Columbia River Project Water Use Plan

Lower Columbia River Fish Management Plan

Implementation Year 1 (2019)

Reference: CLBMON-46

LOWER COLUMBIA RIVER RAINBOW TROUT SPAWNING ASSESSMENT

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EXECUTIVE SUMMARY

Since 1992, BC Hydro has implemented the Rainbow Trout Spawning Protection Flows (RTSPF) through operations on Hugh L. Keenleyside Dam in the Lower Columbia River (LCR). These flows were designed to provide stable or increasing flows during the spawning window for Rainbow Trout. Historically, BC Hydro has monitored Rainbow Trout spawning in the LCR and Lower Kootenay River (LKR) from January to July under RTSPF to assess a) relative population abundance; b) redd numbers and distribution; and c) spawn timing. In 2018, two key uncertainties were identified: 1) whether the RTSPF flows improve incubation success of Rainbow Trout redds, and 2) whether the improvements in incubation success, if any, result in increased Rainbow Trout abundance. The key operating decision that will be affected by this program is whether to continue the annual implementation of RTSPF in the LCR. If the RTSPF significantly increase incubation success, protection flows will be considered for further implementation. Alternatively, spawning protection flows may not be required if the changes in incubation success do not influence Rainbow Trout abundance.

Therefore, the primary objective of the current Rainbow Trout Spawning Assessment monitoring program is to assess flow management effects on Rainbow Trout egg mortality in the LCR. The egg and alevin mortality will be assessed by excavating redds at a range of intervals after redd dewatering and determining the stage of eggs and percentage of mortality. The excavated redds will be nearby the transects of temperature loggers established prior to the onset of spawning at the two sites: Norn's Creek Fan and the Kootenay River Oxbow. Interstitial gravel temperatures as well as air temperature, solar radiation, and stage height will be recorded to refine the understanding of the mechanisms behind the egg and alevin mortality. This is in addition to continuing to track Rainbow Trout abundance, spawn timing and spatial distribution within the study area of the LCR downstream of Hugh L. Keenleyside Dam to the U.S. Border and the LKR downstream of Brilliant Dam.

The current year of the study (2019) represents the first year without RTSPF since 1992. The current order to determine the number of redds dewatered without the protective flow management strategy and this manipulation will occur in alternate years until 2023. In 2019 despite the absence of RTSPF, only 101 redds (representing about 0.7% of the total) were dewatered. On average, the redd dewatering rate over the 1999-2017 period of monitoring was 0.7% so the spawning season in 2019 was typical of an average spawning protection flow year (Irvine et al. 2018).

Egg mortality assessed in dewatered redds varied between 0 and 100% but was typically below 25% and appeared to be unaffected by dewatering for at least the first week given the humidity and temperatures encountered.

Several of the temperature logger locations at two key spawning areas on Norn's Creek Fan and the Kootenay River Oxbow showed inter-gravel temperatures that exceeded 25°C during dewatered periods in May and June and in a warm, lower water period in September. This water temperature is well in exceedance of the value of 15°C where high mortality of Rainbow Trout eggs and embryos is experienced (Carter 2005). To be protective of spawning, incubation and fry emergence, water termperature should remain at or below 13°C (averaging the daily maximum temperature over 7 days) (Carter 2005; Weber et al. 2016).

Peak counts of redds showed the highest numbers at Genelle (1,135) and Norn's Creek Fan (1,000). These two areas have consistently harboured the highest redd numbers through time. The analysis of the redd and spawner counts estimated that there were 9,784 spawners in the mainstem in 2019 (95% CIs from 7,239-13,666). Over the period of monitoring, there has been a 7-fold increase from an estimated abundance of 1,403 spawners in 1999 to the 9,784 spawners in 2019. The abundance has been relatively stable since 2013 with overlapping CIs among years.

The trend in the numbers of spawners in Norn's Creek has shown a similar trend with increases through time and an estimated abundance in 2019 of 1,694 spawners and the peak estimated abundance over the period of monitoring occurred in 2017.

Spawning was estimated to begin between March 18th to 25th (depending on location within the river), to peak on May 11th and to be completed between June 19th to July 7th. This spawn timing is similar to previous years.

ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	Definition
Assessment	Lower Columbia River Spawning Assessment
AUC	Area-Under-the-Curve
CI	Confidence Interval
CRI	Bayesian Credible Interval
DO	Dissolved Oxygen
LCR	Lower Columbia River
LKR	Lower Kootenay River
MAF	Million Acre Feet = 1233.5m^3 volume of water
MASL	Metres above sea level
Nupqu	Nupqu Development Corporation
MWR	Mountain Water Research
Project	Lower Columbia River Rainbow Trout Spawning Habitat and Egg Mortality Study
Poisson	Poisson Consulting Ltd.
SARA	Species at Risk Act
RTSPF	Rainbow Trout Spawning Protection Flows

SYMBOLS AND UNITS OF MEASURE

Symbol / Unit of Measure	Definition
>	greater than
<	less than
%	percent
°C	degrees Celsius
ft	foot
ha	hectare
km	kilometre
m	metre
mm	millimetre
m^2	square metre
m^3	cubic metre
m/s	metres per second
m^3/s	cubic metre per second

1.0 PROJECT OVERVIEW

1.1 Introduction

The primary objective of the current experimental protocol for the Rainbow Trout Spawning Assessment monitoring program is to reduce uncertainties pertaining to flow management effects on Rainbow Trout egg mortality in the LCR and the resulting impact of the egg mortality on Rainbow Trout population abundance (BC Hydro 2018).

Rainbow Trout Spawning Protection Flows (RTSPF) were first implemented on the Lower Columbia River in 1992 to reduce redd dewatering associated with declining discharge during Rainbow Trout spawning and egg incubation. The most recent phase of monitoring program ran from 2008-2017 and focused on changes in the rate of redd dewatering, spawner abundance and the spatial distribution of the spawners. The results demonstrated that RTSPF were very effective at protecting Rainbow Trout redds from dewatering (typically < 1% were dewatered each year). However, the monitoring program was not able to attribute the substantial (four-fold) increase in spawner abundance since 1999 to operations as RTSPF were implemented throughout the study (Irvine et al. 2018).

Continued implementation of the RTSPF represents a significant trade-off for the Columbia River WUP Consultative Committee, as halting RTSPF would provide benefits for vegetation, wildlife, fish, and recreation objectives in Arrow Lakes Reservoir, by releasing the extra 1MAF of water that would otherwise be held back to provide limited flows between April and June. BC Hydro wishes to resolve whether changes to flow management to accommodate other values could occur without significantly altering Rainbow Trout population status.

In 2018, a Technical Committee consisting of representatives from First Nations, government agencies, and BC Hydro reviewed the data and concluded that due to density-dependent mortality, over 50% of the current redd deposition could likely be dewatered with no effect on the subsequent recruitment. In order to test this finding, the Technical Committee agreed to implement an experimental approach, as part of future monitoring of CLBMON-46, where RTSPF would no longer be implemented in alternate years starting in 2019 for a maximum duration of five years (i.e., no RTSPF in 2019, 2021 and 2023), with a review of the interim results in the fall of 2020.

The current study was designed to reduce the uncertainty about the timing of late-season redd construction and dewatering on the LCR and LKR; the timing of emergence; the survival of dewatered redds and alevins and the effect of environmental conditions on inter-gravel temperatures in exposed redds.

The following report summarizes the outcomes from the first year of field monitoring and analysis in a non-RTSPF year. More specifically it documents the findings to date regarding redd dewatering in a non-RTSPF year, egg and alevin mortality and inter-gravel temperatures.

1.2 Study Area

The geographical scope of the monitoring program is the LCR downstream of Hugh Keenleyside L. Dam (HLK) to the Canada-U.S. border and the LKR downstream of Brilliant Dam (BRD). On the Columbia mainstem this study area encompasses approximately 56.5 km of the riverine habitat from the base of HLK to the Canada-U.S. border (Figure 1). In the LKR, the study area includes the 2.8 km of the Kootenay River below BRD until its confluence with the Lower Columbia (Figure 1). The major gravel areas on the LCR and in the LKR are known by name and all areas are surveyed during the flights with the exceptions of those noted below.

For the purposes of this study, the study area was divided into seven sections: 1) the Columbia River from HLK (RKm 0.0) to above Norn's Creek Fan (RKm 7.8); 2) Norn's Creek Fan; 3) below Norn's Creek Fan to the confluence with the Kootenay River (RKm 10.7); 4) the Kootenay River from BRD to the confluence with the Columbia River; 5) the Columbia River from the confluence with the Kootenay River to above Genelle (RKm 25.5); 6) Genelle; and 7) the Columbia River from below Genelle to the Canada-U.S. border (RKm 56.5). Redd and spawner counts from sections 1 and 7 were excluded from the analyses because they historically constituted less than 0.1% of the total count and were not surveyed in all years. The remaining five sections were aggregated into three segments for analysis of spawn-timing. The three segments are the Lower Kootenay River, the LCR above LKR and the LCR below LKR.

