8	0.39	30	70	0	0	0
3	0.7	0.86	30	70	0	0	0
4	0.8	0.87	30	70	0	0	0
5 (directly d/s of egg mat)	1.5	1.37	20	80	0	0	0
6	1.3	0.72	20	80	0	0	0
7	0.6	0.06*	20	80	0	0	0
8	0.5	0.56	90	10	0	0	0
9 (25 m from LM)	0.4	0.49	100	0	0	0	0

* station located downstream of a gravel bar.

Transect 6

Location: Upstream of bridge.

UTM: 433777E 5986888N

			Substrates (%)				
Station #	**Depth (m)**	**Velocity (m/s)**	**Fines**	**Gravel**	**Cobble**	**Boulder**	**Riprap**
1 (10 m from RM)	1.1	0.73	30	70	0	0	0
2	0.8	0.91	40	60	0	0	0
3	0.8	0.87	40	60	0	0	0
4	0.9	0.91	40	60	0	0	0
5 (30 m LM at egg mat location)	1.0	0.88	40	60	0	0	0
6 (18 m from LM)	2.0	0.99	40	60	0	0	0
7 (3 m from LM)	1.5	1.05	40	60	0	0	0

Comment: Substrates all small gravels < 1 cm in diameter.

Transect 7

Location: Downstream of bridge at egg mat location.

UTM: 432927E 5986363N **Secchi depth (m):** 1.0

			Substrates (%)				
Station #	**Depth (m)**	**Velocity (m/s)**	**Fines**	**Gravel**	**Cobble**	**Boulder**	**Riprap**
1 (25 m from RM)	1.0	1.03	70	30	0	0	0
2	1.0	1.07	60	40	0	0	0
3	1.7	0.90	40	60	0	0	0
4	1.7	0.98	40	60	0	0	0
5 (30 m from LM)	1.9	1.00	30	70	0	0	0
6	2.0	0.77	30	70	0	0	0
7 (8 m from LM)	1.2	0.81	30	70	0	0	0

Transect 8

Location: Downstream of bridge at 2nd set of egg mats

UTM: 434197E 5986608N

			Substrates (%)				
Station #	**Depth (m)**	**Velocity (m/s)**	**Fines**	**Gravel**	**Cobble**	**Boulder**	**Riprap**
1 (15 m from RM)	0.8	0.56	80	20	0	0	0
2	1.3	0.71	40	60	0	0	0
3	1.1	0.65	40	60	0	0	0
4	1.6	0.89	40	60	0	0	0
5	1.6	0.68	40	60	0	0	0
6	1.2	0.62	40	60	0	0	0
7 (10 m from LM)	1.0	0.57	80	20	0	0	0
8 (2 m from LM)	0.5	0.35	80	20	0	0	0

Transect 9

Location: Downstream of bridge at 3rd set of egg mats.

UTM: 434197E 5986608N

			Substrates (%)				
Station #	**Depth (m)**	**Velocity (m/s)**	**Fines**	**Gravel**	**Cobble**	**Boulder**	**Riprap**
1 (15 m from RM island)	0.6	0.31	100	0	0	0	0
2	1.9	0.75	40	60	0	0	0
3	1.4	0.98	40	60	0	0	0
4	1.2	0.85	40	60	0	0	0
5	1.3	0.63	40	60	0	0	0
6	1.2	0.63	40	60	0	0	0
7 (4 m from LM)	0.8	0.29	60	40	0	0	0

Appendix 4

Photograph Plates

Plate 1. Examining an egg mat for sturgeon eggs.

Plate 2. One sturgeon egg captured on the coarse material of an egg mat.

Plate 3. One of two observation towers installed to assess the usefulness of the technique.

Plate 4. View from one of two observation towers installed to assess the usefulness of the technique (no polarization filter was used).