Columbia River Project Water Use Plan

Lower Columbia River Fish Management Plan

Lower Columbia River Rainbow Trout Spawning Habitat Assessment

Implementation Year 10

Reference: CLBMON-46

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Study Period: January to July 2017

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LOWER COLUMBIA RIVER RAINBOW TROUT SPAWNING ASSESSMENT 2017

WLR Monitoring Study No. CLBMON-46 (Year 10)

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Cover Photos: A pair of Rainbow Trout spawners constructing a redd in the Lower Kootenay River; Photo © David DeRosa. Rainbow Trout eggs and Rainbow Trout alevin salvaged from dewatered redds in the Lower Columbia River; Photo © Jeremy Baxter.

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EXECUTIVE SUMMARY

Thousands of Rainbow Trout (*Oncorhynchus mykiss*) spawn each spring in the Lower Columbia River (LCR) below Hugh L. Keenleyside Dam (HLK), and in the Lower Kootenay River (LKR) below Brilliant Dam. The monitoring of Rainbow Trout spawning in the study area began in 1999. The current ten-year study program, which aimed to better understand the links between the spring flow regime of the Rainbow Trout Spawning Protection Flows (RTSPF) and the abundance and trends of the ecologically and recreationally important Rainbow Trout population, commenced in 2008 and this is its final year. The Rainbow Trout redds have the potential to be dewatered by flow reductions. To mitigate, BC Hydro has implemented RTSPF from April 1-June 30 since 1992.

The primary purpose of the program was to monitor the status of the Rainbow Trout population to better understand the link between flow management strategy and population abundance (BC Hydro 2007). The first two management questions asked whether RTSPF over the course of the monitoring period (2008-2017) led to an increase in the relative abundance or spatial distribution of spawners, respectively. Although the first two questions can be tested statistically, as RTSPF have been implemented every year since 1992 and no experimental manipulations have been completed to test the impact of flows, there is no scientific reason to attribute any abundance or distributional changes between 2008 and 2017 to RTSPFs (Baxter and Thorley 2010). The third and final management question asked whether RTSPFs protected the majority of redds over the past ten years. The answer is yes: RTSPFs in conjunction with exclusion fencing at Genelle protect on average over 99% of the redds from dewatering.

As stated by Thorley and Baxter (2011) *"… in order to achieve the primary purpose of the program as stated in the TOR, it is necessary to model the population's response to alternative discharge regimes. One approach is to combine habitat suitability curves with substrate maps, 2D models of depths and velocities and a stock-recruitment relationship to predict the consequences of alternative flow scenarios for the population. Alternatively, it might be possible to determine the relationship between discharge and abundance through experimental manipulations of the discharge regime and ongoing monitoring of the population. Ultimately these two approaches are complementary rather than exclusive and the optimal strategy might be to use experimental manipulations to resolve key uncertainties in the Habitat Suitability Stock-Recruitment (HSSR) model."*

To date a stock-recruitment (SR) relationship has been fitted to the spawner abundance estimates and the estimates of age-1 Rainbow Trout abundance from the Lower Columbia River Indexing program. The SR relationship suggests that a stock of 1,500 spawners is required to maximize the number of age-1 recruits if dewatering rates are very low. Surprisingly, there is a significant positive correlation between the number of age-1 recruits and the percentage of dewatered redds. The fact that the relationship is positive implies that the conditions which lead to higher rates of dewatering are coincident with conditions that benefit young Rainbow Trout.

The current knowledge relative to the management questions and null hypotheses of CLBMON-46 is summarized in the table below.

Objectives	Management Questions and Hypotheses	Year 10 (2017) Status
Assess changes in the relative abundance, distribution and spawn timing of Rainbow Trout in the lower Columbia River.	1. Does the implementation of RTSPF over the course of the monitoring period lead to an increase in the relative abundance of Rainbow Trout spawning in the LCR downstream of HLK?	The number of Rainbow Trout spawners has roughly doubled since 2008. RTSPF may be responsible for this increase but no flow changes have occurred over the period of study to allow causal mechanisms to be tested.
	2. Does the implementation of RTSPF over the course of the monitoring period lead to an increase in the spatial distribution of locations (and associated habitat area) that Rainbow Trout use for spawning in the LCR downstream of HLK?	The spatial distribution of Rainbow Trout spawning was significantly higher in 2008-2017 than in 1999-2007. RTSPF may be responsible for this increase but no flow changes have occurred over the period of study to allow causal mechanisms to be tested.
	3. Does the implementation of RTSPF over the course of the monitoring period protect the majority of Rainbow Trout redds (as estimated from spawning timing) from being dewatered in the LCR downstream of HLK?	Yes. RTSPF (in conjunction with exclusion fencing at Genelle Channel E) have protected on average over 99% of the redds from dewatering. The dewatering rate was estimated to be 50-75% in shallow water habitat on Norn's Fan in 1990 and 1991 prior to implementation of RTSPF.

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ABBREVIATIONS

Abbreviations used throughout the report:

Abbreviation	Full Name
2D	Two Dimensional
ALH	Arrow Lakes Hydro
ALR	Arrow Lakes Reservoir
AUC	Area-Under-the-Curve
BCH	BC Hydro
BRX	Brilliant Expansion Project
BIR	Birchbank Gauging Station
BRD	Brilliant Dam
CI	Credibility Interval
HLK	Hugh L. Keenleyside Dam
HSSR	Habitat Suitability Stock Recruitment
KHz	Kilohertz Frequency
LCR	Lower Columbia River
LDR	Lower Duncan River
LKR	Lower Kootenay River
MAF	Million Acre Feet
MFLNRO	Ministry of Forest Lands & Natural Resource Operations
PIT	Passive Integrated Transponder
RTSPF	Rainbow Trout Spawning Protection Flows
SR	Stock Recruitment
TOR	Terms of Reference
UAV	Unmanned Air Vehicle
WLR	Water Licence Requirements
WUP	Water Use Plan

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1.0 INTRODUCTION

The Rainbow Trout (*Oncorhynchus mykiss*) population in the Lower Columbia River (LCR) between Hugh L. Keenleyside (HLK) dam and the U.S. border and in the Lower Kootenay River (LKR) below Brilliant Dam (BRD) has been studied extensively since the early 1990s. Studies have focused on the assessment of effects of hydro-electric dam operations on various life history parameters, genetics, spawn timing, habitat use, and population trends and dynamics. (Heaton and Hildebrand 1997a, 1997b, Arndt 2000, Taylor 2002, Arndt and Klassen 2004, Ford and Hildebrand 2007, Baxter 2011a). A brief summary of the previous studies on the Rainbow Trout in this section of the Columbia River can be found in Irvine et al. (2014).

Prior to 1992, HLK discharge typically decreased from March to May resulting in Rainbow Trout redd dewatering and potential population level effects (Hildebrand and McKenzie 1995, Thorley and Baxter 2011). BC Hydro therefore altered the spring HLK operations to keep river levels stable or increasing from April 1 to June 30 and agreed to consult with the government agencies regarding the timing and ramp down method from the Mountain Whitefish protection flows to Rainbow Trout protection flows at the beginning of April (BC Hydro 2005, Ford et al. 2008). The Rainbow Trout Spawning Protection Flows (RTSPF) have occurred annually since 1992 (BC Hydro 2007) and have been effective at significantly reducing the cumulative elevational drops in the Lower Columbia River (Larratt et al. 2013).

Various programs have monitored Rainbow Trout redds in shallow water areas since 1992 to identify redds at risk of dewatering. From 1999-2012, dewatered redds were excavated as a matter of course after each major flow reduction and the salvaged eggs were transferred to suitable, wetted gravels to minimize egg mortality (Baxter 2010a, 2010b, 2011a). Since 2013, the regulatory agencies have granted BC Hydro permission to dewater up to 111 redds, or 1% of the then estimated annual redd abundance (1999-2011), before commencing salvage. From 2013 onwards the number of dewatered redds has not exceeded the 1% threshold. Prior to the implementation of protection flows stranding was not well defined. The only data from pre-RTSPF flows where the stranding was estimated, found stranding rates of 50-75% in shallow water habitat on Norn's Fan in 1990 and 1991 (Hildebrand and McKenzie 1995, Irvine et al. 2014). The average redd dewatering rate over all years of protection flow data (1999-2017) was 0.7%.

The primary objective of the present program was to monitor the status of the Rainbow Trout population in order to better understand the link between flow management strategy and population abundance and to propose and monitor testing of other flow strategies (BC Hydro 2007). It is important to consider alternatives to the established format of the RTSPF flow strategy as its implementation requires ~1 million acre-feet of retained storage in Arrow Lakes Reservoir (ALR) that is released in summer. Minimizing the volume of water stored in ALR, delaying the onset of storage and quickly releasing the additional storage could improve vegetation survival and increase littoral productivity and wildlife habitat (BC Hydro 2007).

Spawner assessments have occurred every year since 1999. This program annually recorded spawning activity in order to address the primary objectives of the 10 year study which was "- *to* *continue the collection of annual Rainbow Trout monitoring data to qualitatively and quantitatively assess changes in the relative abundance, distribution and spawn timing of Rainbow Trout in the lower Columbia River*" (BC Hydro 2007 p.3) and to address the specific management questions outlined below.

The following management questions are the focus of the LCR Rainbow Trout spawning assessment program:

1) Does the implementation of RTSPF over the course of the monitoring period lead to an increase in the relative abundance of Rainbow Trout spawning in the LCR downstream of HLK?
2) Does the implementation of RTSPF over the course of the monitoring period lead to an increase in the spatial distribution of locations (and associated habitat area) that Rainbow Trout use for spawning in the LCR downstream of HLK?
3) Does the implementation of RTSPF over the course of the monitoring period protect the majority of Rainbow Trout redds (as estimated from spawning timing) from being dewatered in the LCR downstream of HLK?

The TOR state that these three management questions will be answered by testing three key hypotheses:

H_{01}: The relative abundance of Rainbow Trout spawners or redds in the Columbia River mainstem does not increase between the baseline period (1999 to 2006) and the WUP monitoring period associated with the continued implementation of RTSPF.

H_{02}: The spatial distribution of locations and the associated habitat area that Rainbow Trout spawners use in the Columbia River mainstem does not increase between the baseline period (1999 to 2006) and the WUP monitoring period associated with the continued implementation of the RTSPF.

H_{03}: The proportion of redds dewatered relative to the total redd production for Rainbow Trout spawning in the Columbia River mainstem does not increase between the baseline period (1999 to 2006) and the WUP monitoring period associated with the continued implementation of the RTSPF.

In order to achieve the program's primary objective, the population's response to alternative discharge regimes needs to be understood. The possibility of experimentally manipulating the flows were discussed in 2012 (Baxter 2012), but to date the hydrograph has remained relatively constant between years.

2017 is the final year of the current WLR monitoring program assessing the population of Rainbow Trout in the LCR and LKR. As such this report presents an overview of approaches and results to date including the final year's surveys and analyses. It also provides recommendations for addressing the remaining unknowns about the Rainbow trout in the LCR and LKR.

2.0 METHODS

2.1 Mainstem Spawner and Redd Surveys

The mainstem portions of the Canadian LCR below HLK and the LKR below BRD (Figure 1) have been surveyed from helicopter approximately once a week during the Rainbow Trout spawning season since 1999 and the numbers of redds and spawners recorded by location. Prior to commencing helicopter surveys, boat surveys are done to ensure spawning has begun.

The major gravel areas on the LCR and in the LKR are known by name and river kilometre, and all areas are surveyed during the flights. In the last four years (since 2014), the section of river with the lowest density of spawners (from Genelle to the U.S. border) was not surveyed in order to save flight budget. Because of minimal numbers of spawners and redds in this section of river in all years of survey, this section was excluded from all analyses. The helicopter surveys are supplemented by the use of boat surveys, which cover the main spawning areas from Norn's Creek Fan to the lower island at Genelle. The boat surveys allow the identification of redds that are questionable from the air, noting redds in less than 1.0 m of water to monitor the risk of dewatering and confirming possible new spawning areas seen from the air (Baxter 2011a).

In 2017, eight aerial surveys were completed in a single-engine helicopter and each aerial survey to count redds was followed by a boat survey (Table 1). As in previous surveys the spawners and redds were enumerated by two experienced observers situated on the same side of the helicopter with one person responsible for counting redds and the other for counting spawners. The consistency of pilot and viewers is helpful for a project assessing trends through time as it minimizes observer error and inter-annual variation. Boat surveys were conducted to assess the onset of spawning on February 1, 24 and March 3. Boat surveys to assess dewatering potential and enumerate any dewatered redds were done on February 24, March 3, March 10, March 30 and March 31 (Table 1). The visibility was noted as good in all sections for all aerial surveys in 2017.

Table 1. Helicopter and boat-based spawning, redd and dewatering surveys for 2017.

Date	*Survey Type(s)*
February 1	Spawner assessment boat survey
February 24	Spawner assessment boat survey, Dewatering survey
March 3	Spawner assessment boat survey, Dewatering survey
March 10	Helicopter survey, Boat survey, Dewatering survey
March 16	Helicopter survey, Boat survey
March 30	Helicopter survey, Boat survey, Dewatering survey
March 31	Dewatering survey
April 8	Helicopter survey, Boat survey
April 11	Helicopter survey, Boat survey
April 19	Helicopter survey, Boat survey
April 28	Helicopter survey, Boat survey
May 4	Helicopter survey, Boat survey

2.2 Norn's Creek Spawner and Redd Surveys

Spawner and redd surveys are conducted in Norn's Creek when time, resources and conditions permit as the area provides significant spawning habitat. Surveys were completed in 2017 on April 28 with two swimmers and one bank walker. Surveys commenced at 0930h and were completed by 1100h. This is the first time that this survey has been completed since 2014 and followed field methods detailed in Thorley and Baxter (2012). As per previous analyses, the peak spawner counts from 1999 onwards were multiplied by an expansion factor of two based on the work of Arndt (2000) to get the estimated spawner abundance. Prior to 1999, mark recapture studies were done to determine spawner abundance estimates. The spawner and redd counts from Norn's Creek are not added to the Columbia River and Kootenay River aerial count totals because they are not conducted every year.

2.3 Redd Dewatering Surveys

Locations of shallow water redds with the potential to dewater were recorded by crews during 2017 boat surveys. A standard protocol was followed when an operational reduction was predicted by BC Hydro operations. This involved carrying out surveys in several locations with shallow water habitats that were vulnerable to dewatering and marking redds in < 1m of water. The survey was completed by returning to the site after the operational reduction to determine how many redds were exposed by the drop (**Error! Reference source not found.**). The only exception to this was in 2014 and 2015 when the surveys were conducted by BC Hydro. Depending on the river stage, exclusion fencing may be erected in the Channel E (Right Downstream Bank of the Genelle area. It is estimated that without the exclusion fence, approximately 100 additional redds would have been dewatered in 2016 (Thorley et al. 2017a). Exclusion fencing was not required in 2017.

Table 2. Reduction dates, magnitude of reduction, number and general location of dewatered redds in 2017.