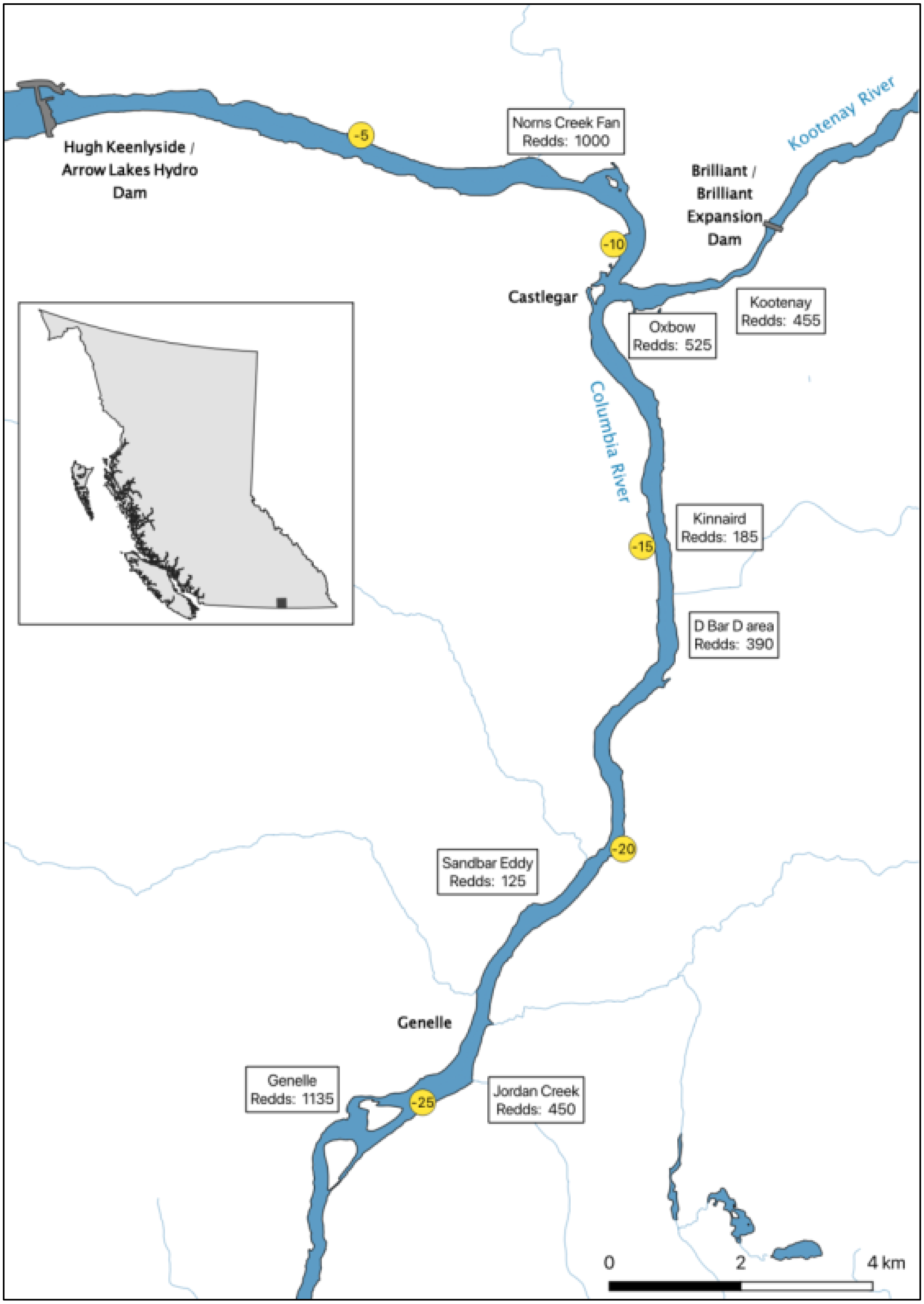

Figure 1 Overview map of the Lower Columbia River and Lower Kootenay River study area with peak count redd numbers by key areas.

2.0 METHODS

2.1 Rainbow Trout Redd and Spawner Surveys

Rainbow Trout redds and spawners were monitored in the Lower Columbia River with boat and helicopter surveys. Prior to commencing helicopter surveys, boat surveys were done to ensure spawning had begun. The aerial surveys were conducted approximately once a week and covered the various sections during the Rainbow Trout spawning season as visibility permitted. 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 helicopter surveys were supplemented by the use of boat surveys, which cover the main spawning areas from Norn's Creek Fan to Genelle. The boat surveys allow the identification of redds that are questionable from the air, the recording of redds in less than 1.0 m of water to monitor the risk of dewatering and the confirmation of possible new spawning areas seen from the air (Baxter 2011).

These surveys have been done in every year since 1999 with varying frequency. Viewing conditions were classified as Good or Poor. If information on the viewing conditions was not available, a decline in the redd count of more than one third of the cumulative maximum count for a particular segment was assumed to be caused by poor viewing conditions. In 2019, due to low flows from HLK dam, surveys were able to be conducted at Norn's Creek Fan until early June.

2.2 Norn's Creek Spawner and Redd Count Snorkel Survey

Spawner and redd count snorkel surveys are conducted in Norn's Creek when time, resources and conditions permit as it provides important spawning habitat. In 2019 the snorkel survey was completed on May 8th. The survey was conducted during daylight hours by three snorkelers who counted spawners and a bank observer moving downstream who counted redds. The four-person crew was sufficient to cover the entire width of the creek that was usable by spawning trout. The snorkelers divided the mean usable width of the creek into approximately three 4 m lanes with the bank observer walking on the left bank. Frequent stops occurred to discuss any potential duplication in counts and record the results. If a snorkeler observed a redd in deep water which might have been missed by the bank observer, it was discussed and counted. All of the redds and spawners were georeferenced by the bank observer using a handheld Garmin GPS. Underwater visibility was recorded at the beginning and completion of the survey by measuring the distance at which a white 10 cm by 18 cm dive notebook page was no longer distinctly identifiable by the snorkelers. 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. The spawner and redd counts from Norn's Creek are not added to the Columbia River and Kootenay River aerial count totals nor are they included in the mainstem abundance estimates.

2.3 Rainbow Trout Redd Dewatering Surveys

Locations of shallow water redds (those in less than 1.0m of water) were recorded using a handheld Garmin GPS unit and marked with an individually numbered weighted tag by crews during boat surveys. Following major flow reductions, boat and foot surveys were conducted at sites with the potential to produce dewatered redds (Table 1). Depending on the river stage, exclusion fencing has sometimes been erected in Channel E on the left upstream bank of the Genelle area. As the purpose of the current year is to assess the impact of dewatering, exclusion fencing was not installed in 2019. Due to the late start of the program it is possible a small number of redds were dewatered by the February 22, 2019 reduction. The uncertainty exists because the exposed gravels were covered by snow when the redd dewatering survey occurred on March 1, 2019.

Table 1 Reduction dates, magnitude of reduction, number and general location of dewatered redds in 2019.

Reduction Date	HLK Discharge Start (m^3/s)	HLK Discharge End (m^3/s)	BRD Discharge Start (m^3/s)	BRD Discharge End (m^3/s)	Dewatered Redd Count	Location
Feb. 22, 2019	1354	734	400	398	-	Locations snow covered
March 8, 2019	1289	494	425	459	7	Genelle Ch.E
March 8, 2019	1289	494	425	459	9	Norn's Creek Fan
May 15, 2019	752	430	1289	1326	3	Norn's Creek Fan
May 18, 2019	426	297	1483	1479	71	Norn's Creek Fan
May 18, 2019	426	297	1483	1479	3	RUB, d/s of Waldie Is.
June 3, 2019	649	341	1804	1842	8	Norn's Creek Fan

2.4 Egg and Alevin Mortality Surveys

The mortality of dewatered Rainbow Trout eggs and alevins was only monitored at Norn's Creek Fan as no redds were dewatered at the Kootenay Oxbow. Individual dewatered redds were marked using a uniquely numbered tag. Egg and alevin mortality was monitored through consecutive redd excavations to better understand the relationship between duration of dewatering and mortality. During the excavations the embryos were inspected using a hand lens and staged using a photographic guide (see Appendix D). The excavation depth, and number of alive and dead embryos were also recorded. All the embryos were reburied in the redd. Subsequent excavations inspected eggs from previously undisturbed areas or undisturbed depths of the redd to reduce the chances of handling effects inflating the mortality. The original approach was to use different redds on each subsequent site visit, but there were insufficient exposed redds to use this approach in the 2019 field season. Elevation above water surface for each inspected redd was measured using a level rod and a laser clinometer.

On May 24th, 2019, eggs from five redds that had been dewatered for between 5-8 days and eggs from two control (wetted) redds in shallow water were incubated in an autoredd to compare survival rates and determine time to hatch. The eggs from each redd were incubated in their own egg capsule. The number of eggs incubated from each redd varied but ranged from 25-200 eggs.

Sampling of Rainbow Trout eggs and associated redd excavations occurred in accordance within the Department of Fisheries and Oceans Canada Species at Risk Permit #18-PPAC-00009 and Scientific Fish Collection Permit #CB19-468675, issued by the Ministry of Forest, Lands and Natural Resource Operations, Kootenay – Boundary Region.

2.4.1 Environmental Data

In order to begin relating egg mortality in dewatered redds to environmental conditions the water elevation, water temperature, air temperature, solar radiation, relative humidity, precipitation and inter-gravel temperatures were recorded at Norn's Creek Fan and the Kootenay Oxbow.

Real-time Onset Hobo RX3000 monitoring stations were installed in mid-March, 2019 in the LCR adjacent to Norn's Fan and in the LKR near the Kootenay River Oxbow (Figure 2, Figure 3). The real-time stations were installed to record water elevation, water temperature, air temperature, solar radiation, relative humidity and precipitation. A backup Onset Hobo MX2001 level logger was also installed upstream of both sites. In addition, 22 spawning gravel temperature monitoring stations (15 at Norn's Fan and 7 at the Kootenay River Oxbow) were installed for the egg mortality study (Figure 2, Figure 3). Each spawning gravel temperature monitoring station has three Onset Hobo MX2201 temperature loggers recording at 10 cm, 20 cm and 30 cm depths. These loggers were affixed to a wooden stake to allow pre-measuring and help with ease of install at reliable and repeatable depths.

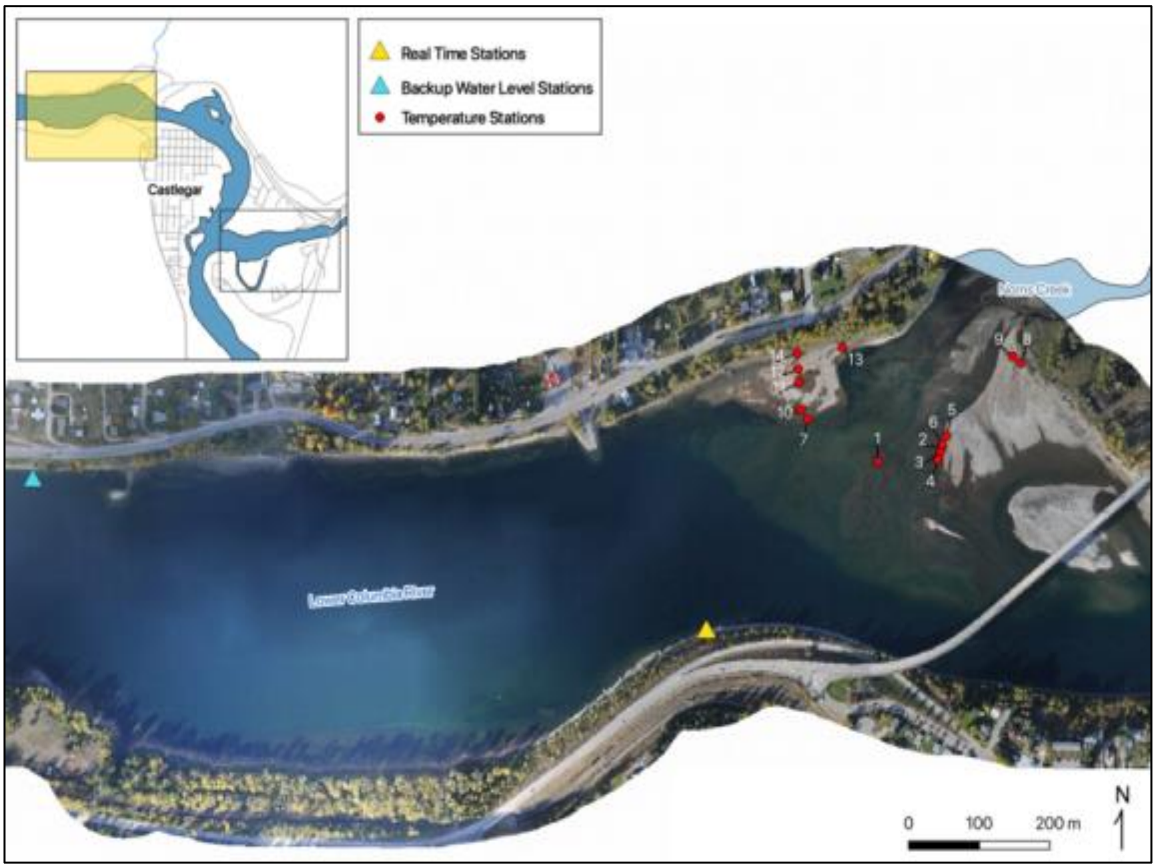

Figure 2 Monitoring stations on the Lower Columbia River at Norn's Creek Fan.

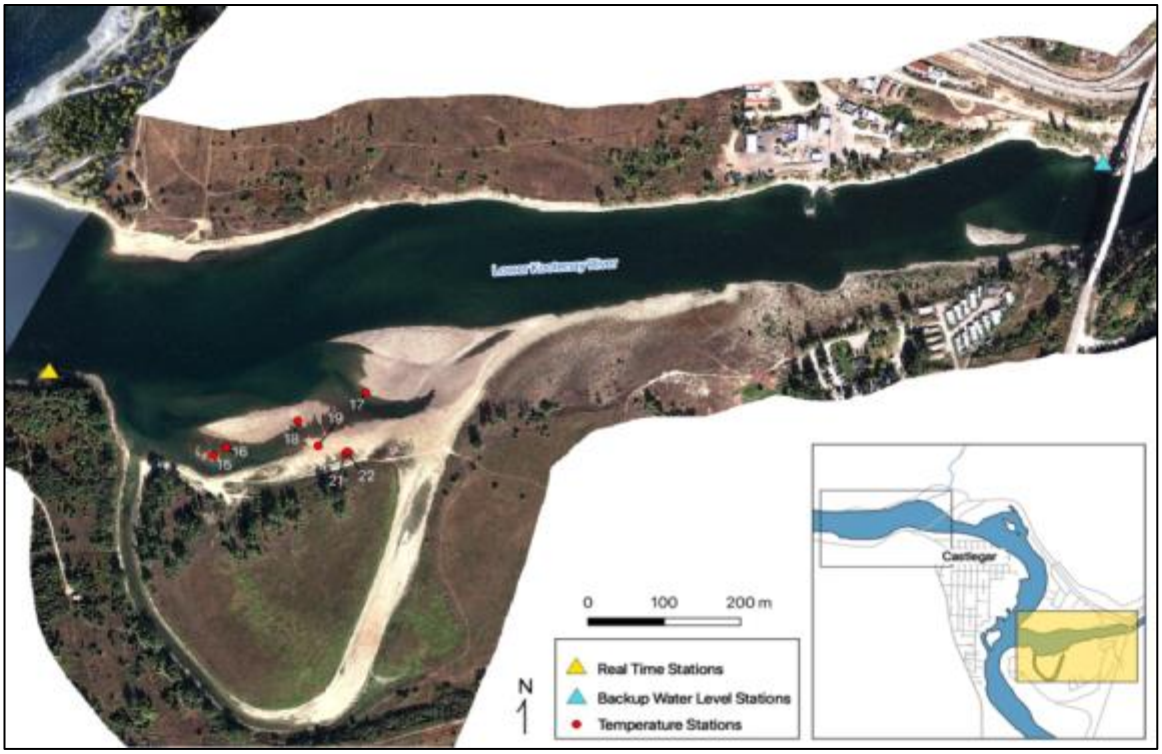

Figure 3 Monitoring stations on the Lower Kootenay River at the Oxbow.

2.5 Data Sources and Preparation

The redd and spawner surveys were conducted by Mountain Water Research and the data were backed up weekly to a secure online server. The age-1 Rainbow Trout abundance estimates were provided by the CLBMON-45 Large Fish Population Indexing Program currently conducted by Okanagan Nation Alliance. The remaining data were collected by Mountain Water Research, Poisson Consulting and Nupqu.

The real-time stations continuously transmitted all sensor data to a project specific HOBOlink account where it was securely stored online. Data from exposed gravel temperature loggers were manually uploaded via Bluetooth to hand-held mobile devices and automatically securely stored online on the user's HOBOlink account. To simplify the data download process, Poisson Consulting developed an Application Programming Interface (API) R client to directly query each of the HOBOlink accounts. An email data delivery subscription was also set up with HOBOlink and files received were stored as a data backup on an external hard drive.

The data were cleaned and prepared for analysis using R version 3.6.1 (R Core Team 2017) and entered into a customized SQLite database.

2.6 Statistical Analysis

Model parameters were estimated using Bayesian methods. The estimates were produced using JAGS (Plummer 2015) and STAN (Carpenter et al. 2017). For additional information on Bayesian estimation the reader is referred to McElreath (2016).

Unless stated otherwise, the Bayesian analyses used weakly informative normal and half-normal prior distributions (Gelman et al. 2017). The posterior distributions were estimated from 1,500 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of tree chains (Kery and Schaub 2011). Model convergence was confirmed by ensuring that the potential scale reduction factor R-hat≤1.05 (Kery and Schaub 2011) and the effective sample size (Brooks et al. 2011) ESS ≥150 for each of the monitored parameters (Kery and Schaub 2011).

The parameters are summarized in terms of the point estimate, standard deviation (sd), the z-score, lower and upper 95% confidence/credible limits (CLs) and the p-value (Kery and Schaub 2011). 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. A p-value of 0.05 indicates that the lower or upper 95% CL is 0.

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 hyper- distributions) (Kery and Schaub 2011). 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 3.6.1 (R Core Team 2019) and the mbr family of packages. The analytic appendix can be found online at http://www.poissonconsulting.ca/f/949693135.

2.6.1 Area-Under-the-Curve

The number of spawners and redds and the timing of spawning were estimated in each of the five sections (which are grouped into three segments) using a hierarchical Bayesian Area-Under-the-Curve (AUC) model.

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.
- Spawner residence time is between 14 and 21 days as determined by Baxter et al. (2016).
- Redd residence time is between 30 and 40 days.
- Spawner arrival and departure times are normally distributed.
- Spawner arrival duration (SD of normal distribution) varies randomly by segment 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.

In previous years, Norn's Creek Fan and Genelle were not analyzed as separate sections, i.e., abundance was estimated for each of the three segments not each of the five sections.

2.6.2 Stock-recruitment Relationship

The relationship between the number of spawners and the number of age-1 fish the following fall was estimated using a Beverton-Holt stock-recruitment model (Walters and Martell 2004):

$$R = \frac{\alpha \cdot S}{1 + \beta \cdot S} \quad ,$$

where S is the spawners (stock), R is the recruits, α is the recruits per spawner at low density and β determines the density-dependence.

Key assumptions of the stock-recruitment model include:

- The recruits per spawner at low density (α) is normally distributed with a mean of 90 and a SD of 50.
- The recruits per spawner varies with the percent of redds dewatered.
- The residual variation in the number of recruits is log-normally 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.
- The carrying capacity is α/β.

3.0 RESULTS

All results from the data processing and analysis are in this section. The analytic appendix including model descriptions and R code is available at *http://www.poissonconsulting.ca/f/949693135*.

3.1 Redd and Spawner Abundance

As in previous years, the areas with the most spawning in 2019 were Genelle (1135 redds; Figure 1) and Norn's Creek Fan (1000 redds; Figure 1). Detailed maps of the peak spawner and redd counts at individual spawning sites within the study area are available in Appendix A.

The analysis of the redd and spawner counts estimated that there were 9784 spawners in the mainstem in 2019 (95% CIs from 7239-13666). Over the period of monitoring, there has been a 7-fold increase from an estimated abundance of 1403 spawners in 1999 to the 9784 spawners in 2019. The abundance has been relatively stable since 2013 with overlapping CIs among years. (Figure 4).

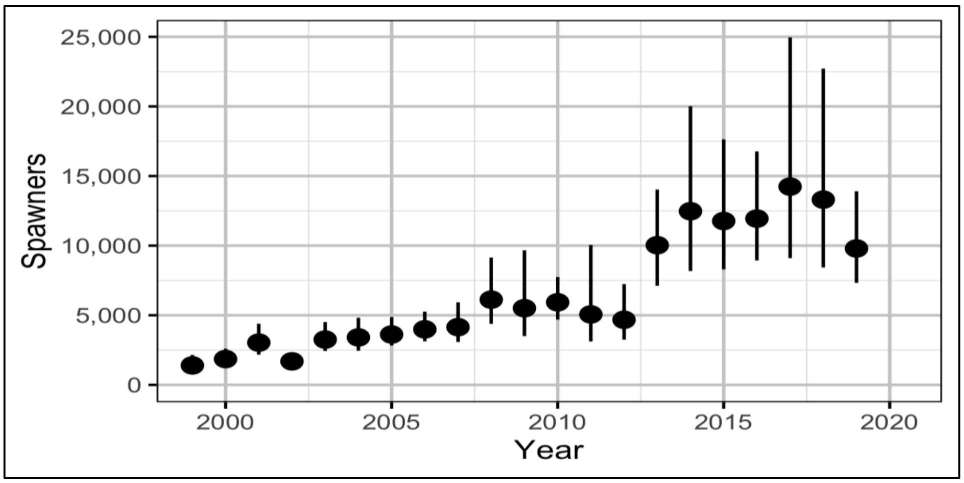

Figure 4 Estimated total spawner abundance by year with 95% CIs.