Reduction Date	HLK Discharge Start (m^3/s)	HLK Discharge End (m^3/s)	BRD Discharge Start (m^3/s)	BRD Discharge Start (m^3/s)	Dewatered Redds	Location
February 24	851.6	566.7	515.9	517.3	9	Norn's Fan
March 3	588.2	425.7	661.9	617	2	Norn's Fan
March 10	No Data	No Data	534	533	6	Genelle Channel E
March 30	No Data	No Data	1192	1204.6	9	Norn's Fan
March 31	737	481.2	1204.6	1191	14	Norn's Fan

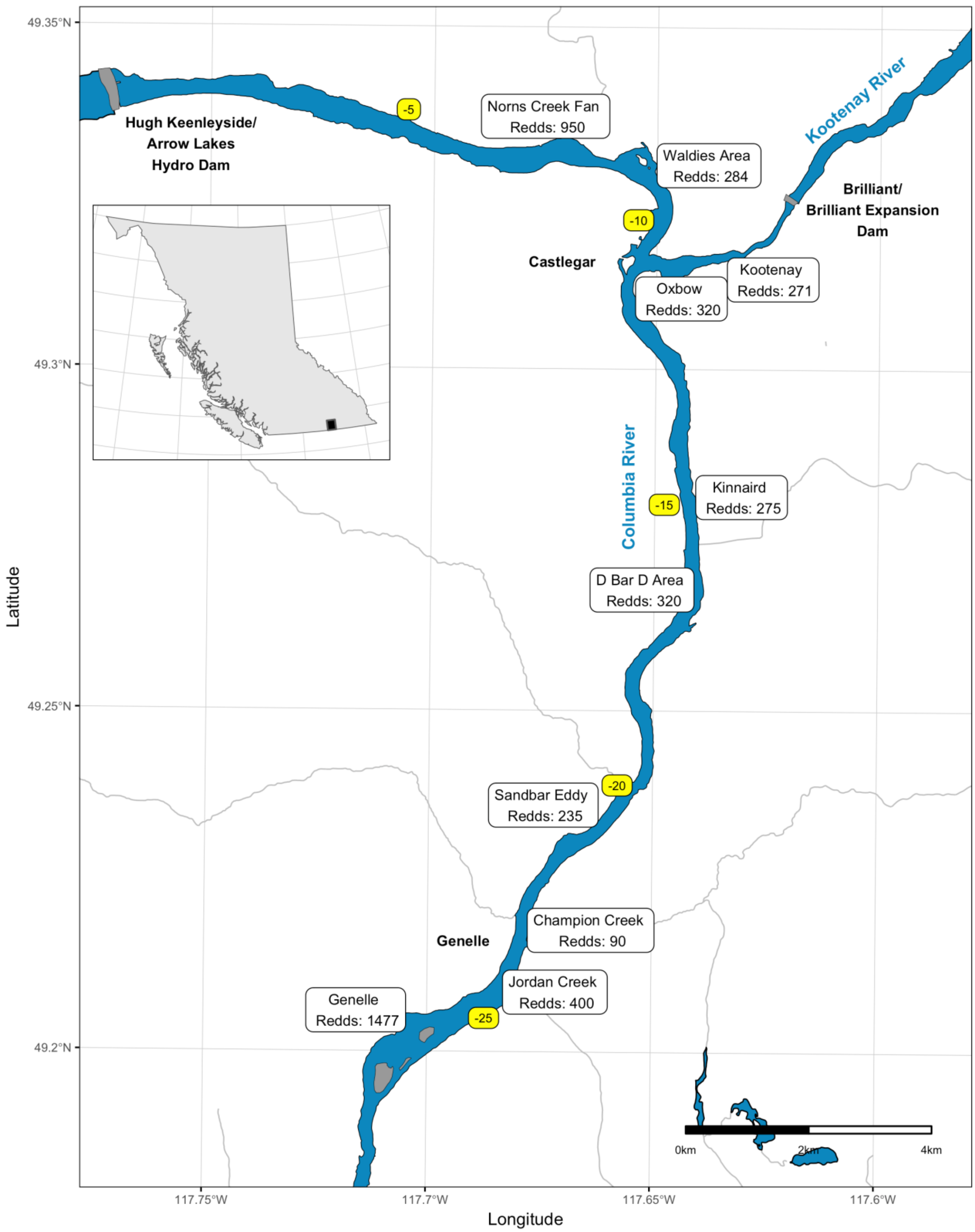

Figure 1. **Study area for the Rainbow Trout spawning assessment program within the Lower Columbia and Lower Kootenay rivers. The counts are the peak redd counts. The yellow numbers indicate river kilometre downstream of HLK dam.**

2.4 Acoustic Telemetry

In order to better understand spawning fish movement throughout the study area and obtain data on Rainbow Trout spawn timing and residence time, 16 adult Rainbow were tagged with Vemco V13-1x-A69-1303 69 KHz tags and PIT tags in 2010 and a further 20 adults were tagged in 2012. The acoustic telemetry program yielded information on residence time by sex of spawners on the Norn's creek fan spawning beds (Thorley et al. 2017), sex ratio of captured fish (Baxter et al. 2016), and biometric data (Irvine et al. 2013; Thorley and Baxter 2012).

2.5 Spawner and Redd Abundance and Spawn Timing

2.5.1 Data Sources and Preparation

The Rainbow Trout spawner and redd aerial count data for the LCR and LKR were collected by Mountain Water Research and imported to an SQLite database maintained by Poisson Consulting Ltd. Okanagan Nation Alliance provided the age-1 Rainbow Trout abundance estimates from the LCR Fish Population Indexing Program (CLBMON-45). Discharge, temperature and water level data were extracted from the Columbia Basin WLR database maintained by Poisson Consulting Ltd.

The study area was divided into three sections: the LCR above the LKR, the LKR and the LCR below the LKR. Redd and spawner counts upstream of Norns Creek Fan and downstream of Genelle were excluded from the section totals because they constitute less than 0.1% of the total count and were not surveyed in all years. The redd and spawner counts for the Right Upstream Bank above Robson Bridge were also excluded as they appear to be primarily driven by viewing conditions (and constitute less than 2.5% of the total). Viewing conditions from 2003 onwards were classified as Good or Poor based on field notes. Poor viewing conditions from 1999 to 2002 were identified by redd counts 1/3 lower than the cumulative maximum redd count for the site.

In Thorley et al. (2017), it was recommended that the upper river section be split to obtain better data at the end of the spawning period using only Norn's Creek fan where the visibility remained good over a longer time period. However, in the upper section only 12% of the spawning is outside of Norn's Fan so this approach was not implemented.

The data were prepared for analysis using R version 3.4.2 (R Core Team 2017).

2.5.2 Data Analysis

In order to estimate spawner and redd abundance as well as the spawn timing of Rainbow Trout in the LCR, hierarchical Bayesian Area-Under-the-Curve (AUC) models were fitted to the aerial spawner and redd counts in the LCR and LKR.

Key assumptions of the AUC model include:

- Spawner abundance varies by river section.
- Spawner abundance varies randomly by year and section within year.
- Spawner observer efficiency is between 0.8 and 1.0.

- Number of redds per spawner is between 1 and 2 (Thorley 2017b). This assumption is partly based on a 50:50 sex ratio, 2,900 eggs per spawning female, 1,100 eggs per completed redd and 43% test redds (Baxter 2011b) which results in an estimate of 2.3 redds per spawner. The number of redds per spawner is lower because the proportion of test redds is assumed to decrease later in the season.
- Spawner residence time is between 14 and 21 days and did not vary by fish sex as determined using telemetry data and modelling in previous analyses (Baxter et al. 2016, Thorley et al. 2017a).
- Redd residence time to fading is between 30 and 40 days.
- Spawner arrival and departure times are normally distributed.
- Spawner arrival duration (standard deviation of normal distribution) varies randomly by section within year.
- Peak spawner arrival timing varies randomly by year.
- The residual variations in the spawner and redd counts are described by separate Negative Binomial distributions.

Preliminary analysis of skew normal and sine arrival and departure functions did not improve the fit of the model.

The models' variables, parameters, distributions and assumptions are more fully described in the online analytic report (Thorley et al. 2017b) at http://www.poissonconsulting.ca/f/453582501.

2.6 Spatial Distribution of Spawners

The proportions of redds at each site when viewing conditions were good throughout the LCR and LKR were used to calculate the Shannon Index, an information-theoretic measure of the diversity in the distribution of a resource (Krebs 1999). In the current context, the Shannon Index takes into account both the number of spawning sites and how the spawning activity is distributed among these, with a higher index indicating a greater spatial distribution of spawning.

The Shannon Index (H) is given by:

$$H = -\sum p_i log(p_i)$$

Where, p_i is the proportion of the spawning activity at the i^{th} location.

2.7 Fry Emergence Timing

The expected annual emergence timing was calculated from the estimated spawn timing and the mean daily surface water temperature at three locations to match with the river sections. Norn's Creek Fan temperature gauge was used for the upper section, the Golder deployed Hobo Tidbit was used for the LKR and the Birchbank gauge was used for the lower section. The assumption was made that Rainbow Trout embryos require 480 accumulated thermal units (ATUs) to emerge (K. Scheer and O. Schoenberger, Freshwater Fisheries Society of BC, pers. comm., 2010). Daily water temperatures were used and data were interpolated if less than 8 consecutive days of data were missing.

2.8 Stock-Recruitment Relationship

The spawner estimates were combined with the following year's boat electrofishing based estimates of age-1 Rainbow Trout abundance for the LCR from HLK dam to the U.S. Border and in the ~1.8 km of the lower Kootenay River below Brilliant Dam (Ford et al. 2012) to estimate the stock-recruitment relationship. Previous genetic work shows that the fish in the Kootenay and the Columbia interbreed readily so they are considered the same population for the purposes of assessment (Taylor 2002).

The relationship between the adults and the resultant number of age-1 subadults was estimated using a Bayesian Beverton-Holt stock-recruitment model (Walters and Martell 2004):

$R = \alpha * S / (1 + \beta * S)$

Where, S is the adults (stock), R is the subadults (recruits), α is the recruits per spawner at low density and β is the density-dependence coefficient.

Key assumptions of the Beverton-Holt stock-recruitment model include:

- The recruits per spawner at low density is normally distributed with a mean of 90 and a standard deviation of 50
- The recruits per spawner varies with the percent of redds dewatered
- The residual variation in the number of recruits is lognormally distributed

The mean of 90 for α was based on an average of 2,900 eggs per female spawner, a 50:50 sex ratio, 50% egg survival, 50% post-emergence fall survival, 50% overwintering survival and 50% summer survival (Allen and Sanger 1960, Hildebrand and McKenzie 1995, Thorley 2009).

The carrying capacity is α/β.

2.9 General Analytic Approach

Model parameters were estimated using Bayesian methods. The Bayesian estimates were produced using JAGS (Plummer 2015) and STAN (Carpenter et al. 2017). For additional information on Bayesian modelling in the BUGS language or in the JAGS dialect of BUGS, see Kery and Schaub (2011). For additional information on Bayesian modelling in the Stan language the reader is referred to STAN Development Team (2017).

Unless indicated otherwise, the Bayesian analyses used uninformative uniform or normal prior distributions (Kéry and Schaub 2011). The posterior distributions were estimated from 1,500 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of three chains (Kery and Schaub 2011). Model convergence was confirmed by ensuring that R^<1.1 (Kery and Schaub 2011) for each of the monitored parameters (Kéry and Schaub 2011).

The parameters are summarised in terms of the point estimate, standard deviation (sd), the z-score, lower and upper 95% credible limits (CLs) and the p-value (Kéry and Schaub 2011). A p-value of 0.05 indicates that the lower or upper 95% CL is 0. The estimate is the median (50th percentile) of the MCMC samples, the z-score is mean/sd and the 95% CLs are the 2.5th and 97.5th percentiles.

The results are displayed graphically by plotting the modeled relationships between particular variables and the response(s) with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their mean and first level values, respectively, while random variables are held constant at their typical values (expected values of the underlying hyperdistributions). When informative the influence of particular variables is expressed in terms of the effect size (i.e., percent change in the response variable) with 95% confidence/credible intervals (CIs, Bradford et al. 2005) .

The analyses were implemented using R version 3.4.2 (R Core Team 2017) and the jmbr and smbr packages (Muir and Thorley 2017, Thorley 2017a).

3.0 RESULTS

3.1 Mainstem LCR and LKR Spawner and Redd Abundance and Spawn Timing

The two locations that contained the majority of the Rainbow Trout redds in the study area in 2017 during the peak count were found at Genelle (1477 redds; Figure 1) and on Norn's Creek Fan (950 redds; Figure 1). Habitat throughout both rivers was used extensively in this year with the high abundance of spawning fish in the system. The LKR had 591 redds and the remainder of the LCR (outside of Genelle and Norn's Fan) 1604 enumerated redds during the peak count (Figure 1).

The spawner and redd counts from the eight aerial surveys conducted in 2017 were analysed together to produce abundance estimates by year (Figure 2) and annual spawn timing estimates by river section (Figure 3). The estimated abundance of Rainbow Trout for 2017 was 11,017 fish (95% CI 7,846 – 17,359). While this is a decrease of 434 fish from the 2016 estimate of abundance and a decrease from the 2015 peak abundance, the trend is neither biologically nor statistically significant (Figure 2).

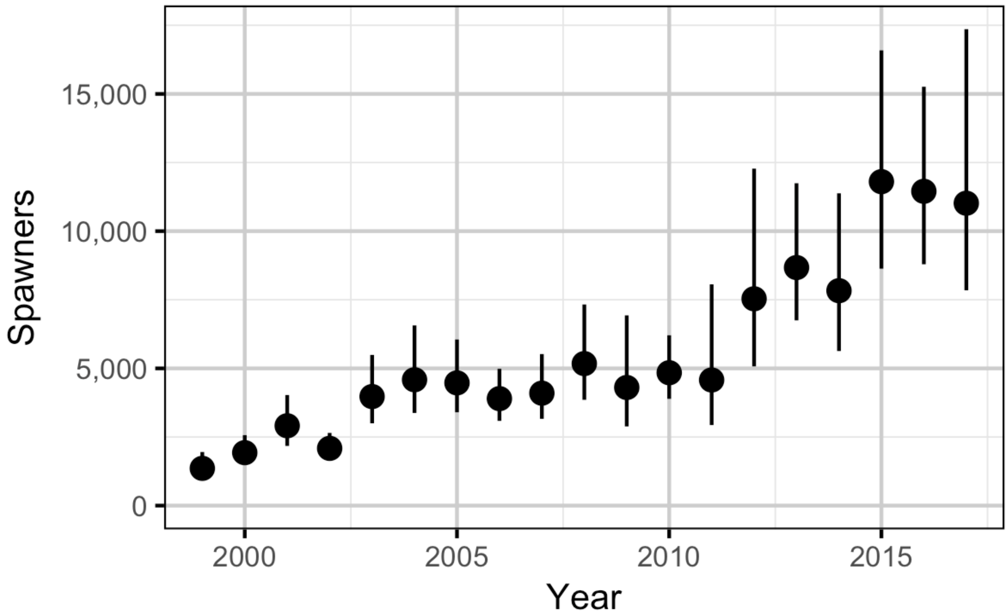

Figure 2. **Annual estimates of abundance of Rainbow Trout spawners in the Lower Columbia River below HLK dam and the Lower Kootenay River below Brilliant Dam from 1999-2017 with 95% credible intervals.**

The timing of the start, peak and end of spawning was estimated with 95% credibility intervals for each river section from the AUC model. In 2017, the spawn timing was identical amongst all three sections. The spawning was estimated to start on March 19 (95% CI March 16 - March 23), peak on May 2 (95% CI April 26 – May 10) and end on June 15 (95% CI June 4 – June 28) (Figure 3). The spawning window in 2017 was one of the narrowest on record with the year 2000 also showing a tight period from March to June for spawning (Figure 3).

The peak spawner and redd counts for 2017 are mapped in Appendix A. The spawner and redd counts and the AUC estimates are plotted together in Appendix B.

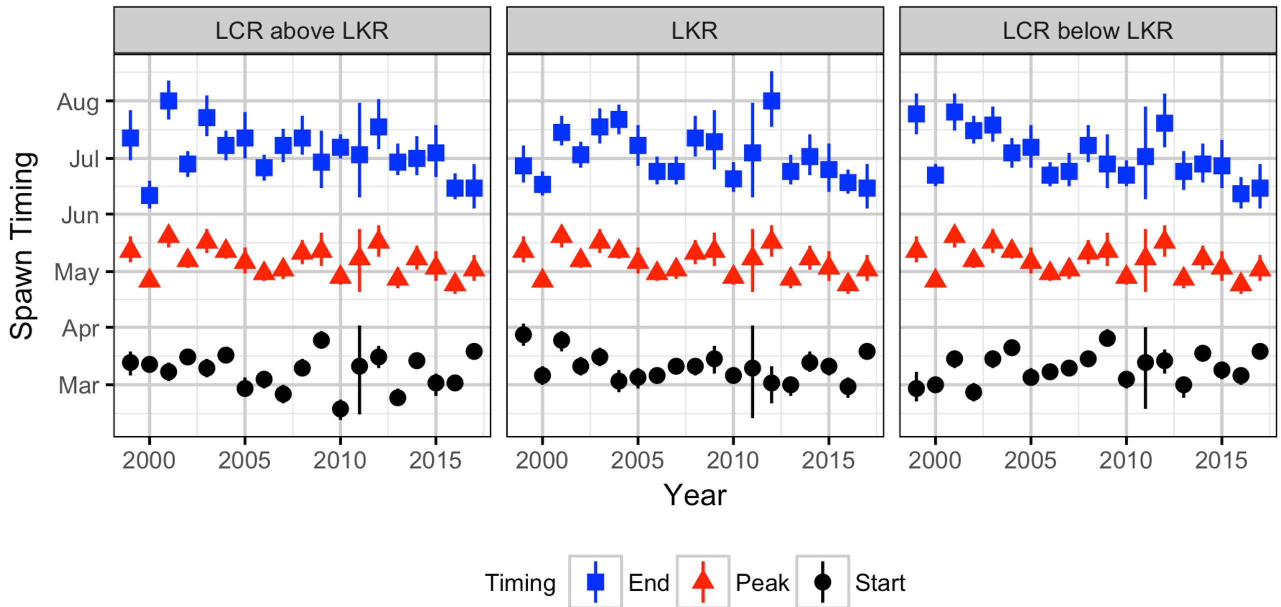

Figure 3. Annual estimates of peak, start and end of spawn of Rainbow Trout in the three study sections Lower Columbia River below HLK dam and the Lower Kootenay River below Brilliant Dam from 1999-2017 with 95% credible intervals.