3.2 Norn's Creek Snorkel Survey

A total of 1694 spawners were enumerated during the snorkel and shore-based survey of Norn's Creek on May 8th, 2019 (**Figure 5**). Overall, the trend in spawner numbers in Norn's Creek since 1999 is a 2-3 fold increase. This year's estimated spawner abundance was similar to the abundance observed in 2009 and is 38% less than the number of spawners observed in 2017 at the peak abundance over the period of monitoring.

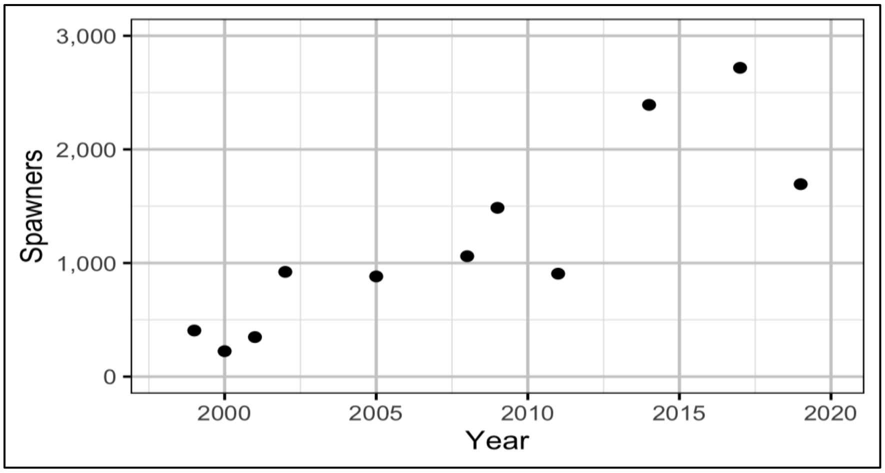

Figure 5 Total spawner abundance in Norn's Creek by year.

3.3 Redd Dewatering

Five operational reductions were identified as possible dewatering events in 2019. A total of 101 redds were dewatered by these five reductions (Figure 6) corresponding to 0.7% of the estimated total number of redds (95% CI 0.4-1.2 %) (Figure 7).

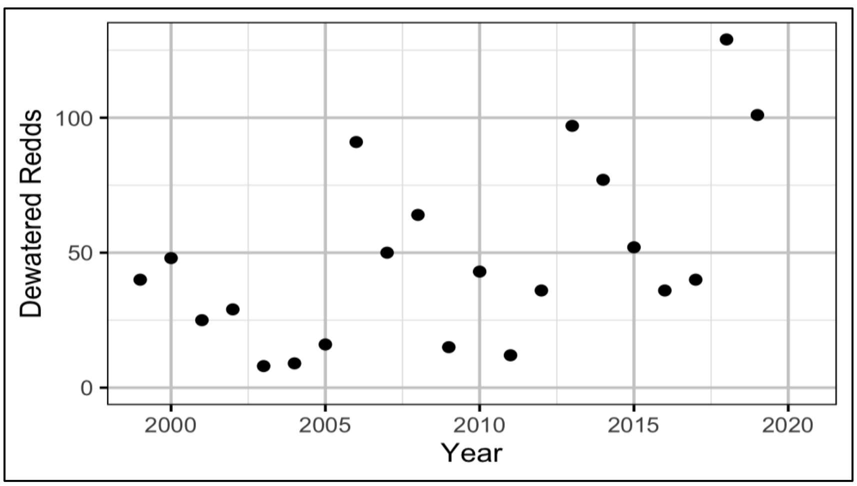

Figure 6 Actual number of enumerated dewatered redds by year.

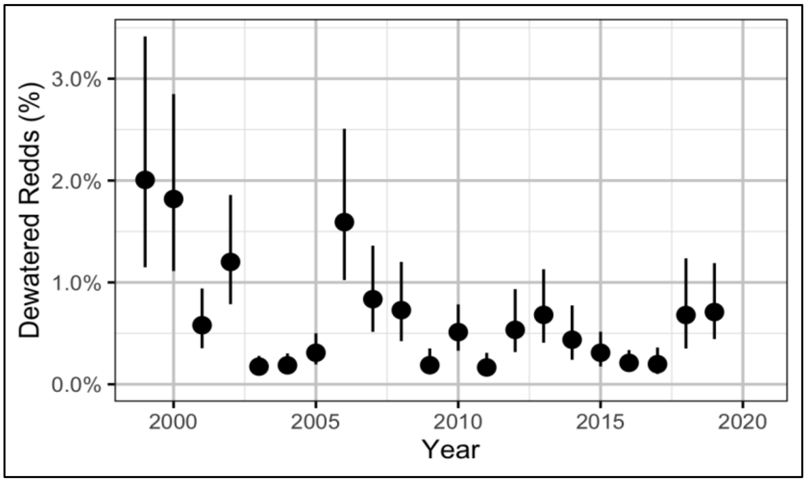

Figure 7 Estimated percentage of redds dewatered by year with 95% CIs.

3.4 Environmental Data

3.4.1 Discharge and Elevation

The discharge from HLK dam in 2019 underwent reductions that caused redd dewatering in March, mid-May and early June (Figure 8). In comparison to average pre-RTSPF flows, the 2019 discharge year dropped its discharge earlier and stayed steady or increasing through the early (Mar-May) period, then increased more rapidly than the historic average (Figure 8). In comparison to average-RTSPF flows, 2019 had more variability in the May-June period; rather than a steady increase, the discharge increased and decreased by 250-700 m^3/s over short periods (Figure 8).

There was no dewatering recorded on the LKR in 2019 despite the substantial protracted reduction in discharge at BRD dam from early June onwards (Figure 8). This was partly because the Kootenay Oxbow was inundated by the increasing discharge from HLK dam which offset the reductions (Figure 9). BRD has never been operated to implement the RTSPF flows, so the average flow is unrelated to consideration of the impacts of the RTSPF and 2019 was a slightly lower flow year than average (Figure 8).

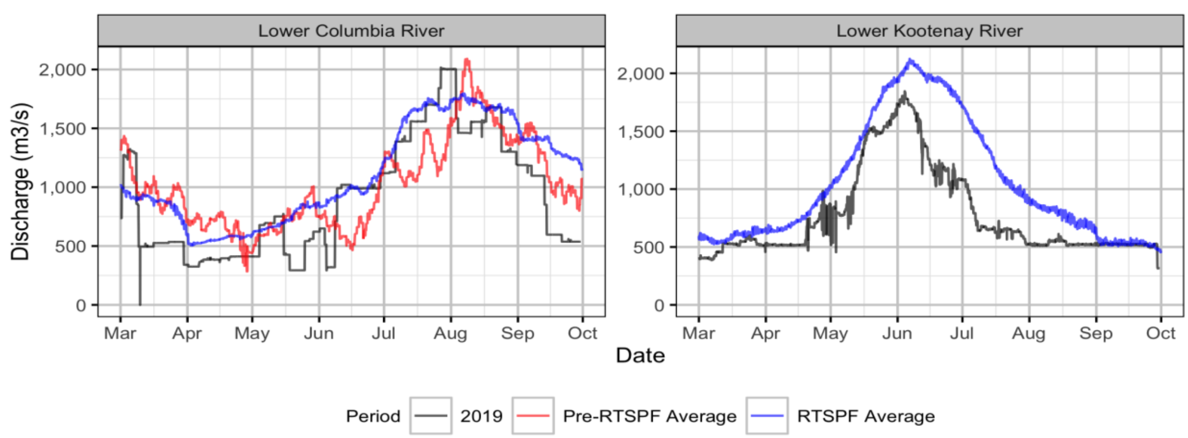

Figure 8 Discharge by river where Lower Columbia River discharge is that from HLK dam and Lower Kootenay River discharge is from Brilliant Dam. Average pre-RTSPF flows were calculated using discharge from 1980-1991 (red) and average post-RTSPF flows utilized discharge from 1992-2018 (blue).

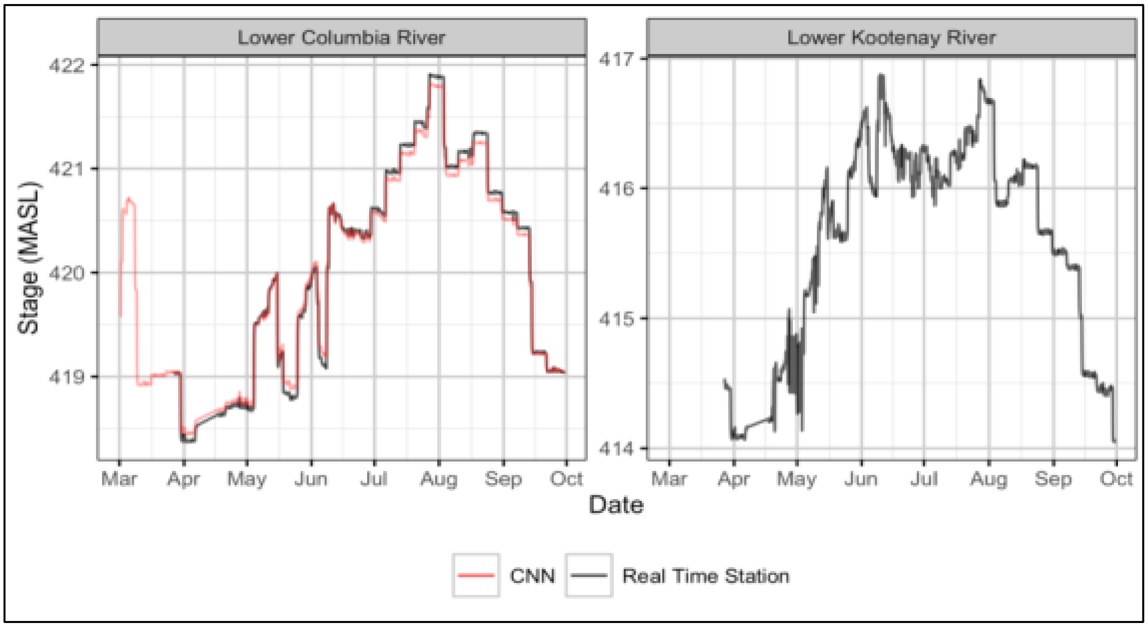

Figure 9 River elevation (stage) by river where the LCR station is at Norn's Creek Fan and the LKR station is at the Kootenay Oxbow. CNN (Columbia Near Norns) is the real-time BC Hydro hydrometeorologic station.

The gravel temperature logger stations covered a range of elevations between 419.25 and 421.25 MASL at Norn's Creek Fan and between 415 and 415.8 MASL at the Kootenay Oxbow.

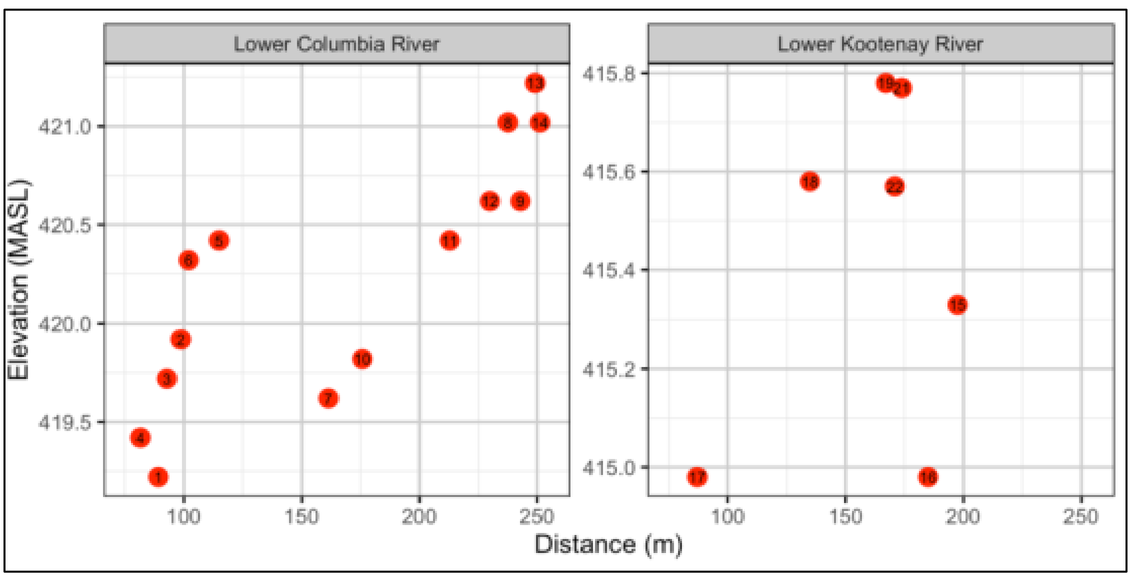

Figure 10 Elevations of gravel temperature logger stations by distance from river center line where the LCR stations are at Norn's Creek Fan and the LKR stations are at the Kootenay Oxbow.

3.4.2 Solar Radiation and Humidity

The mean daily solar radiation consisted of a seasonal trend with short-term fluctuations due to cloud cover.

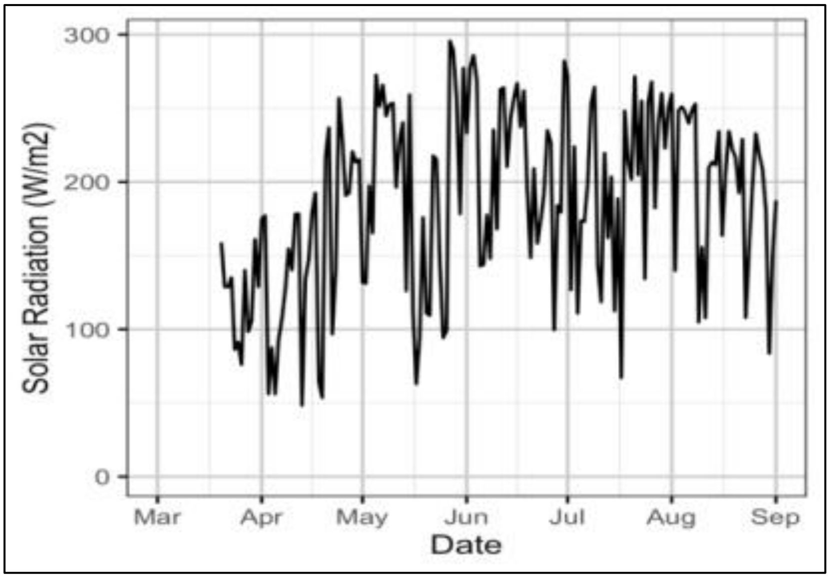

Figure 11 Mean daily solar radiation at the Kootenay Oxbow.

The mean relative humidity typically varied between 50 and 85 % with fluctuations partly due to precipitation.

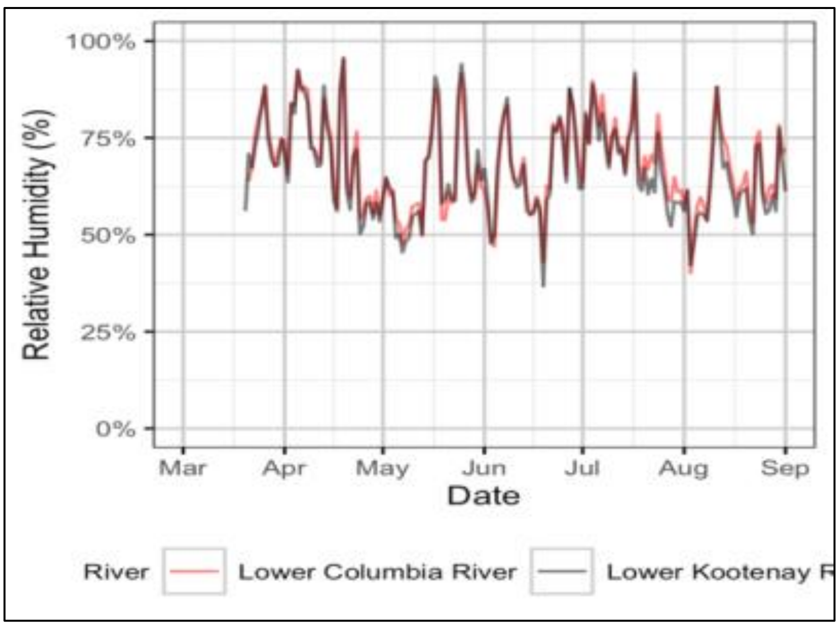

Figure 12 Mean daily humidity where the LCR station is at Norn's Creek Fan and the LKR station is at the Kootenay Oxbow.

3.4.3 Water and Air Temperature

The water temperature was around 5°C at the beginning of April but increased to 15°C in June before exceeding 18°C on the LKR by the end of July (Figure 13). The water temperature trends between the two rivers were similar early season, but diverge from July onwards with the LKR getting substantially warmer than the LCR (Figure 13).

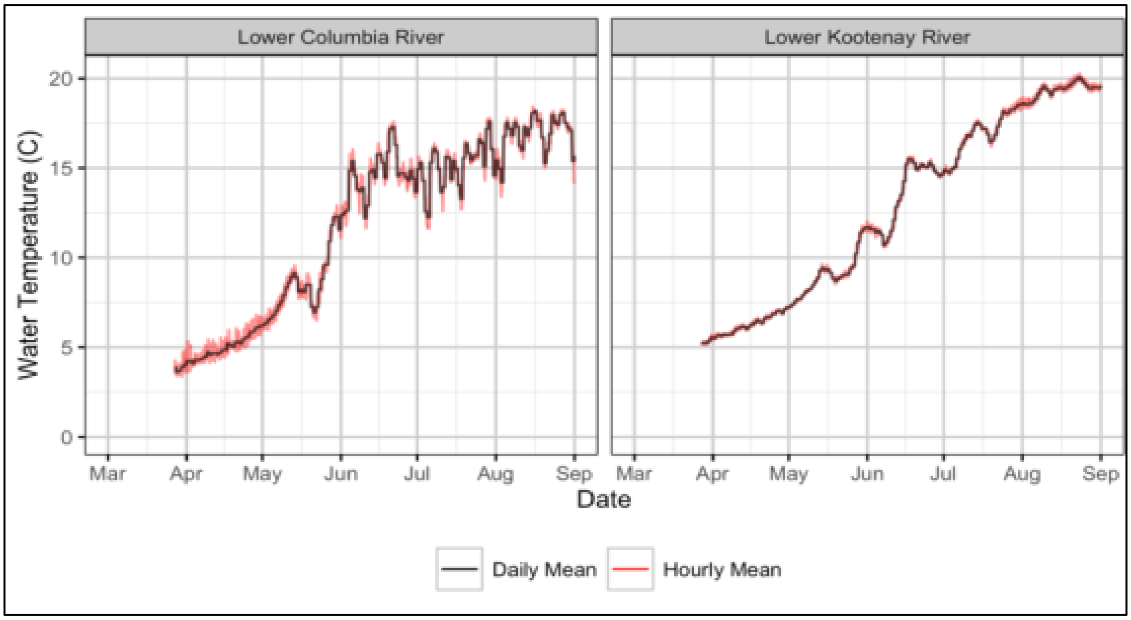

Figure 13 Water temperature by river where the LCR station is at Norn's Creek Fan and the LKR station is at the Kootenay Oxbow.

The air temperature in the shade was very similar at both sites. It increased from around 5°C at the beginning of April to over 20°C by the end of July (Figure 14).

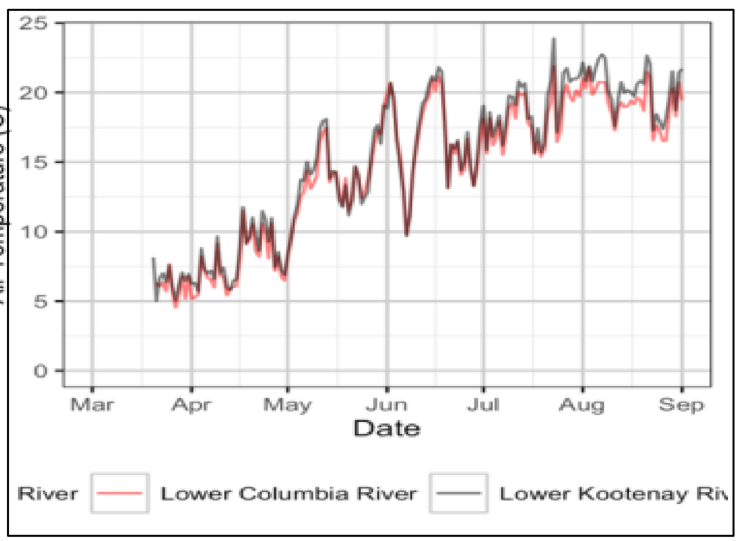

Figure 14 Mean daily air temperature by river where the LCR station is at Norn's Creek Fan and the LKR station is at the Kootenay Oxbow.