3.2 Norn's Creek Spawner and Redd Abundance

A total of 1,390 redds and 2,718 spawners were enumerated during the snorkel and shore-based survey of Norn's Creek on April 28, which is the highest estimated abundance of spawners and redds over the period of record. This year's estimated abundance is significantly higher than the 48 redds and 406 spawners observed in 1999 in the first year of this survey (Figure 4).

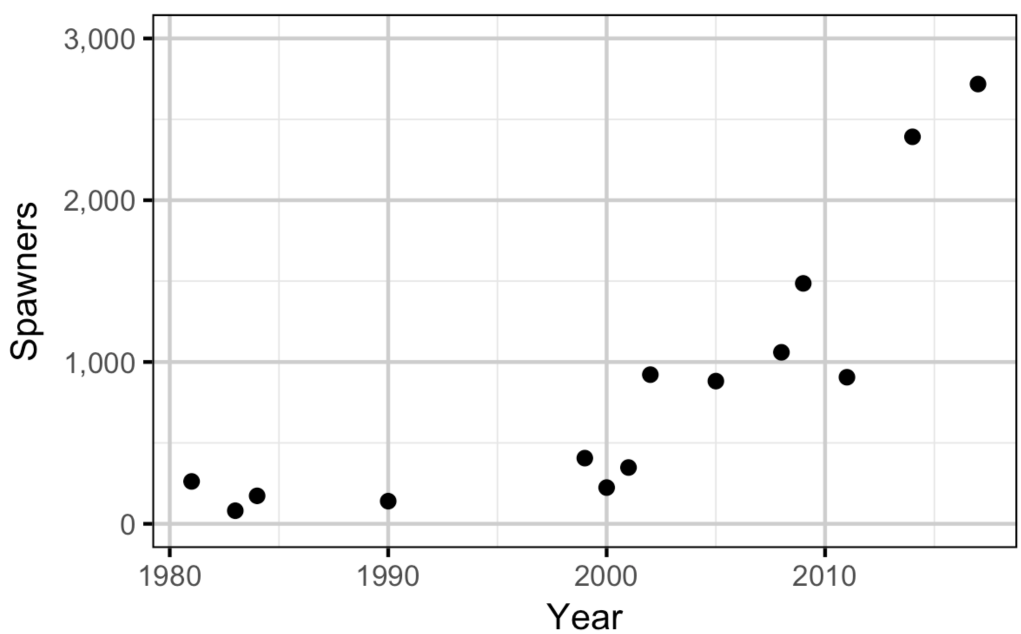

Figure 4. Irregular annual estimates of the abundance of Rainbow Trout spawners in Norn's Creek

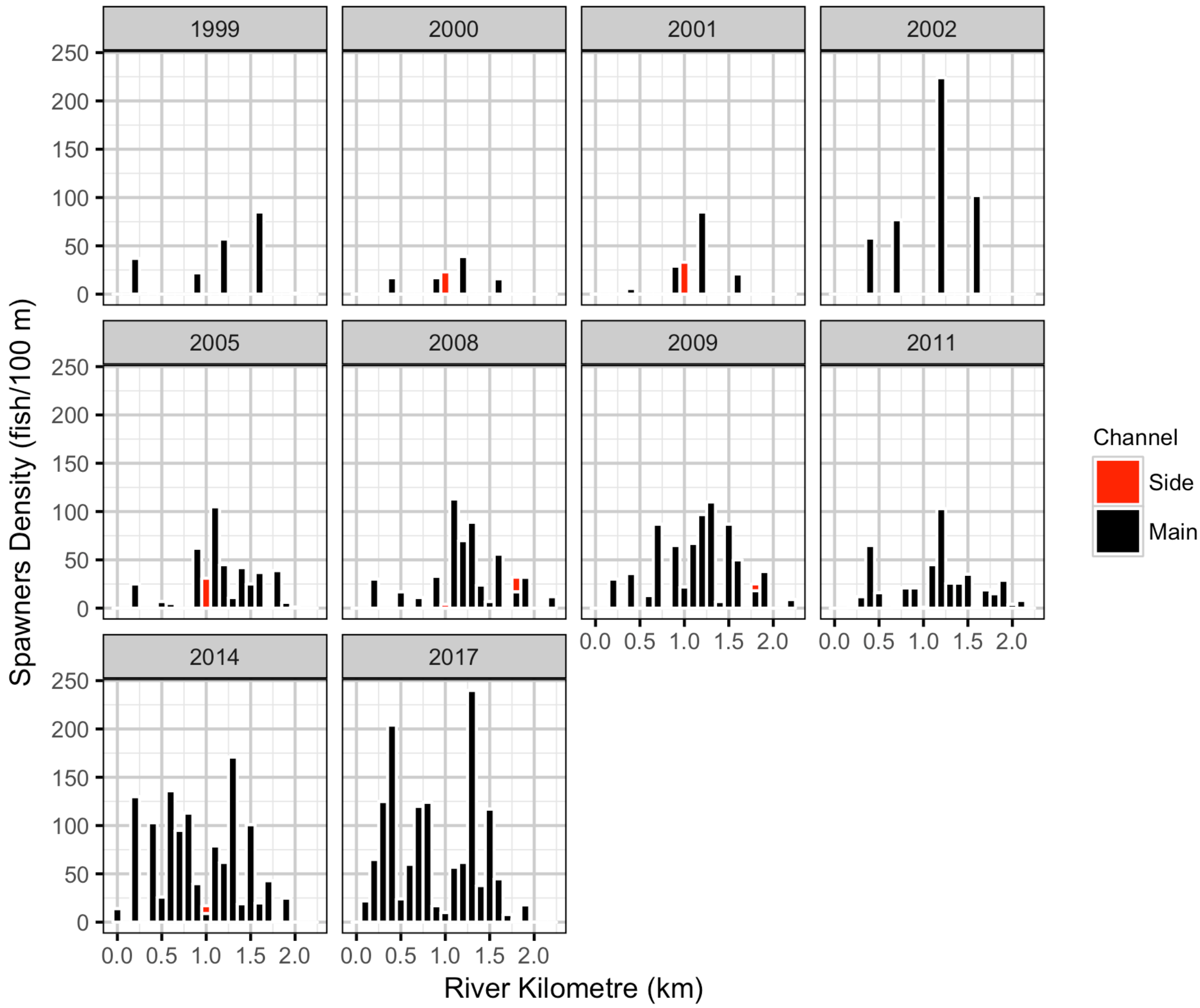

Figure 5. **Spatial distribution of Rainbow Trout spawners in Norn's Creek in all surveyed years since 1999. From 1999 to 2002 spawner counts were aggregated into four sections (plus the side channel).**

3.3 Redd Dewatering

Five operational reductions were flagged as possible dewatering events in 2017, which prompted a survey response. A total of 40 Rainbow Trout redds were dewatered during the February to March period when the events occurred. The average number of redds dewatered per year is 50 with the worst years for absolute abundance of dewatered redds occurring in 2006 and 2013 (Figure 6). When the annual dewatering rate for each year was averaged over the fifteen years for which there were data, the mean percentage of dewatered redds was 0.7% and ranged from near zero to 2.1% (Figure 7). These estimates exclude redds that would have been dewatered without the introduction of exclusion fencing in Genelle Channel E. For example in 2016, 36 redds were dewatered but the exclusion fence prevented an estimated 100 additional redds from being dewatered (Thorley et al. 2017a). Exclusion fencing was erected in 2005, 2006, 2010, and 2016. Even though absolute numbers of dewatered redds were low in the early years of monitoring the LCR Rainbow Trout population, the percentage of dewatered redds was relatively high due to low numbers of spawning adults in the late 1990s.

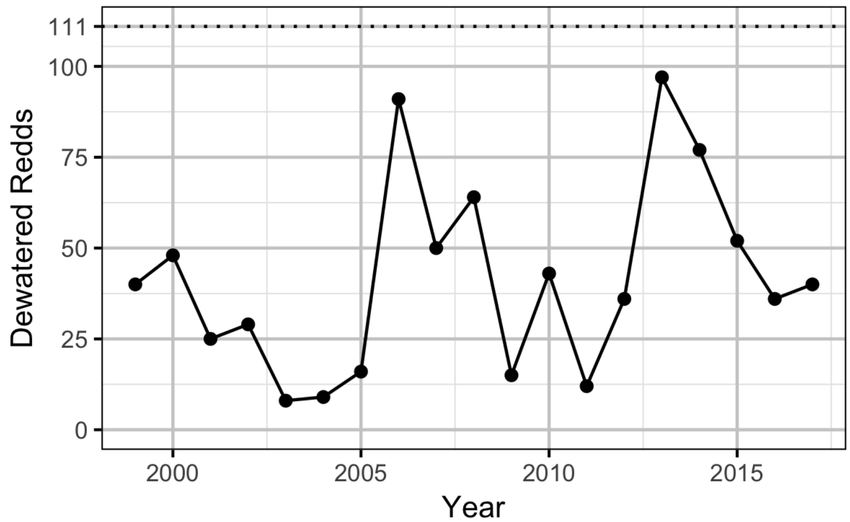

Figure 6. **Dewatered redd abundance by year from 1999-2017. The dotted line indicates the current threshold of dewatered redds approved by the agencies.**

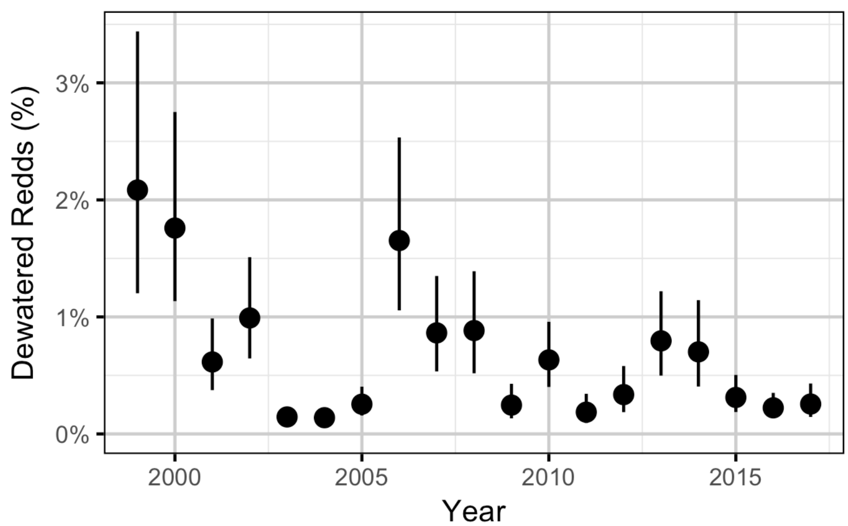

Figure 7. **Percentage of redds dewatered in the Lower Columbia River below Hugh L. Keenleyside Dam and the Lower Kootenay River below Brilliant Dam by year from 1999 to 2017. The bars represent 95% credible intervals.**

3.4 Spatial Distribution of Spawners

The percent of the peak redd count by river kilometre in 2017 was highest in the section of the LCR below the LKR and was driven by the high spawner densities in Genelle. The main spawning locations were above the Kootenay River at Norn's Fan (river km -7.5) and in Genelle (river km -26) though many other locations along the study reach are used in most years (Figure 8).

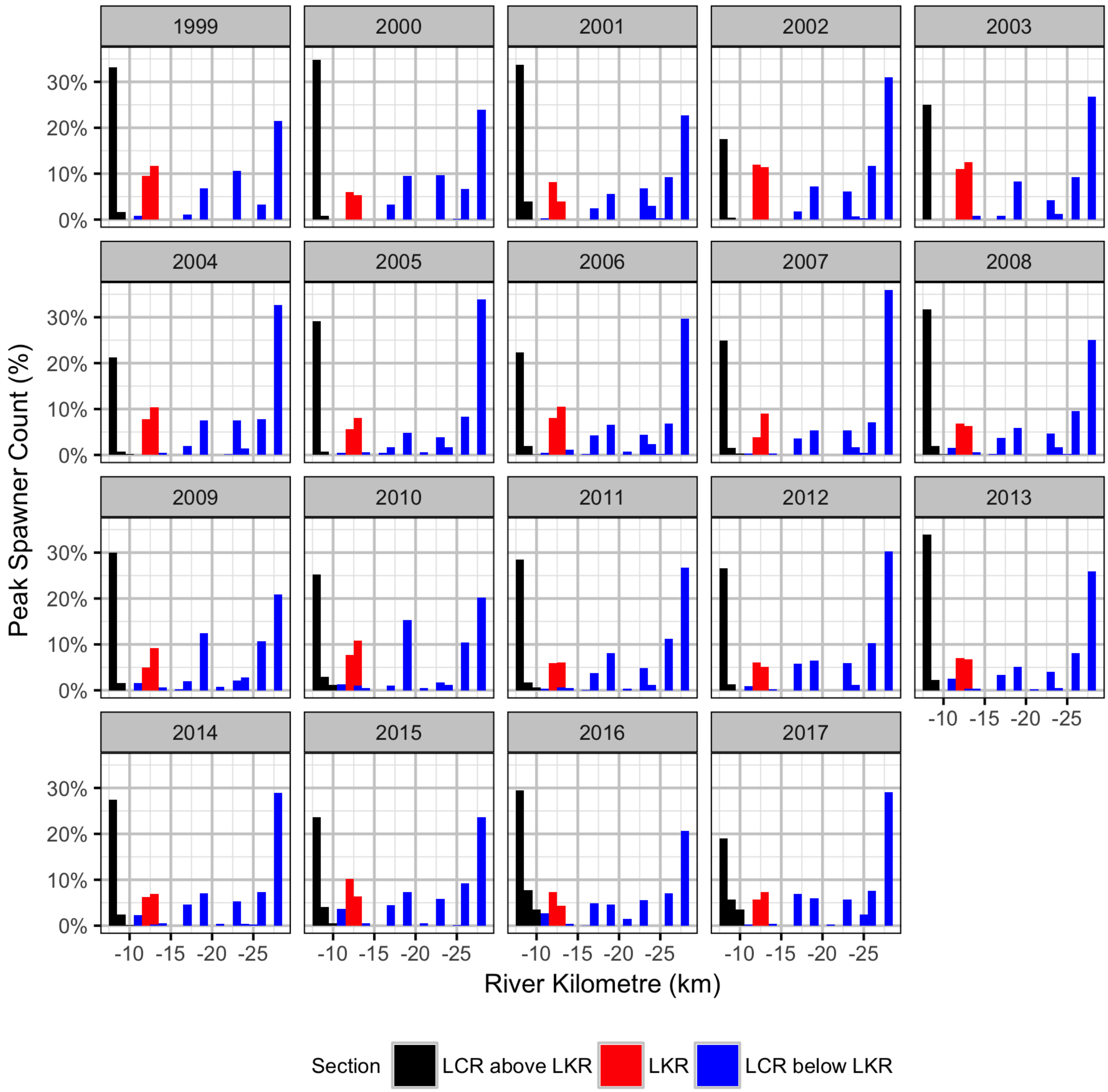

Figure 8. **Percent of peak redd count by river kilometre and year and coded by river section with the mainstem Lower Columbia River above the Kootenay confluence in black, the Lower Kootenay River in red and the Lower Columbia River below the Kootenay confluence in blue.**

A higher Shannon index value indicates a greater spatial distribution of the Rainbow Trout redds throughout the sites in the river. The redd distribution was extracted from the day on which the peak number of redds was present and the viewing conditions were good over the whole river. The spatial distribution in the 1999-2006 period was compared to the spatial distribution in the 2007-2018 period with a t-test and there was a statistically significant increase in the distribution between the two periods ($p<0.05$) (Figure 9). It should be noted that there is not a large change in the spatial distribution index values over the time series span nor is the increase explained by the flow regime which remained constant over the period of study (Figure 9).