At each of 14 stations on Norn's Creek Fan and 7 at the Kootenay Oxbow, three temperature loggers were installed at 10, 20 and 30 cm below surface to measure the temperatures in the gravels (assumed to be similar to the temperatures experienced by the eggs). Most of the plots showing inter-gravel temperatures from these stations can be found in Appendix C, but two are presented below for illustrative purposes. The plots show the relative difference in temperature between those recorded in the gravels and the surface water temperature recorded by the real-time station. The red lines in each plot indicate the absolute temperature thresholds of 25°C and 0°C. The plot from Norn's shows a station with temperatures that exceed the threshold of 25°C (**Figure 15**) while the one from the Oxbow does not (**Figure 16**). Of the 13 stations retained throughout the monitoring season (one was vandalized and removed from the area) on Norn's Creek Fan, 10 exceeded the 25°C threshold (**Figure 15**; Appendix C). Not surprisingly the inter-gravel temperatures were higher during periods of dewatering (indicated by grey shading). The temperatures tended to exceed the 25°C threshold in May, June and September (**Figure 15**). Most of the instances where the inter-gravel temperatures exceeded 25°C at the Norn's Creek fan were at the 10cm depth, but in June at Stations 8, 9,10,11,12,13,14 the temperatures exceeded 25°C at a depth of 30cm (Appendix C). Of the 7 stations on the Kootenay Oxbow, 2 were removed by vandals, while 3 of the 6 with some data exceeded the 25°C limit (Appendix C). Station 15 at the Oxbow is an example of a location that did not exceed the upper temperature limit (**Figure 16**). The 0°C threshold was not crossed in the 2019 monitoring season at any of the stations in either location. The project started after early spawning had already completed when freezing temperatures were most probable.

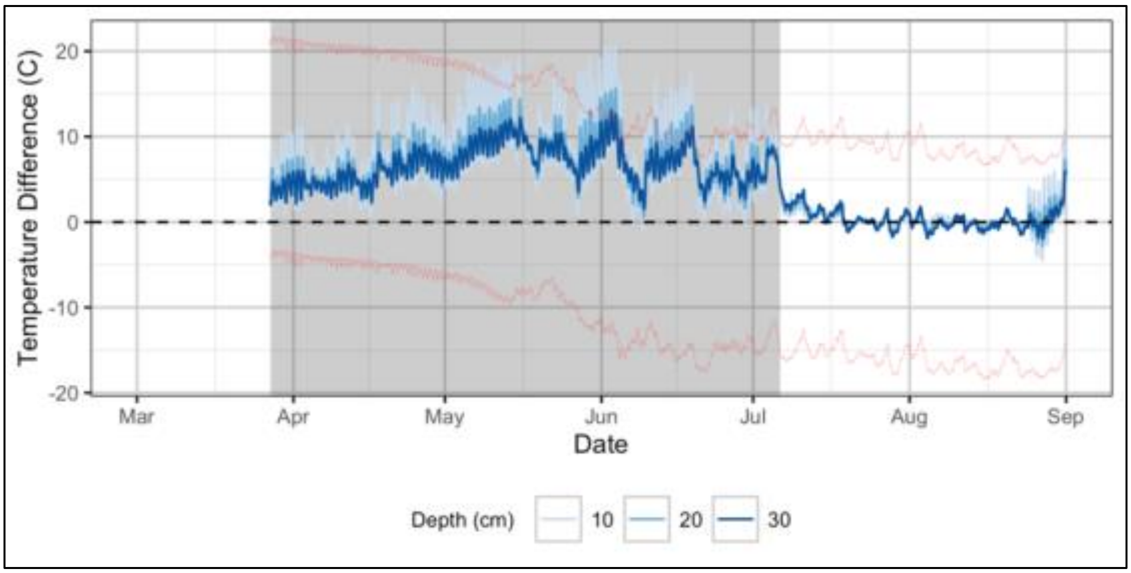

Figure 15 Station 14 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0°C) and upper (25°C) temperature egg mortality thresholds are shown in red.

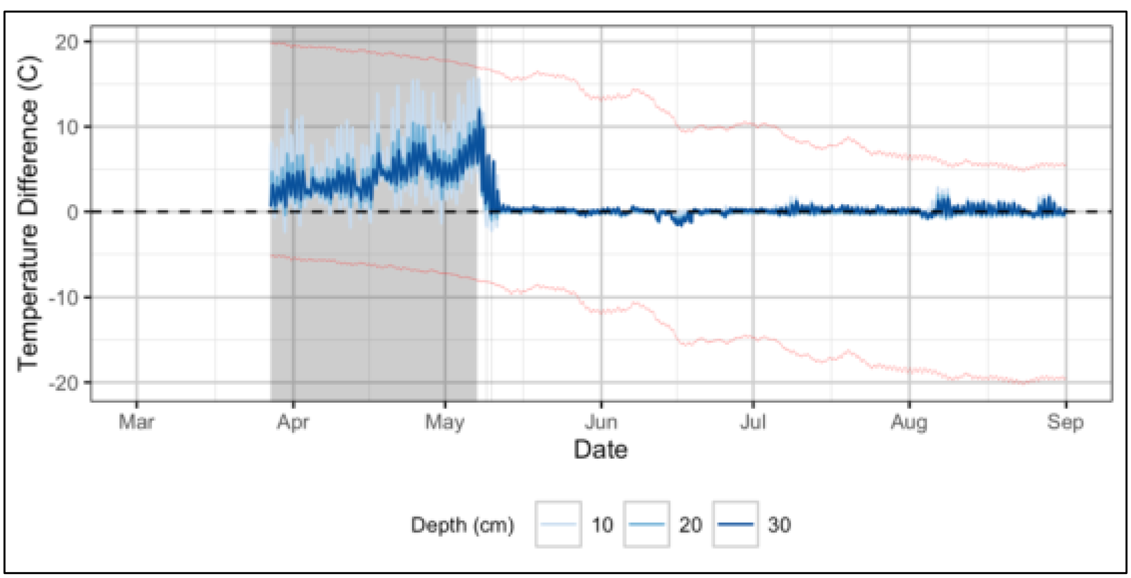

Figure 16 Station 15 at The Oxbow. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0°C) and upper (25°C) temperature egg mortality thresholds are shown in red.

3.5 Egg Mortality

Egg mortality was less than 25% in 78% of the samples and was greater than 25% in 22% of the samples (**Figure 17**). The eggs did not suffer complete mortality after dewatering as has previously been assumed.

Additional redd excavations and a modelling approach once there are sufficient data are required to determine the effect of longer periods of dewatering and more extreme environmental conditions on the mortality.

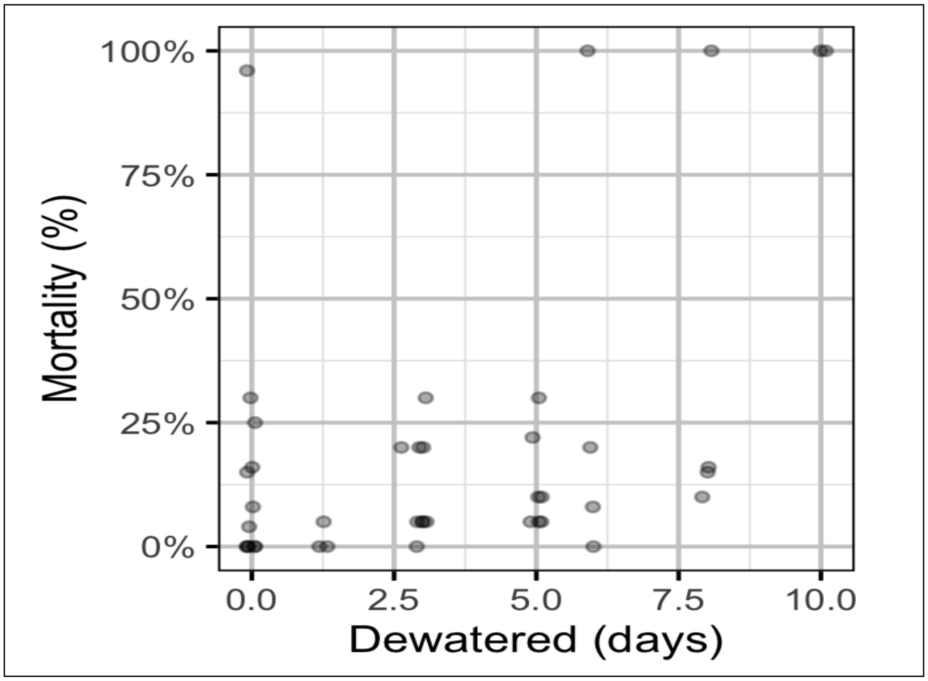

Figure 17 Observed egg mortality in natural redds by days dewatered.

When the eggs that had been incubated in the autoredds on May 24th were recovered on June 7th the eggs from the two control (wetted) redds and two of the previously dewatered redds (redd ID 13 and 49) were all dead. The embryo survival for the remaining three dewatered redds (redd ID 33, 71 and 81) that were also incubated in autoredds and recovered on June 7th ranged between 10 and 78%. Most of the surviving embryos were recently hatched alevins (stage 8 – see Appendix F for staging details).

3.6 Spawn Timing

Generally, the spawn timing has been quite stable through the period of monitoring (Figure 18). In 2019, spawn timing in the LKR to Genelle section was compressed compared to other years with a later spawning start time, an average peak spawn timing and early completion timing (Figure 18). When comparing the total number of days in the estimated spawn period, this section has changed from 157 days in 1999 to 93 days in 2019 (Figure 18). In the 2019 spawning year, peak spawning was estimated to occur on May 11 (95% CIs ranged from the 6th May to the 17th of May), the start was on the 18th or 25th of March (depending on segment), and the end of spawning was estimated to be on either the 26th of June or the 7th of July depending on the segment (**Figure 18**).