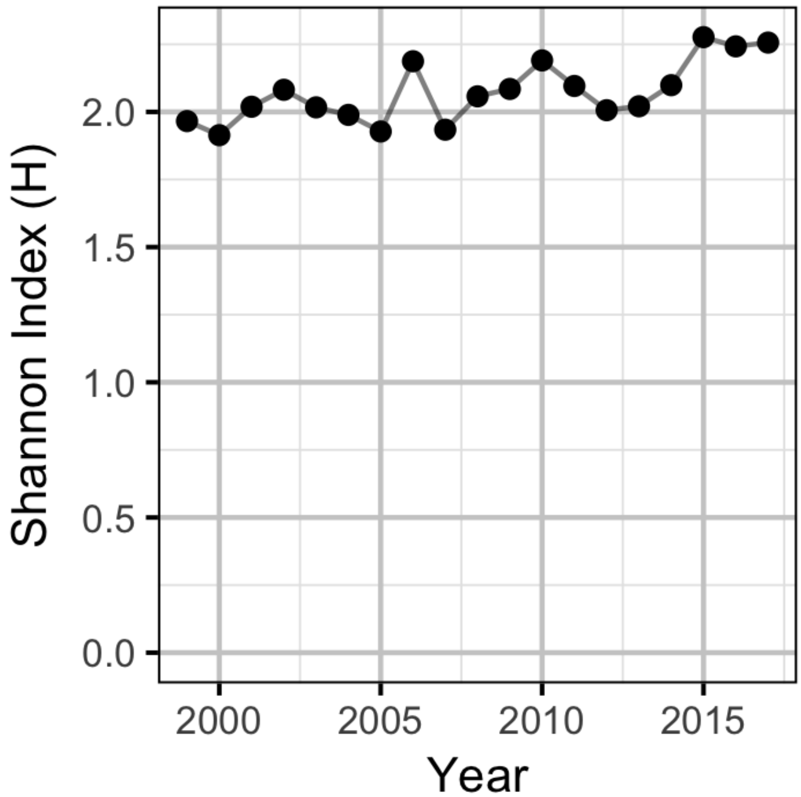

Figure 9. **Shannon index values for the spatial distribution of Rainbow Trout redds from 1999 to 2017.**

3.5 Fry Emergence Timing

Fry emergence timing estimates were completed using the results of the spawn timing model and water temperatures from the representative gauges as described in Section 2.6. Three periods of emergence were estimated (start, peak, and end) with 95% credibility intervals. The peak fry emergence for the 2017 spawn year was June 15 in the LKR (95% CI June 11 – June 20), June 26 in the LCR above the LKR (95% CI June 24 – June 29). Due to missing water temperature data, there was no estimate for the lower section of the river in 2017 (Figure 10). Fry emergence can still be occurring in late August although it is usually complete by early August (Figure 10). The water temperature can reach 17°C in early July (Figure 11), particularly in the LKR where water temperatures tend to be warmer (Figure 12). A temperature of 17°C is associated with increased embryonic mortality (Weber et al. 2016, Thorley et al. 2017a). There is no indication that the mean July water temperature has increased over the course of the study (Figure 12).

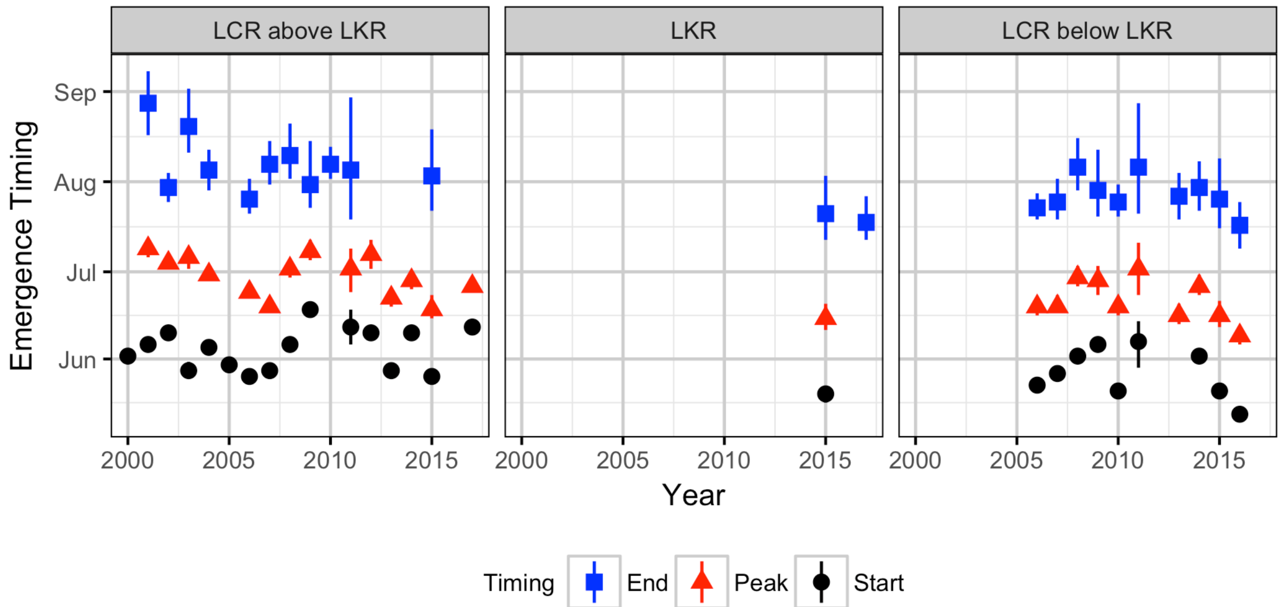

Figure 10. **Annual estimates of the timing of emergence of Rainbow Trout fry from 2000 to 2017 in three river sections (L-R): the Lower Columbia River above the Lower Kootenay River, the Lower Kootenay River below Brilliant Dam, the Lower Columbia River below the Lower Kootenay River. The bars indicate the 95% credibility intervals for each estimated timing point.**

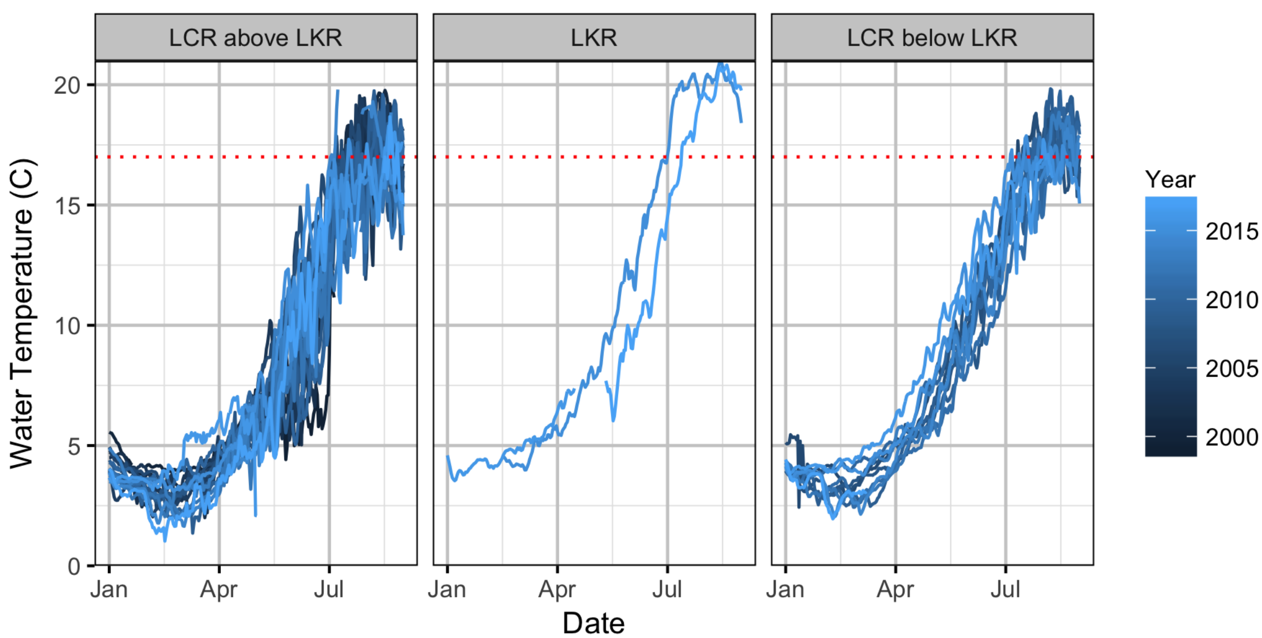

Figure 11. **Water temperature by year where data are available for each of the three river sections (L-R): the Lower Columbia River above the Lower Kootenay River, the Lower Kootenay River below Brilliant Dam, the Lower Columbia River below the Lower Kootenay River. The red dashed line indicates 17°C, which is associated with increased embryonic mortality.**

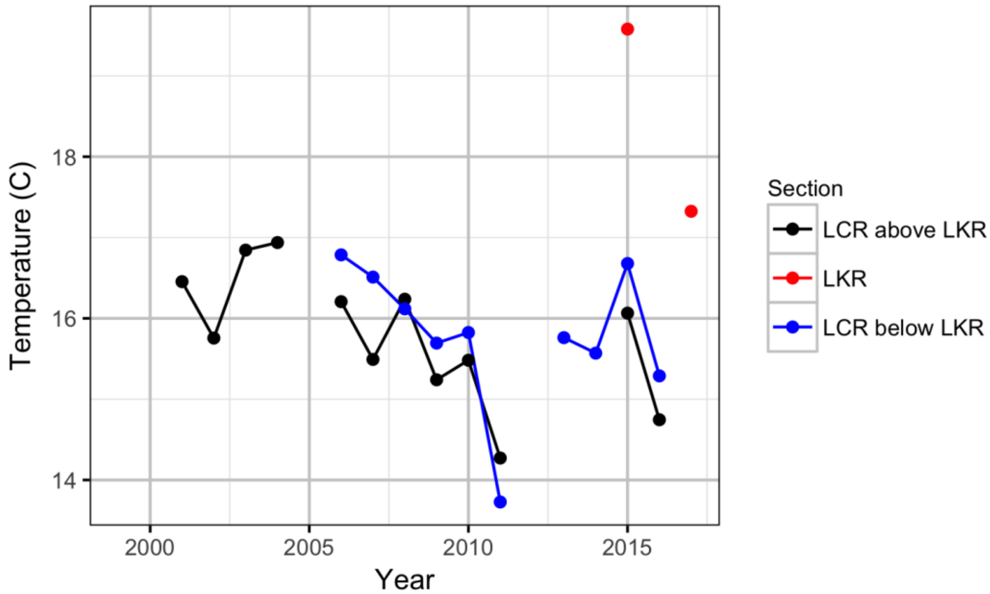

Figure 12. Mean water temperature in July where data were available for each of the three river sections.

3.6 Stock-Recruitment Relationship

The Beverton-Holt stock recruitment model fitted to age-1 Rainbow Trout abundance vs. spawner abundance suggests density-dependent survival (Figure 13). The model assumes that the age-1 abundance estimates are representative of the juvenile densities. There were no data pertaining to the slope of the line through the origin at low densities of spawners, so the slope of the initial portion of the curve was informed based on the known biology of the species including information on the number of eggs, survival of eggs and survival of 1 year old fish.

The abundance of age-1 Rainbow Trout at the index sites in the Lower Columbia River and Lower Kootenay River as estimated by the indexing program (Ford et al. 2013) was highest in the 2000, 2001, 2006 and 2010 spawn years and showed no increase in recruitment associated with the highest spawner abundance years (Figure 13).

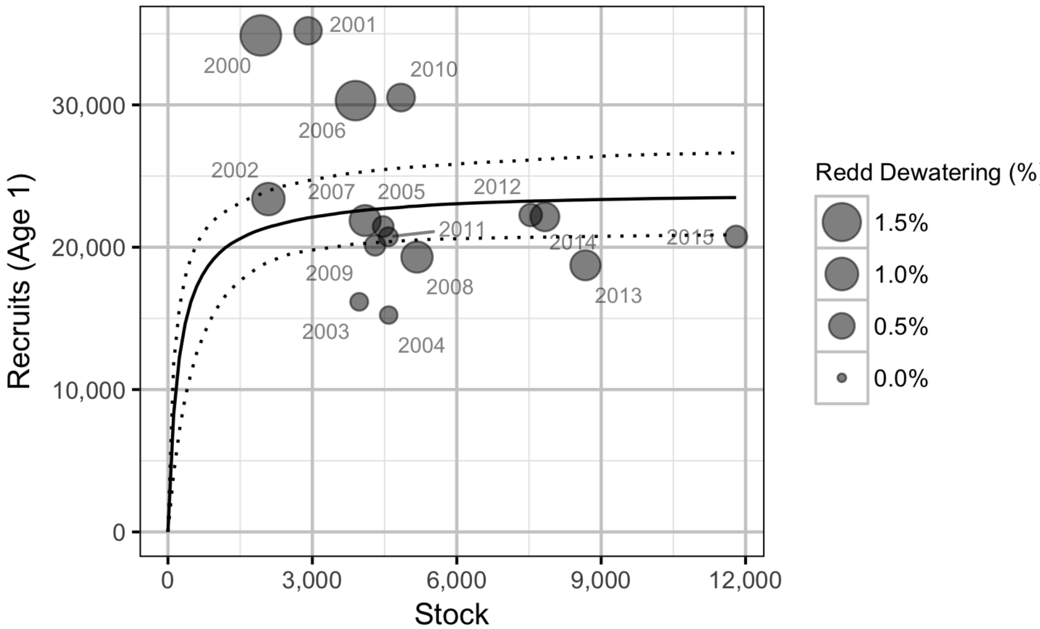

Figure 13. **Beverton-Holt stock recruitment curve including prior information for estimating the starting slope of the curve for Age 1 Rainbow Trout in the Lower Columbia River below Hugh L. Keenleyside Dam and the Lower Kootenay River below Brilliant Dam for the spawn years from 1999 to 2015.**

The trend in the age-1 recruits was highly correlated with the trend in the dewatered redd percentages so the carrying capacity from the stock-recruitment model was plotted against the redd dewatering rate to illustrate this relationship where more dewatered redds are associated with a higher carrying capacity for the Rainbow Trout population (Figure 14).

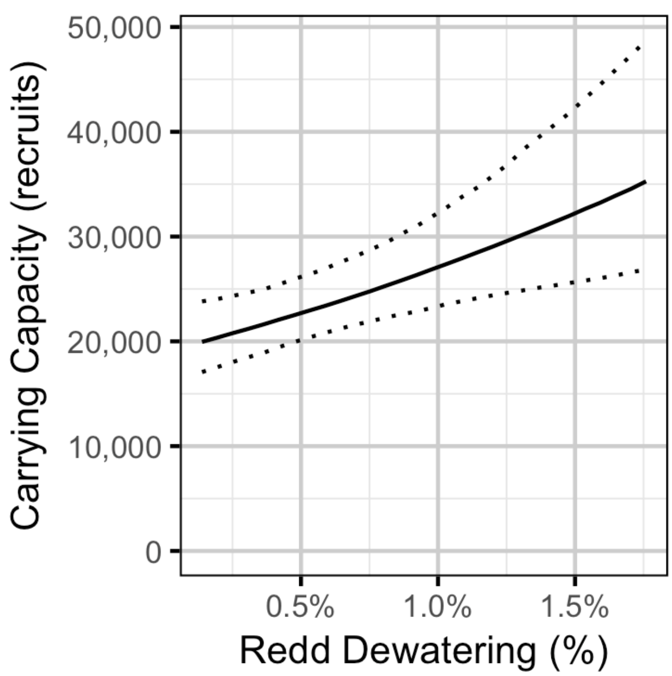

Figure 14. **Carrying capacity from stock-recruitment model of the Lower Columbia River and Lower Kootenay River for age-1 Rainbow Trout vs. redd dewatering rate.**

4.0 DISCUSSION

4.1 Management Question 1

The first management question asks whether RTSPF are linked to an increase in the number of spawners. The first null hypothesis states that the relative abundance of Rainbow Trout spawners or redds in the Columbia River mainstem does not increase between the baseline period (1999 to 2006) and the WUP monitoring period associated with the continued implementation of RTSPF.

The AUC-based estimates were approximately 11,500 spawners in 2017 compared to 1,600 in 1999 which is an approximately 8-fold increase of Rainbow Trout in the Lower Columbia and Lower Kootenay Rivers. The number of spawners was estimated to be approximately 5,200 spawners in 2008. The null hypothesis of no change in spawners can thus be rejected, although it remains unknown, as has been noted in past reports (e.g., Thorley et al., 2017), whether the increase is due to the RTSPF or other factors. A number of environmental and biological factors have changed during the same time period which could have had a positive impact on Rainbow Trout numbers including the opening of 26 km of Blueberry Creek for Rainbow Trout spawners (Arndt and Klassen 2004), and the fertilization programs in Kootenay Lake and Arrow Lakes Reservoir. It is also probable that some of the spawning population in the study area is from the United States portion of the Columbia River given historic tagging studies (Hildebrand and McKenzie 1995, Heaton and Hildebrand 1997a) so some of the increase may be due to management strategies undertaken in the U.S. Nonetheless it is an impressive increase in Rainbow Trout abundance.

The accuracy and magnitude of the abundance estimates depend on the extent to which the assumptions of the model are met. There were significant model improvements this year with the incorporation of viewing condition information. Where viewing conditions were recorded as good, the data were used; when conditions for observing redds were poor, the data for redds and fish were removed from the model. This implementation allowed the previous data exclusion rule to be amended. Previously, when numbers of redds dropped by more than a third from the peak number of redds observed in a section of river, the data was considered unreliable and removed from the model (Thorley et al. 2017). This led to the model fitting poorly at the end of the spawning period when the number of fish may actually be decreasing with the completion of spawning, but the phenomenon of the actual decrease was not captured due to the regular deterioration of spring viewing conditions with the advent of freshet. Where there are no historical data for viewing conditions, the data exclusion rule is still applied. This allows a much better fit of the model to the data, particularly at the end of the spawning season where there was previously considerable uncertainty.

In addition, the arrival time curve was allowed to vary by year in this year’s model, which made the curve shapes more distinct from year to year and a better fit to the data. The result of this is that the absolute abundance estimates of the Rainbow Trout spawner numbers is much more precise than in previous years and could allow more targeted management and monitoring to occur. The absolute abundance dropped from an estimated 25,000 fish with the old version of the model to approximately 11,000 fish for the peak years of abundance (2015 to 2017). The currently suggested 1% dewatering threshold based on the new model and revised abundance is 143 redds (Thorley

2018). A further improvement to the model that could be considered in future is the incorporation of river stage effects on viewing conditions. Redd viewing conditions could be updated to take into account the fact that redds are static and may not be visible when water levels rise even if viewing conditions are good due to increased water depth over the redds.

The AUC-based estimates exclude fish spawning in tributaries (other than the Lower Kootenay River below Brilliant Dam), in deep-water sites, downstream of Genelle including below the US Border and upstream of Norn's Creek fan. The current state of knowledge with regard to the numbers of fish spawning in tributaries, deep-water sites and in the US is summarized in Thorley and Baxter (2011, 2012), but in brief, tributaries to the LCR were thought to provide habitat for over 3,000 spawners. Norn's Creek is the most significant tributary for Rainbow Trout spawning within the study area and may serve as an indicator of what is occurring in other tributaries throughout the system.

In addition to the tributary spawners that are not summed into the overall abundance estimate, fish are likely spawning unrecorded in the deeper parts of the Lower Columbia and Lower Kootenay Rivers (based on deep water observations on an exceptionally clear viewing day in 2010) and Rainbow Trout in the U.S. spawning locations may contribute to the LCR Canadian population. In a 1990s Rainbow Trout study in LCR, 34 radio-tagged fish were tracked and 15 of them (44%) moved downstream into the U.S. (Hildebrand and McKenzie 1995, Heaton and Hildebrand 1997a) and acoustically tagged fish have been observed to undertake 50 km spawning migrations.

The AUC model also makes several assumptions that influence the abundance estimates. In particular the model assumes that the observer efficiency for spawners is 80 to 100%, the number of redds per spawner is 1 to 2 and that redds fade after 30 to 40 days. It may be possible to derive estimates of the latter two parameters from field studies.

In 2017, the Norn's Creek surveys were completed with an estimated spawner abundance of 2,718 fish and 1,390 redds. The surveys on Norn's are completed opportunistically and attempt to coincide with peak spawning rather than surveying periodically over the spawning period. The goal is to survey during peak spawning but before the visibility drops during freshet, which is sudden and dramatic in tributaries like Norn's Creek. Due to the methodology, the absolute numbers are unlikely to be completely representative, but the relative magnitude and trend do reflect the increased abundance through time that is also seen in the mainstem.

The distribution and number of fish throughout the creek may also be related to the restoration work that has been done in the area (Klym et al. 2016). The structures built in Norn's Creek between 1998-2001 are between river km 0.5 and km 1.0 where the fish preferentially spawned at lower abundance levels in the mid 2000s. The hydrological processes that create better spawning habitat would have had sufficient time to act on the structures by that time and may be influencing the number of fish spawning in the tributary and spawning success. The spawning habitat in Norn's Creek is important on its own as a system that encounters different flows and temperatures and it also likely acts as an overflow for the fish when the Norn's Creek Fan in the mainstem Columbia River is saturated. The placement of acoustic receiver arrays in 2014 showed that some fish were spending time on the fan and then moving upstream into the creek presumably to spawn again, splitting their gonadal investment between two or more locations (Irvine et al. 2015).

As stated by Thorley and Baxter (2011) *"… in order to achieve the primary purpose of the program as stated in the TOR, it is necessary to model the population's response to alternative discharge regimes. One approach is to combine habitat suitability curves with substrate maps, 2D models of depths and velocities and a stock-recruitment relationship to predict the consequences of alternative flow scenarios for the population. Alternatively, it might be possible to determine the relationship between discharge and abundance through experimental manipulations of the discharge regime and ongoing monitoring of the population. Ultimately these two approaches are complementary rather than exclusive and the optimal strategy might be to use experimental manipulations to resolve key uncertainties in the Habitat Suitability Stock-Recruitment (HSSR) model."*

To date a stock-recruitment (SR) relationship has been fitted to the spawner abundance estimates and the estimates of age-1 Rainbow Trout abundance from the LCR Indexing program (Golder et al. 2017). The SR relationship suggests that a stock of just 1,500 spawners are required to maximize the number of age-1 recruits if dewatering rates are very low. The relationship assumes that the spawner and age-1 abundance estimates are reliable as relative indices. Although there is some concern about the sensitivity of the LCR indexing program to changes in the abundance of the adult Rainbow Trout, it appears to be sensitive to changes in the abundance of age-1 Rainbow Trout (as evidenced by the large inter-annual variation). Finally, it is worth noting that the LCR indexing program indicates that Rainbow Trout condition and growth has declined in recent years suggesting that the adult population is at carrying capacity.

One of the most interesting results from the past three years' analyses was the strong positive correlation between the number of age-1 Rainbow Trout recruits estimated by the LCR indexing program and the percentage of dewatered redds. This suggests that the conditions which result in more redd dewatering are correlated with substantially higher survival and an associated higher carrying capacity for the recruitment levels in the remaining redds. One possible explanation is that the discharge and river stage conditions that result in more redds in shallower water, thus leading to the higher dewatering percentage, cause less redd disturbance at higher discharges later in the incubation period. Further exploration of the relationship between dewatering and age-1 recruits may clarify the role of river stage and discharge in influencing abundance. This would require an experimental research approach assessing the potential hypotheses and using the recruitment of juvenile Rainbow Trout as the response metric to determine which is the most likely explanation.

There may be different mechanisms operating to affect Rainbow Trout survival from egg to age-1 in the different river systems due to the operational choices enacted at BRD and HLK in the summer months. The discharge from HLK dam increases or stays flat throughout the summer months, while the discharge from BRD decreases over 1000 m^3/s from mid-late June until early August. Within the LKR, where approximately 15% of the Rainbow Trout population spawns, the range of emergence timing predicted from the modeling indicates that some redds with developing eggs may be dewatered or reach lethal water temperatures before the end of their development window. In this system dewatering and lowered flows leading to inhospitable water temperatures may limit recruitment.

However, in the LCR where the majority of the spawners develop their redds, a mechanism where increased flows may cause water velocities to increase over the redds could limit recruitment. Rainbow Trout fry are most susceptible to being washed away by high flows in the 30-70 days after absorbing the yolk sac (Fausch et al. 2001). Flow regime was predictive of whether Rainbow Trout could survive after being introduced into rivers. Trout are most successful when the flow regime of the river into which they are introduced matches the flow regime in which they evolved (Fausch et al. 2001). When HLK increases summer flows in a year when protection flow levels were low, this may result in a flow regime that differs substantively from the flow regime within which the population evolved. The Rainbow Trout would have used the available inundated habitat to spawn lower down in the river's contour due to the stage of the river. Increases in flow would then substantively increase the velocities and potentially lead to increased susceptibility to wash out by high flows in the first 30-70 days after absorbing their yolks as has been found in other studies (e.g., Nehring and Anderson 1993). Conversely, when the benched cobble habitat higher up the river's bathymetric contours is utilised by the fish, the dewatering percentage for the year would be higher, but the velocities encountered by the emergent fry would be lower with less mortality and therefore greater recruitment. This type of interaction between velocity, accessible habitat and flow regime could explain the counter intuitive link between the number of age-1 recruits and dewatering percentage and may be key to maximizing the recruitment of Rainbow Trout in the LCR.

4.2 Management Question 2

The second management question concerns the spatial distribution and associated habitat area of spawning Rainbow Trout within the study area. The second null hypothesis states that the spatial distribution of locations and the associated habitat area that Rainbow Trout spawners use in the Columbia River mainstem does not increase between the baseline period (1999 to 2006) and the WUP monitoring period associated with the continued implementation of the RTSPF. We can reject this null since a statistically significant increase in spatial distribution of redds occurred between the baseline and the WUP monitoring period.

As discussed by Thorley & Baxter (2011), the spawner and redd count data indicate that the spatial distribution and habitat area of spawning have increased through time. This year, the t-test of the peak redd distribution during good viewing conditions comparing the 1999-2006 period to the 2007-2017 period was statistically significant. This significant increase in spatial distribution cannot be attributed to the flow regime since it remained constant between the two periods. One possible explanation is that as spawner abundance has increased, some areas have become saturated with redds and as a result fish have begun to utilize additional locations. This could mean a differential survival rate depending upon spawning location given that some habitat will be less optimal or more influenced by flow or water temperature changes than other habitat. Using only data from peak redd counts obtained on days with good visibility controls for variation that would be driven by visibility conditions.

Field crews have noted over the years of monitoring that the locations available for spawning Rainbow Trout vary considerably with the river stage and the discharge from HLK and BRD. Rainbow Trout spawning in the LCR and LKR select habitats where velocities range from 0 to 1.4 m/s with peak spawning activity at a velocity of ~0.6 m/s and depth ranges from 1 to 1.5 m with peak habitat suitability curve values at ~1.1 m (Thorley and Baxter 2012). Therefore, although there are some spawning areas that are used every year, there are locations and habitats that are used sporadically depending on their suitability. In 2012, which was a very high water year, the percentage of fish observed above the Kootenay confluence was higher which may have been habitat or food related as much of the low lying forest was inundated that spring.

4.3 Management Question 3

The third and final management question asks whether RTSPF protect the majority of redds from dewatering. The answer is a clear yes. The third null hypothesis states that the proportion of redds dewatered does not increase between the baseline period (1999 to 2006) and the WUP monitoring period associated with the continued implementation of the RTSPF. Unsurprisingly (as the flow regime did not change) we fail to reject the null hypothesis. In 2017, 40 Rainbow Trout redds or approximately 0.36% were estimated to have been dewatered during the spawning season. The RTSPF therefore clearly protects the vast majority of the redds. The redd dewatering estimates from the hierarchical model suggest that the mean dewatering rate is 0.7% with the current flow regime. It is worth noting that this estimate is partly due to the timely deployment of exclusion fencing in Genelle Channel E. There are no good, continuous data on the level of redd dewatering prior to the protection flows, but in a study done in 1990-1991 approximately 50-75% of the redds observed during field surveys were exposed by ensuing flow reductions (Hildebrand and McKenzie 1995).

Each year the vast majority of dewatering occurs during the early spawning period (beginning of January to the end of March). Genetic samples from early and late spawners in the LCR study area demonstrated that the early timing group was not genetically unique from the peak spawners (Taylor 2016).

4.4 Recommendations

Long term ecological monitoring has proven repeatedly that it provides the most powerful data sets to detect changes due to large scale environmental variables such as climate as well as mitigations of human caused disturbance (Magurran et al. 2010, Lindenmayer et al. 2012). It also tends to capture the unexpected, simply by continuing to monitor while changes both small and large occur around and to the population. The ten years of data (2008 to 2017) on the LCR and LKR Rainbow Trout population have been collected consistently and provide leverage for detecting changes due to the many impacts occurring in the river systems in the current period. For the LCR and LKR these changes include climatic alterations, invasive species such as Northern Pike (*Esox lucius*), the maturation of a White Sturgeon (*Acipenser transmontanus*) population at high hatchery stocking rates, the hyperabundance of Didymo (*Didymosphenia geminata*) and increasing angling pressure. While the long term fish indexing study on the LCR provides key data on a number of important parameters including growth rate, body condition, and spatial distribution of Rainbow Trout, Walleye (*Sander vitreus)* and Mountain Whitefish (*Prosopium williamsoni*), the low recapture rates may be limiting the program's ability to detect population trends in Rainbow Trout (Ford et al. 2013, 2014).

It is recommended that consistent monitoring of the LCR and LKR Rainbow Trout population continue due to the changes occurring outlined above and also since this population is thriving at the moment, but may collapse due to its current high abundance. If it does, continual monitoring and analysis can point to management tools to recover the population. Studies focused on Rainbow Trout fry in the LCR and LKR could address some of the questions regarding the whole population dynamics as well as fry recruitment to corroborate the index of abundance obtained by the large river indexing program. The changes in the large river indexing program using observation as well as mark recapture should over time increase the power of that study program to track the Rainbow Trout abundance. Guided angler days have been recorded digitally from 2013-2016 and show approximately a 10% increase annually (J. Burrows, Pers. Comm.). This increased pressure may be due to human population growth in the region as well as the lack of other significant fisheries regionally and points to the importance of successful management of this Rainbow Trout population.

The primary purpose of the program is '*to better understand the link between flow management strategy and population abundance'* (BC Hydro 2007). Specifically, the next obvious direction for this study program is to understand what mechanisms may be driving the strong relationship determined in this year's analysis between age-1 recruit abundance and percentage of dewatered redds. It is proposed that BC Hydro provide the CLBMON-46 study team with the existing River 2D and transect data (depth and velocity over Rainbow Trout redds). This would allow advanced exploration of the data and modelling to occur in order to explore the possibility that increasing velocity from flow changes out of HLK during the summer months when fry emerge may be reducing recruitment.

Further research is also recommended to assess which mechanisms are driving recruitment in the Lower Kootenay River and the Lower Columbia River. Recommended research in the LKR would include: 1) obtaining accurate and precise stage data from a levellogger/barologger combination to determine what drops actually dewater usable and utilised habitat, and 2) reliable water temperature data for the LKR during the incubation period to refine the timing of when habitats need to remain watered in order to protect fry.