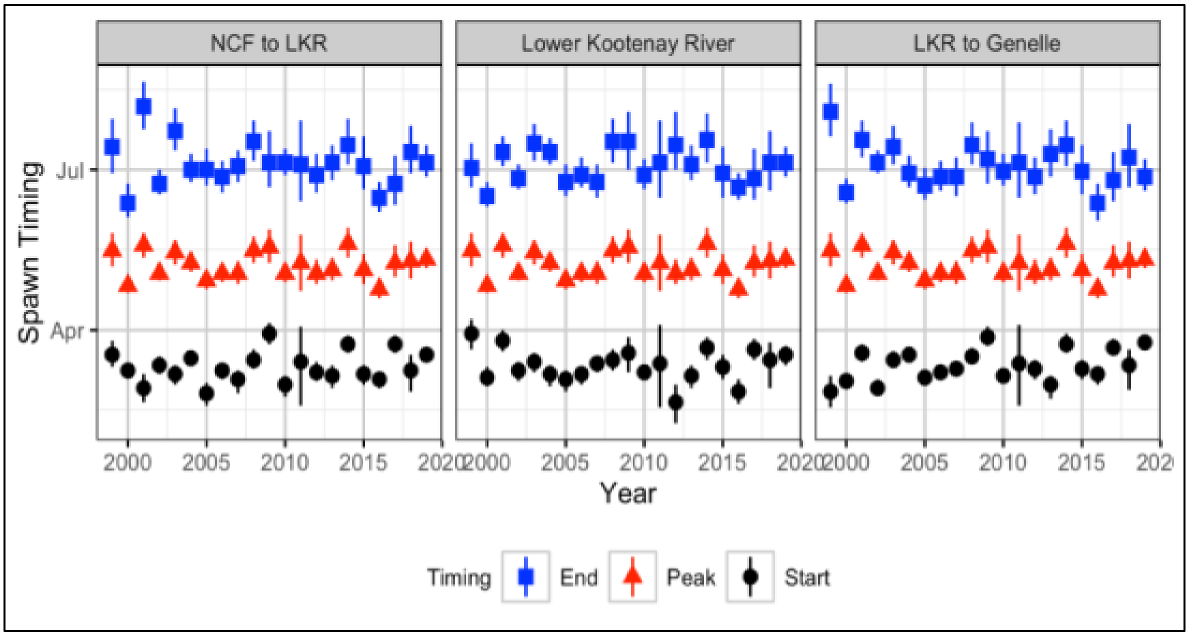

Figure 18 Estimated start (2.5% of spawners arrived), peak and end (2.5% of spawners remaining) spawn timing by year and segment with 95% CIs.

3.7 Stock Recruitment

The Beverton-Holt stock recruitment model fitted to age-1 Rainbow Trout abundance vs. spawner abundance suggests density-dependent survival (Figure 19). 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. The number of recruits showed no increase associated with the highest spawner abundance years. The spawner to recruits ratio has consistently decreased through time from a high of 1:11 in the 2000 spawn year with the lowest value occurring in the 2017 spawn year where the ratio of spawners: recruits was 1:1.3 (Figure 19).

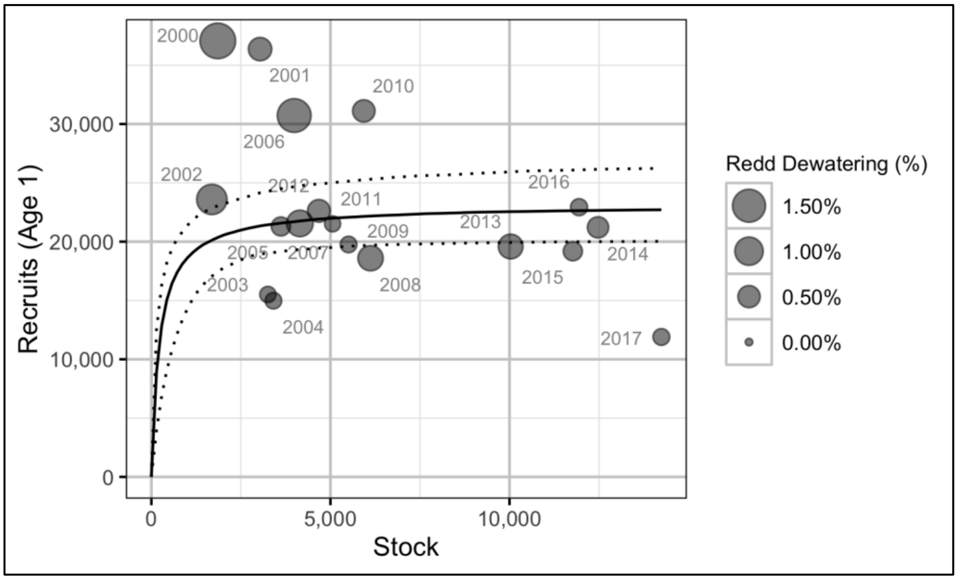

Figure 19 Predicted stock-recruitment relationship from spawners to subsequent age-1 recruits by spawn year with 95% CIs.

The number of age-1 recruits was positively correlated with number of dewatered redds (**Figure 20**) suggesting that higher redd dewatering is associated with increased recruitment success.

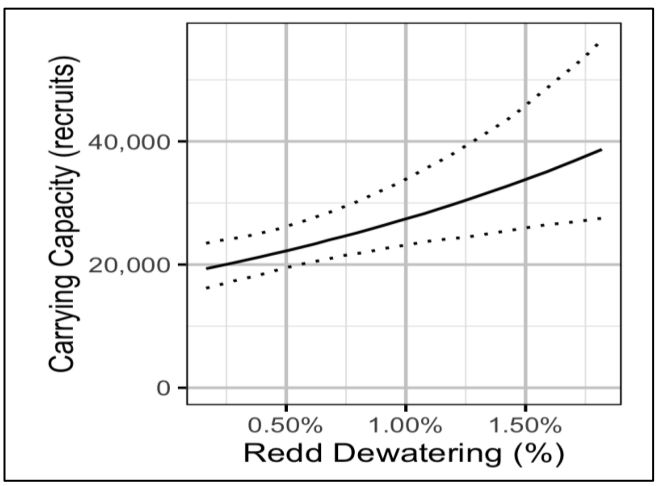

Figure 20 Predicted age-1 recruits carrying capacity vs. percentage egg dewatering with 95% CRIs.

4.0 DISCUSSION

Consistent with the experimental design, RTSPF were not enforced in 2019 to assess egg mortality and to test for a detectable impact on the subsequent abundance of age-1 recruits. However, despite the absence of RTSPF, only 101 redds were dewatered in 2019. The average number of redds dewatered per year with RTSPF in place was 46 (data from 1999-2018) so the dewatering was higher than average when considering abundance of redds dewatered, but was right on the average value when considering the proportion of redds dewatered with only 0.7% of the total redds in the mainstem dewatered. This level of dewatering is extremely unlikely to have a population-level effect.

Salmonids like most fish have a high fecundity which compensates for the high mortality at the egg and larval stages. Mortality effects on eggs include siltation, predation, temperatures that either too high causing desiccation or too low causing freezing and rupture, low water flow and low oxygen levels, (Dahlberg 1979 and references therein). Of the many processes that can kill eggs, those primarily linked to mortality in dewatered redds are: 1) dissolved oxygen level, 2) relative humidity, 3) temperature, 4) fine sediment levels and 5) duration of dewatering (Gibbins et al. 2008).

Salmonid eggs absorb oxygen by diffusion across their surface. Consequently, provided the humidity in the gravels remains close to 100% and the temperature stays within acceptable bounds then eggs can survive dewatering for several weeks. If, however, the eggs dry up or experience freezing or high temperatures they can die within a few hours. The humidity is affected by rain and hyporheic flow (Neitzel and Becker 1985) while the temperature depends on the water temperature, air temperature, incident solar radiation and burial depth. Not surprisingly, there is a great deal of variation in the reported mortality rates with different dewatering times (Table 3). Once they have hatched, alevins absorb oxygen through their gills and require immersion in water. As a result, they are much more sensitive to dewatering.

Table 2 Reported egg mortality rates by species, life stage, dewatered status, temperature (C), duration (hours), mortality rate (%) and reference.

Species	Stage	Dewatered	Temp (C)	Duration	Mortality	Source
Chinook	Alevin	Yes	-	32	100	Neitzel and Becker (1985)
Chinook	Alevin	Yes	10	6	95-99	Becker and Neitzel (1983)
Kokanee	Egg	Yes	-10	12	100	Neitzel and Becker (1985)
Chinook	Egg	Yes	-	480	47	Becker and Neitzel (1983)
Chinook	Egg	Yes	10	472	40	Becker and Neitzel (1983)
Chinook	Egg	Yes	-	384	36	Becker and Neitzel (1983)
Chinook	Egg	Yes	-	168-240	24	Reiser and White (1983)
Brown Trout	Egg	Yes	-	840	20	Bjornn and Reiser (1991)
Chinook	Egg	Yes	10	288	0-20	Becker and Neitzel (1983)
Chinook	Egg	Yes	-	288	8	Becker and Neitzel (1983)
Steelhead	Egg	Yes	-	168-672	6	Reiser and White (1983)
Steelhead	Alevin	No	15	-	0-5	Rombough (1988)
Chinook	Egg	No	1.7	-	100	Myrick and Cech (2001)
Chinook	Egg	No	18	-	100	Myrick and Cech (2001)

Species	Stage	Dewatered	Temp (C)	Duration	Mortality	Source
Chinook	Egg	No	17.2	0.5	100	Jensen and Groot (1991)
Chinook	Egg	No	16	-	64	Myrick and Cech (2001)
Steelhead	Egg	No	15	-	15	Rombough (1988)

Given the variation in responses, developing a model to predict mortality is challenging. Currently the monitoring program assumes that mortality is immediate (0 hours) and complete (100%). Casas-Mulet et al. (2016) assumed that critical conditions for Atlantic salmon eggs occur when air temperatures are below 0°C and redds are dewatered for three or more hours, and that critical conditions for alevins occur when they are dewatered for 3 or more hours irrespective of air temperatures (Casas-Mulet et al. 2016). Neitzel and Becker (1985), Myrick and Cech (2001) and Korman et al. (2011) assumed upper temperature thresholds of 24, 16.7 and 16° C, respectively, while Myrick and Cech (2001) assumed a lower threshold of 1.7°C. The temperature thresholds for Rainbow Trout on the LCR are unknown but the upper threshold may exceed 16°C as the water temperature commonly reaches or exceeds this value (Irvine et al. 2018) with no obvious effect on recruitment (Golder et al. 2017). There could be very high mortality of eggs and alevins above 15°C as observed in literature reviews on temperature impacts on Rainbow Trout and other salmonids (e.g., Carter, 2005) and the large numbers of eggs deposited compensate for the mortality. If the temperature threshold was known it may be possible to estimate egg mortality rates by using the water and air temperatures to calculate the temperatures experienced by the eggs and alevins based on the thermal conductivity (Dalla Santa et al. 2017) and specific heat capacity of the gravels together with the burial depth.