Drone technology or Unmanned Air Vehicles (UAV) as they are referred to in the regulations, continues to advance and is increasingly being used in biological survey work and may be under consideration for the LCR Rainbow assessments so is briefly discussed here. Most of the work has been done in wildlife settings, but those that have used UAVs for fisheries work found that UAVs: 1) were more expensive to run than helicopters, 2) showed a higher ability to detect redds due to a lower flying height and the ability to review footage after the flight (helicopter surveys counted 77% of the redds that UAVs captured), and 3) covered much less of the river in the spawning window than helicopters, necessitating more assumptions and modelling to extrapolate the UAV results to the whole system estimate (Groves et al. 2016). Generally, UAVs have the advantages of being safer in canyon or complex terrain, being able to be armed to collect thermal data or other remote sensing data from the air above and for using short time windows to respond to real time phenomena (Baggaley 2016). Disadvantages of UAVs include the short battery life which limits the flight time and area to be surveyed, particularly in cooler weather, the doubling of staff time budgets since the observations have to be reviewed and extracted from the footage after flying, the inability to fly them out of line of sight and their susceptibility to weather conditions. Usage of drones in an area frequented by anglers and other recreational users also raises the issue of privacy and right to use the footage, which would have to be addressed in alignment with current BC legislation. Aviation regulations in BC require a Special Flight Operations Certificate for Unmanned Air Vehicles[1]. If BC Hydro wishes to proceed with using a drone for counting and assessing the areal extent of Rainbow Trout spawning in the LCR, it is critical that both helicopter and drone methods overlap for 2 to 3 years in order to map the results of the past ten years of surveys onto the new method so that trend analyses are not biased by the change in methods and so the accuracy and precision can be assessed for UAV in this specific setting. Backup drones are furthermore considered essential in order to ensure data collection occurs (Groves et al. 2016).

5.0 CONCLUSIONS

Over the past ten years of the WUP program, the population abundance, spatial distribution and redd dewatering of Rainbow Trout spawning in the LCR and LKR have been assessed and analysed. The study program has been successful at determining the population increase, the increasing spatial distribution and the decrease in dewatered redds. However, as discussed by Thorley and Baxter (2011) in order to achieve the primary purpose of the program as stated in the TOR, it is necessary to model the population's response to alternative discharge regimes. Nonetheless, it is apparent that on average Rainbow Trout Spawning Protection Flows with a contribution from exclusion fencing in Genelle Channel E protect over 99% of the redds from dewatering.

[1] http://www.tc.gc.ca/eng/civilaviation/opssvs/getting-permission-fly-drone.html

6.0 REFERENCES

Allen, G.H., and Sanger, G.A. 1960. Fecundity of rainbow trout from actual count of eggs. Copeia **1960**(3): 260–261.

Arndt, S. 2000. Effect of an Artificial Side Channel on Fry Production and Rearing Densities of Rainbow Trout in Murphy Creek, Southeastern British Columbia. Columbia Basin Fish & Wildlife Compensation Program., Nelson, BC.

Arndt, S., and Klassen, K. 2004. Evaluation of Rainbow Trout Spawning Migrations in Blueberry, China, and Murphy Creeks from 1999 to 2003. Columbia Basin Fish and Wildlife Compensation Program, Nelson.

Baggaley, K. 2016, February 10. Drones are setting their sights on wildlife. Popular Science. Available from https://www.popsci.com/drones-wildlife-biology-animal-research.

Baxter, J.T.A. 2010a. Rainbow Trout Redd Excavation and Egg Salvage Activities in the Lower Kootenay and Lower Columbia Rivers - 2009 Data Report. A Mountain Waters Research Report, BC Hydro, Castlegar, BC.

Baxter, J.T.A. 2010b. Rainbow Trout Redd Excavation and Egg Salvage Activities in the Lower Kootenay and Lower Columbia Rivers - 2010 Data Report. A Mountain Waters Research Report, BC Hydro, Castlegar, BC.

Baxter, J.T.A. 2011a. Rainbow Trout Redd Excavation and Egg Salvage Activities in the Lower Kootenay and Columbia Rivers - 2011 Data Report. A Mountain Waters Research Report, BC Hydro, Castlegar, BC.

Baxter, J.T.A. 2011b. Lower Columbia River and Lower Kootenay River Rainbow Trout Redd Dewatering Threshold. Memo Report, Castlegar, B.C.

Baxter, J.T.A. 2012. CLBMON-46 Lower Columbia River Rainbow Trout Spawning Assessment: Implementation of a new hydrograph to determine the relationship bewten discharge and rainbow trout abundance through long term monitoring. Memo Report, A Mountain Water Research report prepared for BC Hydro, Castlegar, B.C.

Baxter, J.T.A., and Thorley, J.L. 2010. Lower Columbia River Rainbow Trout Spawning Assessment: Year 2 (2009 Study Period). A Mountain Waters Research Report, BC Hydro, Castlegar, BC.

Baxter, J.T.A., Thorley, J.L., and Irvine, R.L. 2016. Lower Columbia River Rainbow Trout Spawning Assessment: Year 8 (2015 Study Period). A Mountain Water and Poisson Consulting Ltd. Research Report, Prepared for BC Hydro, Kootenay Generation Area, Castlegar, B.C. Available from https://www.researchgate.net/publication/294875664_Lower_Columbia_River_Rainbow_Trout_Spawning_Assessment_Year_8_2015_Study_Period?ev=prf_pub.

BC Hydro. 2005. Consultative Committee Report: Columbia River Water Use Plan. BC Hydro, Burnaby, BC.

BC Hydro. 2007. Lower Columbia River Rainbow Trout Spawning Assessment Monitoring Program Terms of Reference. BC Hydro.

Bradford, M.J., Korman, J., and Higgins, P.S. 2005. Using confidence intervals to estimate the response of salmon populations (Oncorhynchus spp.) to experimental habitat alterations. Canadian Journal of Fisheries and Aquatic Sciences **62**(12): 2716–2726. doi:10.1139/f05-179.

Carpenter, B., Gelman, A., Hoffman, M.D., Lee, D., Goodrich, B., Betancourt, M., Brubaker, M., Guo, J., Li, P., and Riddell, A. 2017. *Stan* : A Probabilistic Programming Language. Journal of Statistical Software **76**(1). doi:10.18637/jss.v076.i01.

Fausch, K.D., Taniguchi, Y., Nakano, S., Grossman, G.D., and Townsend, C.R. 2001. Flood Disturbance Regimes Influence Rainbow Trout Invasion Success among Five Holarctic Regions. Ecological Applications **11**(5): 1438. doi:10.2307/3060931.

Ford, D., and Hildebrand, L. 2007. Brilliant Upgrade Project: Monitoring of Rainbow Trout Spawning in the Lower Kootenay River 2005 Report. A Golder Associates Ltd. Report, BC Hydro, Castlegar, BC.

Ford, D., Irvine, R.L., Thorley, J.L., Schmidt, D., and Hildebrand, L. 2008. Lower Columbia River Fish Population Indexing Surveys: Year 1 (2007 Study Period). A Golder Associates Ltd. Report, BC Hydro, Castlegar, BC.

Ford, D., Roscoe, D., Thorley, J.L., Hildebrand, L., and Schmidt, D. 2013. Lower Columbia River Fish Population Indexing Surveys: Year 6 (2012 Study Period). A Golder Associates Ltd. Report, BC Hydro, Castlegar, BC.

Ford, D., Roscoe, D., Thorley, J.L., Hildebrand, L., and Schmidt, D. 2014. Lower Columbia River Fish Population Indexing Surveys: Year 7 (2013 Study Period). A Golder Associates Ltd. Report, BC Hydro, Castlegar, BC. Available from https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/clbmon-45-yr7-2014-12-16.pdf.

Ford, D., Thorley, J.L., Hildebrand, L., and Schmidt, D. 2012. Lower Columbia River Fish Population Indexing Surveys: Year 5 (2011 Study Period). A Golder Associates Ltd. Report, BC Hydro, Castlegar, BC.

Golder, Okanagan Nation Alliance, and Poisson Consulting Ltd. 2017. Lower Columbia River Fish Population Indexing Surveys: Year 10 (2016 Study Period). An Okanagan Nation Alliance, Golder Associates and Poisson Consulting Report, BC Hydro, Castlegar, BC. Available from https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/clbmon-45-yr9-2016-08-01.pdf.

Groves, P.A., Alcorn, B., Wiest, M.M., Maselko, J.M., and Connor, W.P. 2016. Testing Unmanned Aircraft Systems for salmon spawning surveys. Facets **1**: 187–204.

Heaton, A., and Hildebrand, L. 1997a. Monitoring of Rainbow Trout Spawning in the Columbia River 1996 Data Report. An R.L. & L. Report, BC Hydro, Castlegar, BC.

Heaton, A., and Hildebrand, L. 1997b. Monitoring of Rainbow Trout Spawning in the Columbia River 1995 Data Report. An R.L. & L. Report, BC Hydro, Castlegar, BC.

Hildebrand, L., and McKenzie, S. 1995. Rainbow Trout Spawning in the Columbia River, B.C. with Emphasis on the Norns Creek Area 1990 to 1993. Vancouver, B.C.

Irvine, R.L., Baxter, J.T.A., and Thorley, J.L. 2014. Lower Columbia River Rainbow Trout Spawning Assessment: Year 6 (2013 Study Period). A Poisson Consulting Ltd. and Mountain Water Research Report, Prepared for BC Hydro, Kootenay Generation Area, Castlegar, B.C.

Irvine, R.L., Baxter, J.T.A., and Thorley, J.L. 2015. Lower Columbia River Rainbow Trout Spawning Assessment: Year 7 (2014 Study Period). A Mountain Water Research and Poisson Consulting Ltd. Report, BC Hydro, Castlegar, B.C. Available from http://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/southern-interior/clbmon-46-yr7-2015-02-04.pdf.

Klym, C., Smith, E., and Alliance, O.N. 2016. Rip-Rap Repair, Structure Maintenance, and Creation of Fish Habitat in Pass (Norns) Creek 2015-2016.

Larratt, H., Schleppe, J., Olson-Russello, M.A., and Swain, N. 2013. Columbia River Project Water Use Plan; CLBMON#44, Lower Columbia River Physical Habitat and Ecological Productivity Monitoring (Year 5). An Ecoscape Environmental Consultants Ltd. report prepared for BC Hydro.

Lindenmayer, D.B., Likens, G.E., Andersen, A., Bowman, D., Bull, C.M., Burns, E., Dickman, C.R., Hoffmann, A.A., Keith, D.A., Liddell, M.J., Lowe, A.J., Metcalfe, D.J., Phinn, S.R., Russell-Smith, J., Thurgate, N., and Wardle, G.M. 2012. Value of long-term ecological studies: VALUE OF LONG-TERM ECOLOGICAL STUDIES. Austral Ecology **37**(7): 745–757. doi:10.1111/j.1442-9993.2011.02351.x.

Magurran, A.E., Baillie, S.R., Buckland, S.T., Dick, J.M., Elston, D.A., Scott, E.M., Smith, R.I., Somerfield, P.J., and Watt, A.D. 2010. Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. Trends in Ecology & Evolution **25**(10): 574–582. doi:10.1016/j.tree.2010.06.016.

Muir, C., and Thorley, J.L. 2017. smbr: Analyses Using STAN. Available from https://github.com/poissonconsulting/jmbr.

Nehring, R.B., and Anderson, R.M. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the Physical Habitat Simulation system. Rivers **4**: 1–19.

Plummer, M. 2015, October 1. JAGS version 4.0.1 user manual. Available from http://sourceforge.net/projects/mcmc-jags/files/Manuals/4.x/jags_user_manual.pdf.

R Core Team. 2017. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available from https://www.R-project.org/.

Stan Development Team. 2017, September 5. Stan Modeling Language User’s Guide and Reference Manual.

Taylor, E.B. 2002. An Assessment of the Origins of Wild-Spawning Rainbow Trout (Oncorhynchus mykiss) in the Mainstem Columbia River near Castlegar, B.C., Using Microsatellite DNA. BC Hydro, Castlegar, BC.

Taylor, E.B. 2016. An assessment of genetic differences among Rainbow Trout (Oncorhynchus mykiss) spawning at different times and places in the Columbia River area near Castlegar, British Columbia: supplement to an initial report submitted in 2014. A UBC Zoology Report for BC Hydro, Castlegar, University of British Columbia, Vancouver, B.C.

Thorley, J. 2017a. jmbr: Analyses Using JAGS. Available from https://github.com/poissonconsulting/jmbr.

Thorley, J. 2018. Lower Columbia River Rainbow Trout Redd Dewatering Threshold Update 2018. A Poisson Consulting Ltd. Memorandum, BC Hydro, Castlegar.

Thorley, J.L. 2009. Lower Columbia River Rainbow Trout Stock Recruitment: Would ceasing redd excavations have population-level consequences? A Poisson Consulting Ltd. Report, BC Hydro, Castlegar, BC.

Thorley, J.L. 2017b. Lower Columbia River Rainbow Trout Redd Dewatering Threshold Update 2017. BC Hydro, Castlegar, BC.

Thorley, J.L., and Baxter, J.T.A. 2011. Lower Columbia River Rainbow Trout Spawning Assessment: Year 3 (2010 Study Period). A Mountain Waters Research Report, BC Hydro, Castlegar, BC.

Thorley, J.L., and Baxter, J.T.A. 2012. Lower Columbia River Rainbow Trout Spawning Assessment: Year 4 (2011 Study Period). A Mountain Waters Research Report, BC Hydro, Castlegar, BC. Available from http://www.bchydro.com/etc/medialib/internet/documents/planning_regulatory/wup/southern_interior/2012q1/clbmon-46_yr4_2012-02-08.Par.0001.File.CLBMON-46-Yr4-2012-02-08.pdf.

Thorley, J.L., Irvine, R.L., and Baxter, J.T.A. 2017a. Lower Columbia River Rainbow Trout Spawning Assessment: Year 9 (2016 Study Period). A Mountain Water and Poisson Consulting Ltd. Research Report, Prepared for BC Hydro, Kootenay Generation Area, Castlegar, B.C. Available from https://www.researchgate.net/publication/294875664_Lower_Columbia_River_Rainbow_Trout_Spawning_Assessment_Year_8_2015_Study_Period?ev=prf_pub.

Thorley, J.L., Muir, C.D., and Dalgarno, S. 2017b. Lower Columbia River Rainbow Trout Spawning Analysis 2017. A Poisson Consulting Analysis Report. Available from http://www.poissonconsulting.ca/f/453582501.

Walters, C.J., and Martell, S.J.D. 2004. Fisheries Ecology and Management. Princeton University Press, Princeton, N.J.

Weber, G.M., Martin, K., Kretzer, J., Ma, H., and Dixon, D. 2016. Effects of incubation temperatures on embryonic and larval survival in rainbow trout, *Oncorhynchus mykiss*. Journal of Applied Aquaculture **28**(4): 285–297. doi:10.1080/10454438.2016.1212447.

APPENDIX A

2017 Spawner and Redd Count Maps

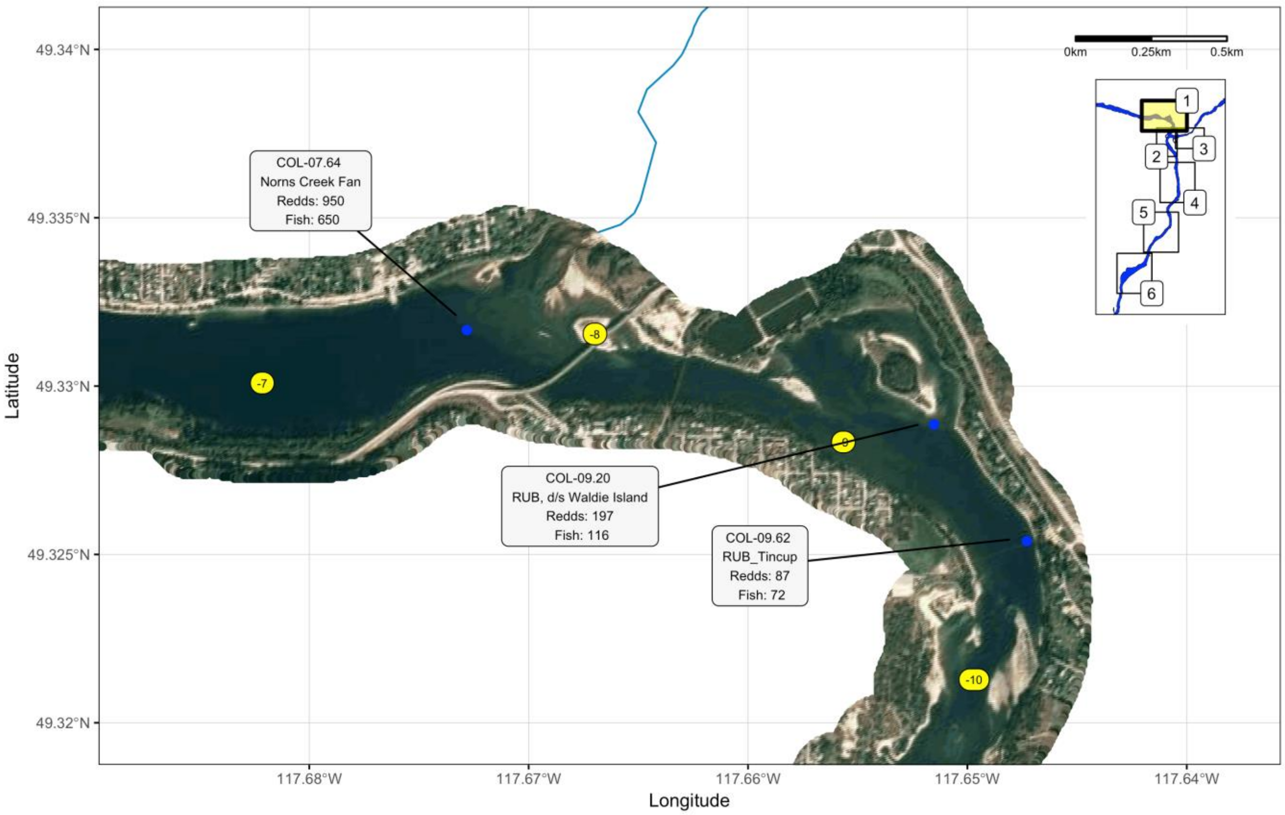

Figure A1. **Peak spawner and redd counts in Norn's Fan Area in 2017.**

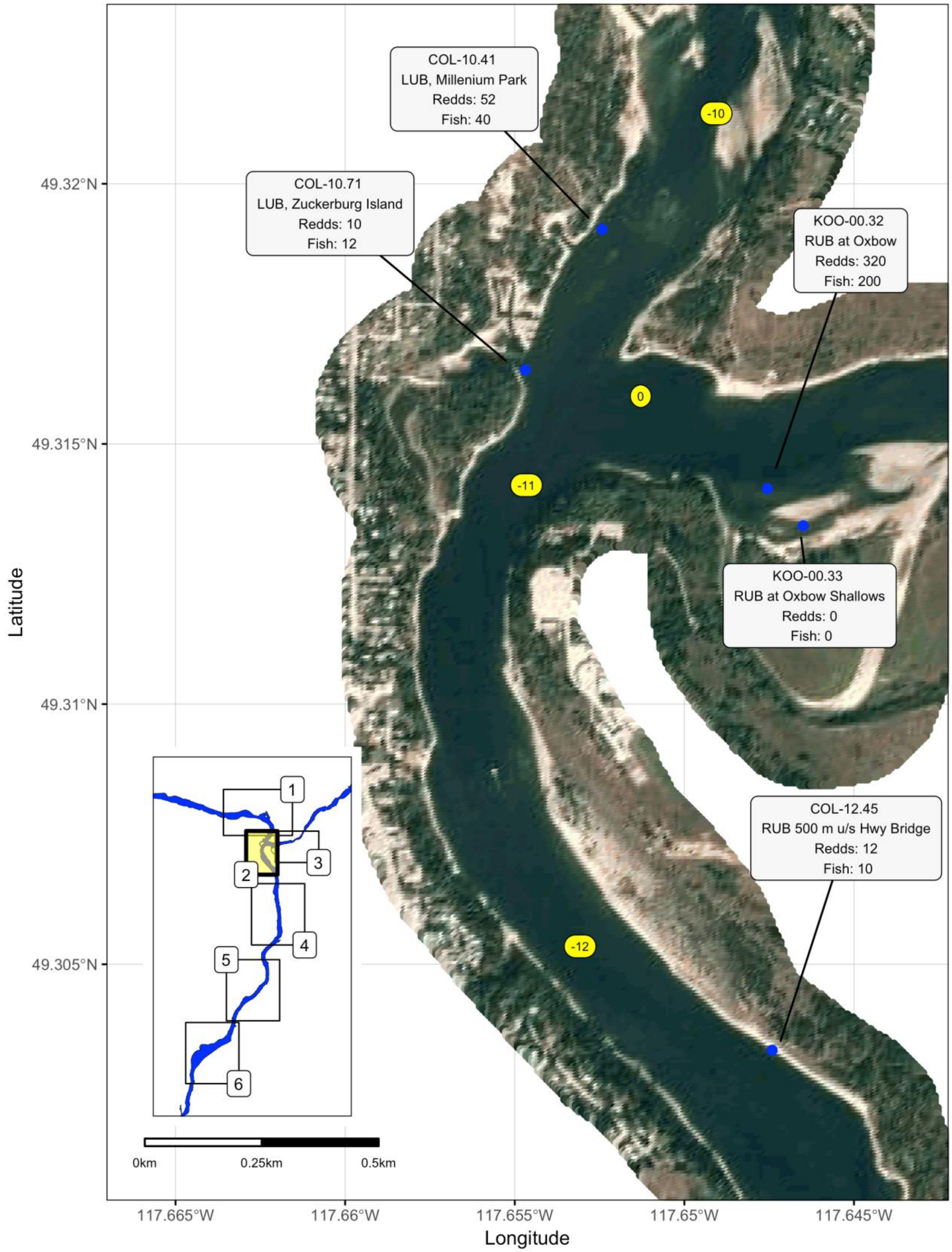

Figure A2. Peak spawner and redd counts by location in the Kootenay-Columbia confluence area in 2017.

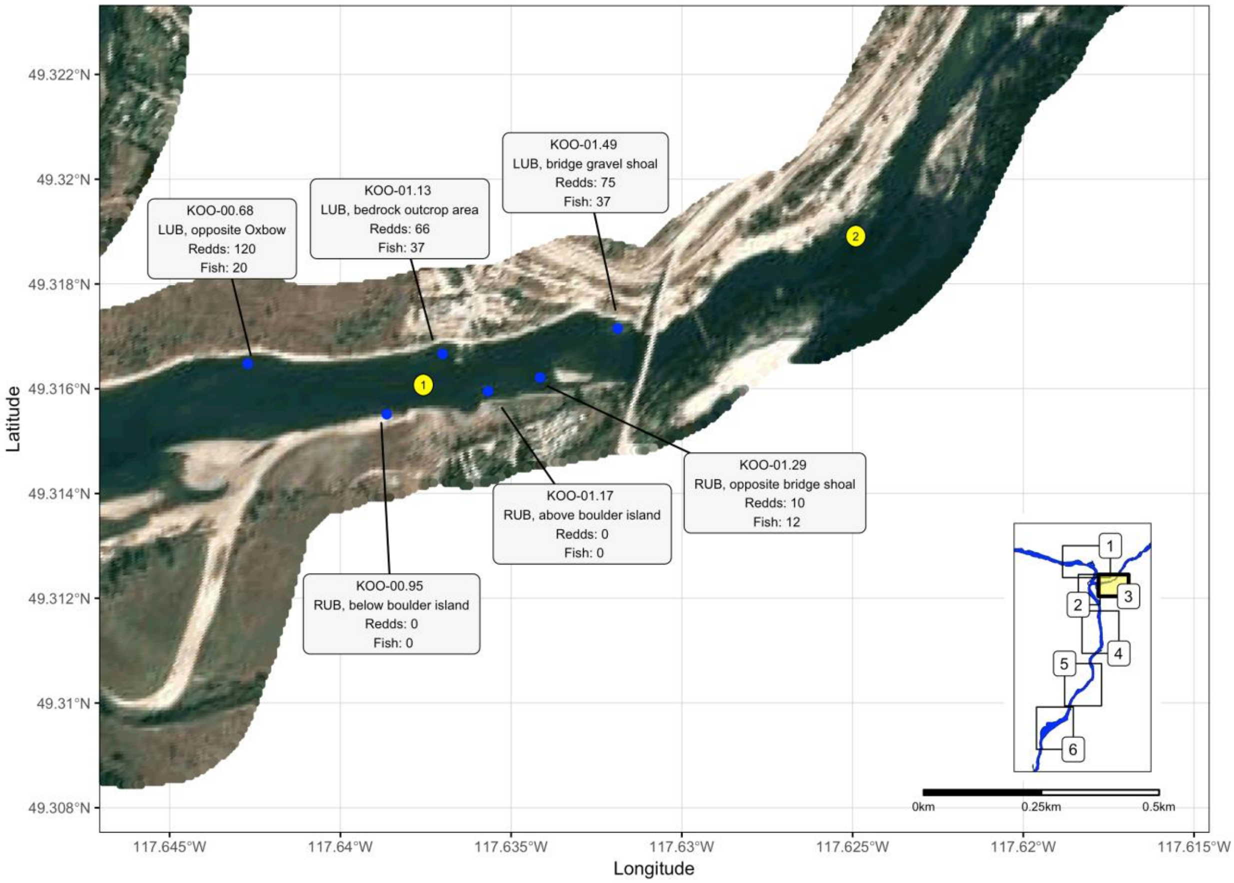

Figure A3. Peak spawner and redd counts by location in the Kootenay River area in 2017.

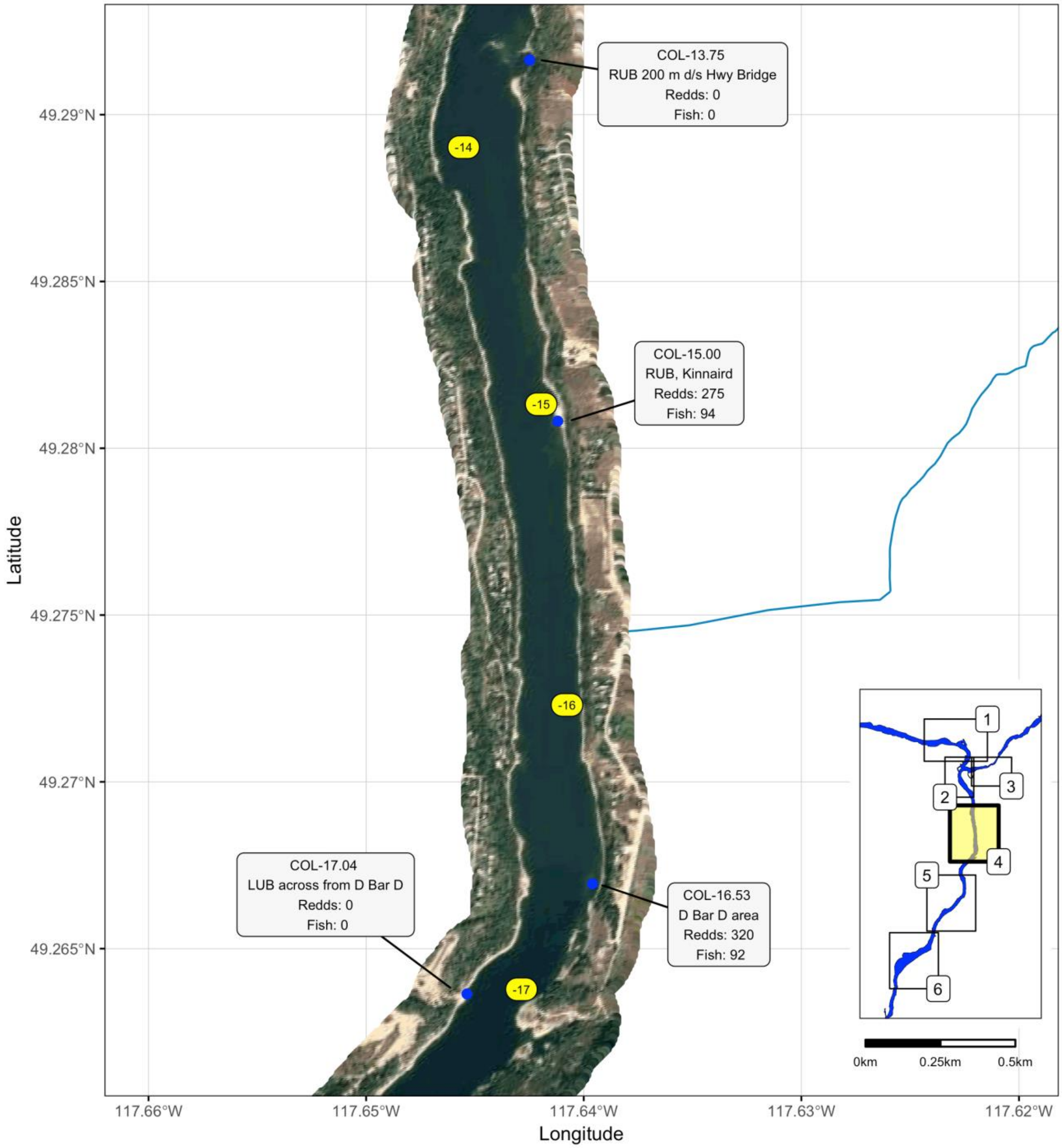

Figure A4. **Peak spawner and redd counts by location in the Kinnaird and D Bar D area in 2017.**

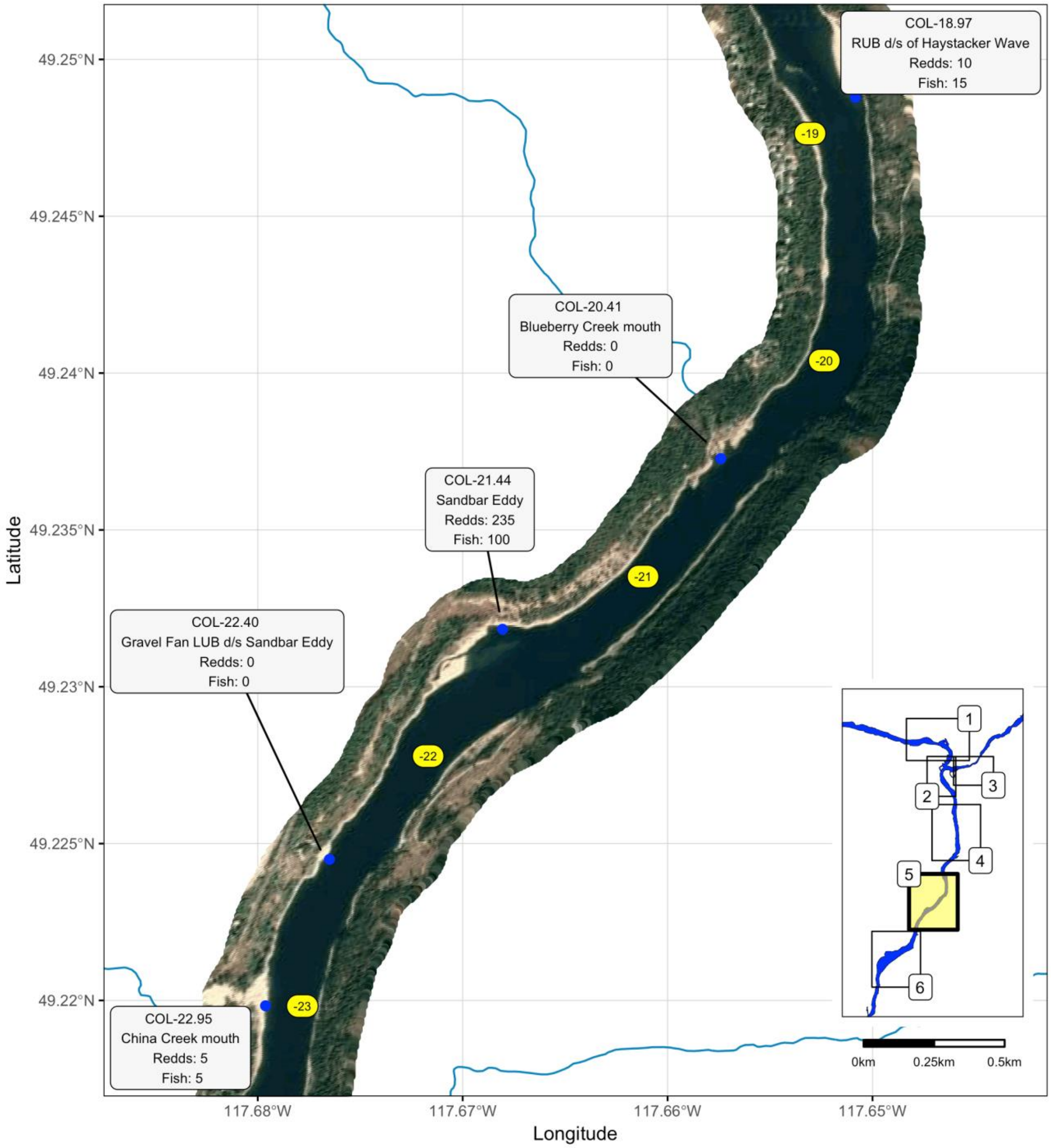

Figure A5. **Peak spawner and redd counts by location in the Blueberry –Sandbar Eddy – China Creek area in 2017.**

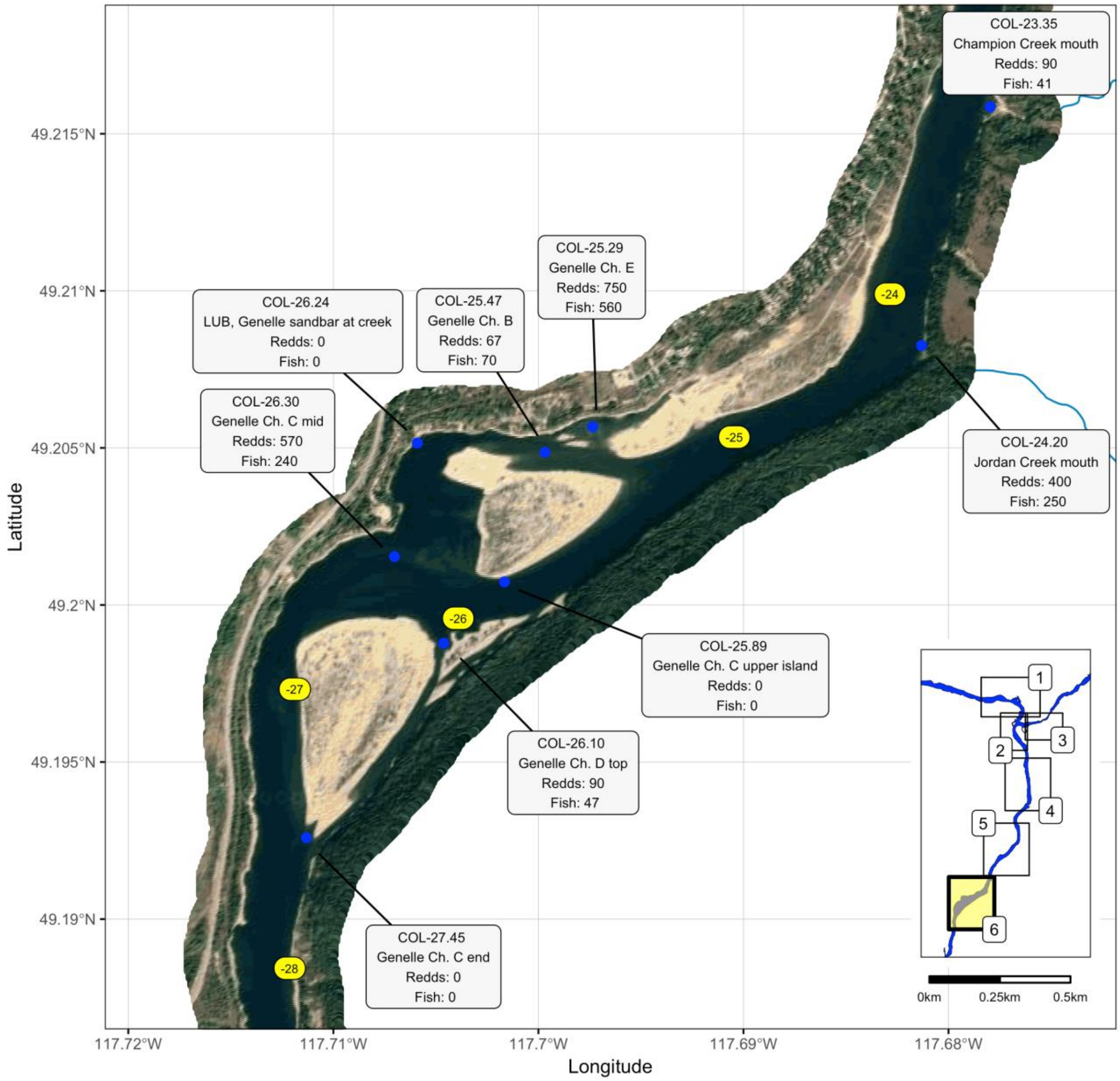

Figure A6. **Peak spawner and redd counts by location in the Genelle area in 2017.**

APPENDIX B

2017 Spawner and Redd Counts with AUC Estimates and Viewing Conditions

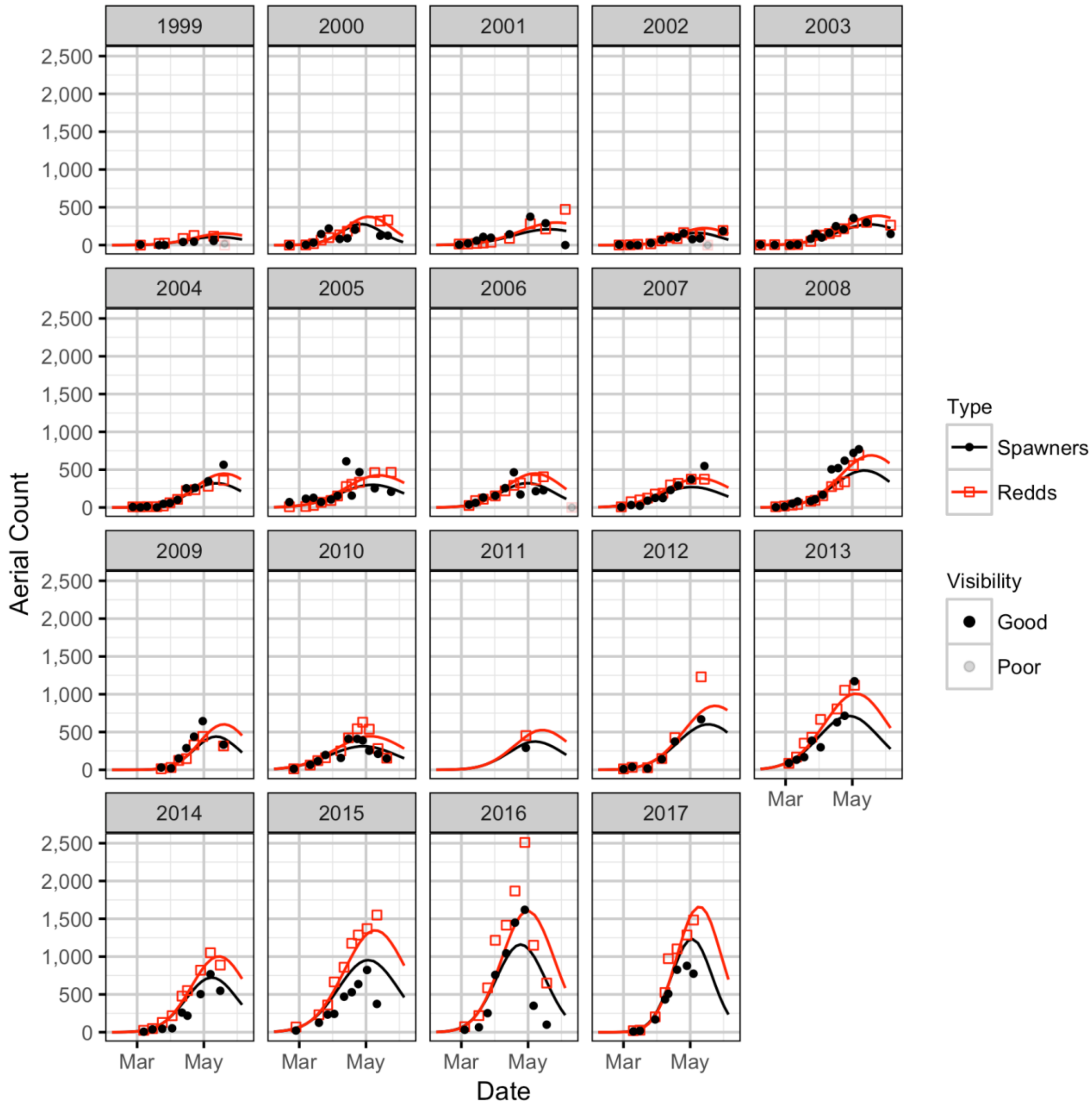

Figure B1. **The spawner and redd counts for the Lower Columbia River above the Kootenay River with the AUC-based estimates of the expected counts 1999-2017.**

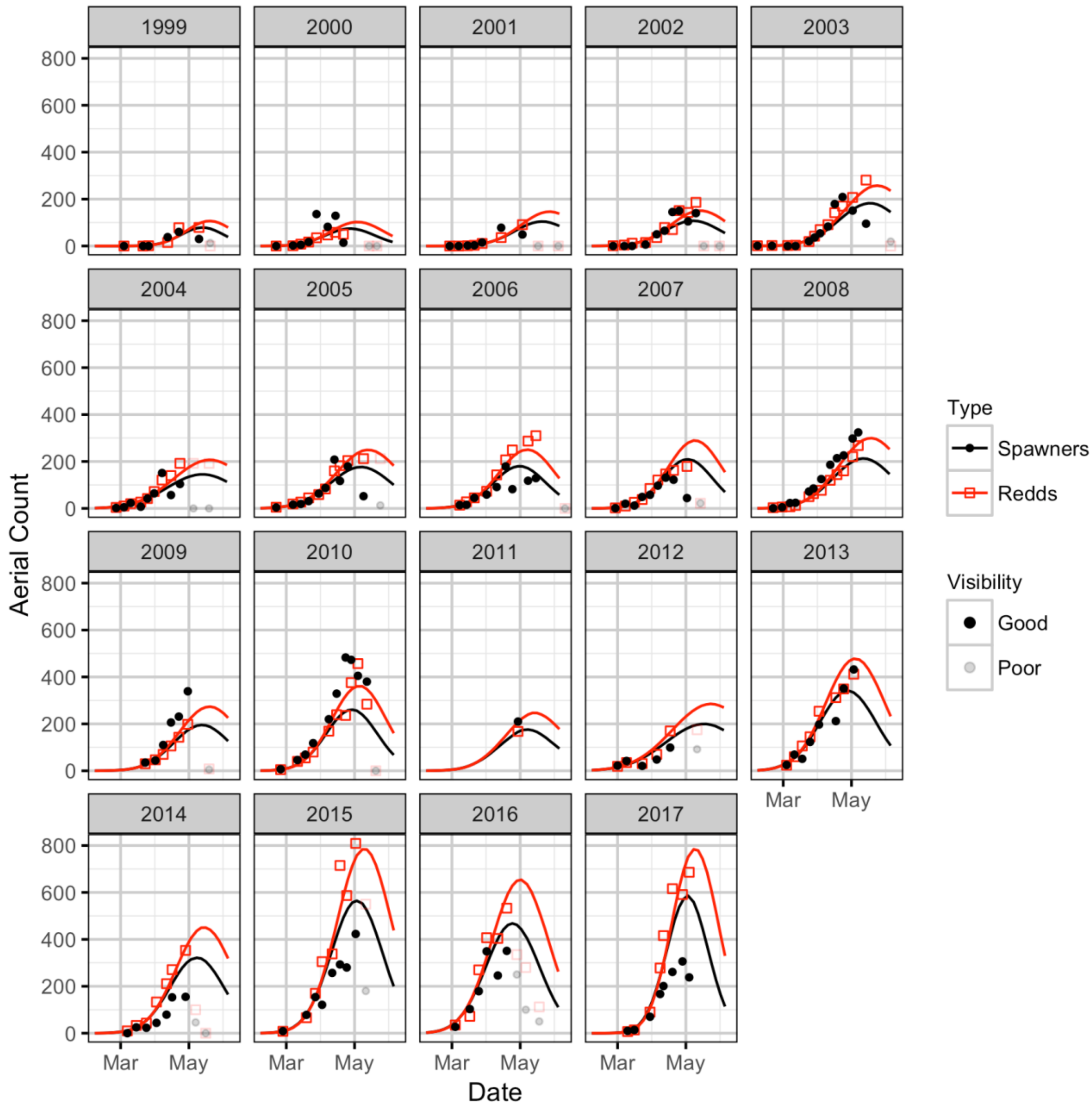

Figure B2. **The spawner and redd counts for the Kootenay River below Brilliant Dam with the AUC-based estimates of the expected counts 1999-2017.**

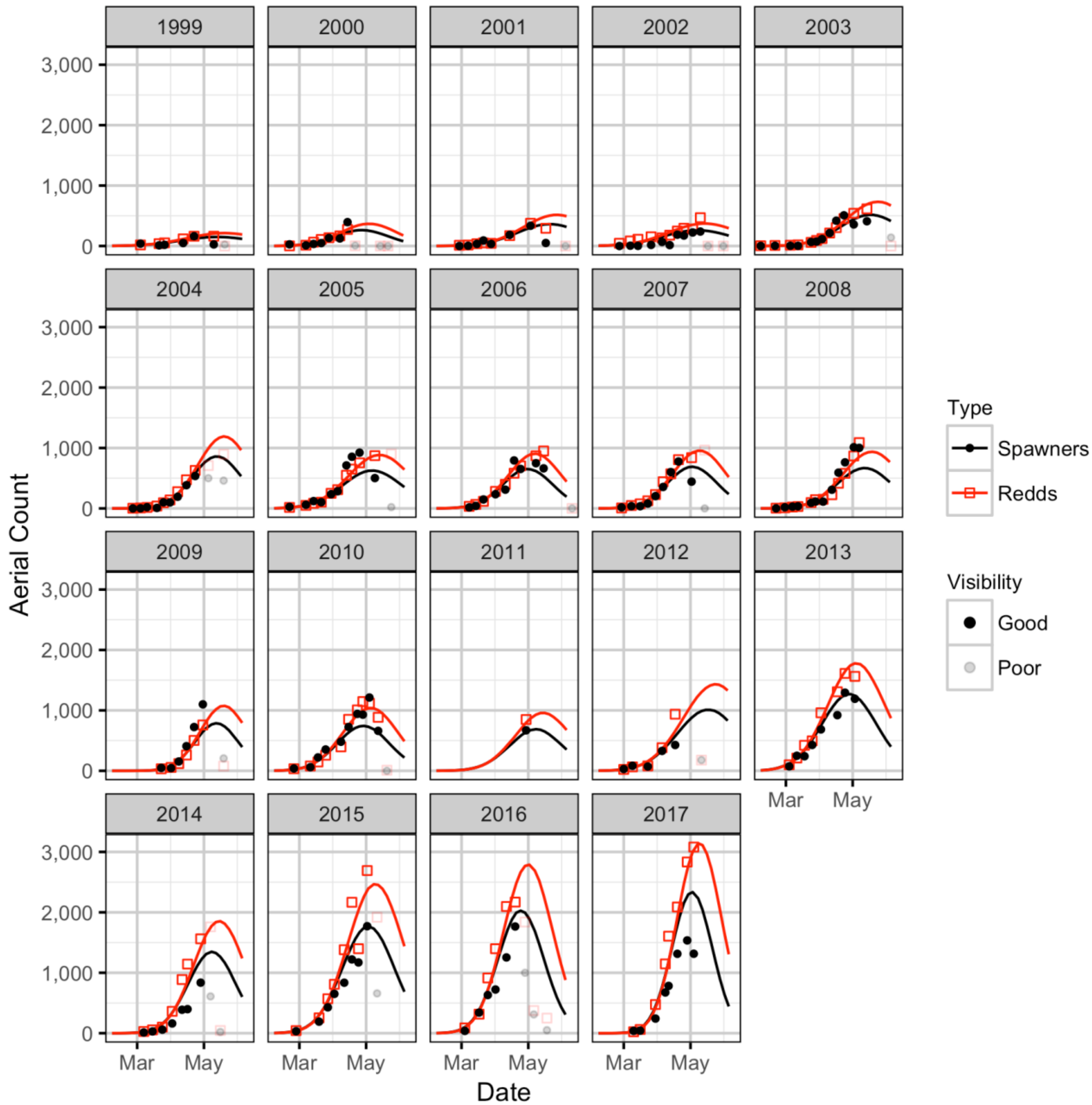

Figure B3. **The spawner and redd counts for the Lower Columbia River below the Kootenay River with the AUC-based estimates of the expected counts 1999-2017.**