The eggs did not suffer complete mortality immediately after dewatering as has previously been assumed. Additional redd excavations are required to determine the effect of longer periods of dewatering and environmental conditions on the mortality. Additional field data will be paired with a modelling approach assessing the impact of water temperature, time since dewatering and other measured variables on the dependent variable of egg mortality. The weather in the spring and summer of 2019 was quite moist and temperate relative to recent years so mortality could vary considerably in a hotter and drier year.

For the purposes of estimating when eggs would be impacted by environmental conditions, thresholds of 25°C and 0°C were compared to the temperatures encountered by the loggers in the gravel. Of the 13 stations retained throughout the monitoring season on Norn's Creek Fan, 10 exceeded the 25°C threshold (Appendix C). For the 6 stations on the Kootenay Oxbow, 3 exceeded the 25°C limit (Appendix C). The 0°C threshold was not crossed in the 2019 monitoring season at any of the stations in either location. However, the project started after early spawning had already completed when cold temperatures were most probable.

Peak counts of redds were highest at Genelle (1,135) and Norn's Creek Fan (1,000). These two areas have consistently shown the highest redd numbers since surveys began in 1999. The abundance of Rainbow Trout in the study area has increased approximately 7-fold since monitoring began in 1999 and peak abundance was recorded in 2018 with an estimate of 13,756 spawners. The estimated abundance in 2019 was 9,784 spawners (95% CI 7,239-13,666).

Spawn timing estimates in 2019 had a start date between March 18th to 25th (depending on location within the river), spawning peaked on May 11th and was completed between June 19th to July 7th.

The number of recruits per spawner has dropped as the population abundance has increased, exhibiting classic density dependent effects. The available data suggest that the spawner population could be as low as 4,500 fish and still fully recruit with a spawner to recruit ratio of 1:4. In the most recent years of the stock recruitment curve (2017 spawn year) the ratio has dropped to almost 1:1 with 9,259 spawners giving rise to about 11,897 recruits.

5.0 RECOMMENDATIONS

- At peak spawning, on a day with excellent water clarity and good visibility, carry out a survey of the full length of the LCR to confirm that only low levels of spawning are still occurring in the LCR above Norns Creek Fan and below Genelle. This would also allow a whole river estimate of abundance.
- Install environmental monitoring stations as discretely and cryptically as possible to avoid the level of vandalism (2 temperature and 1 humidity station vandalized) experienced in 2019.
- Continue to refine the accuracy of elevations at monitoring stations. Currently, elevations are within 20 cm accuracy at the higher elevation stations, but this will be refined further as sampling days occur when the water levels are closer to the stations by using the elevations of the realtime stations.
- Record gravel temperatures without a wooden stake at set locations within the transect to confirm it is not influencing the inter-gravel temperatures.

6.0 CLOSING

If there are any questions related to the information provided in this report, please contact the undersigned.

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8.0 APPENDIX A - MAPS OF PEAK FISH AND REDD COUNTS 2019

Figure A1 Fish and redd peak counts in the Norn's Creek Fan and Robson Bridge area.

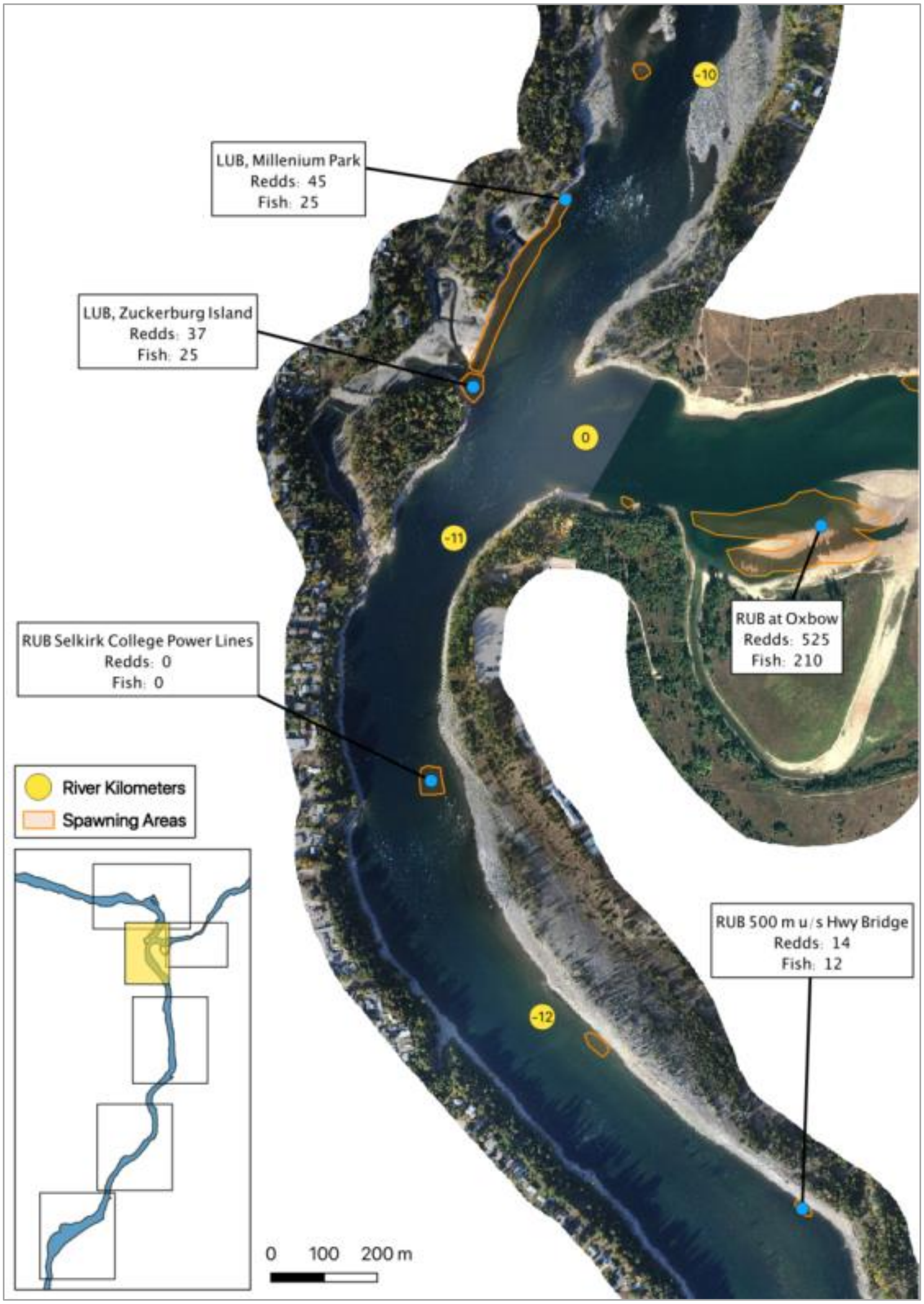


Figure A2 Fish and redd peak counts in the Zuckerberg and Millennium Park area.

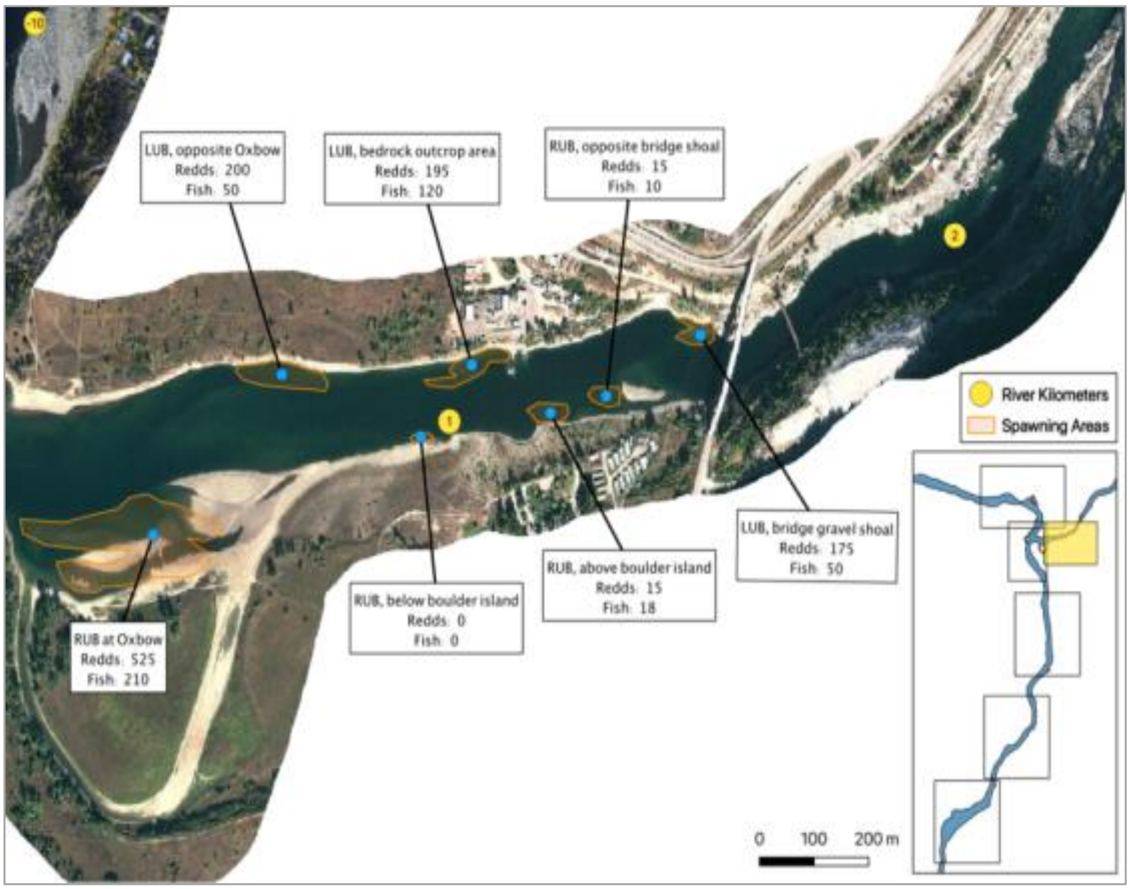


Figure A3 Fish and redd peak counts in the Lower Kootenay river area.

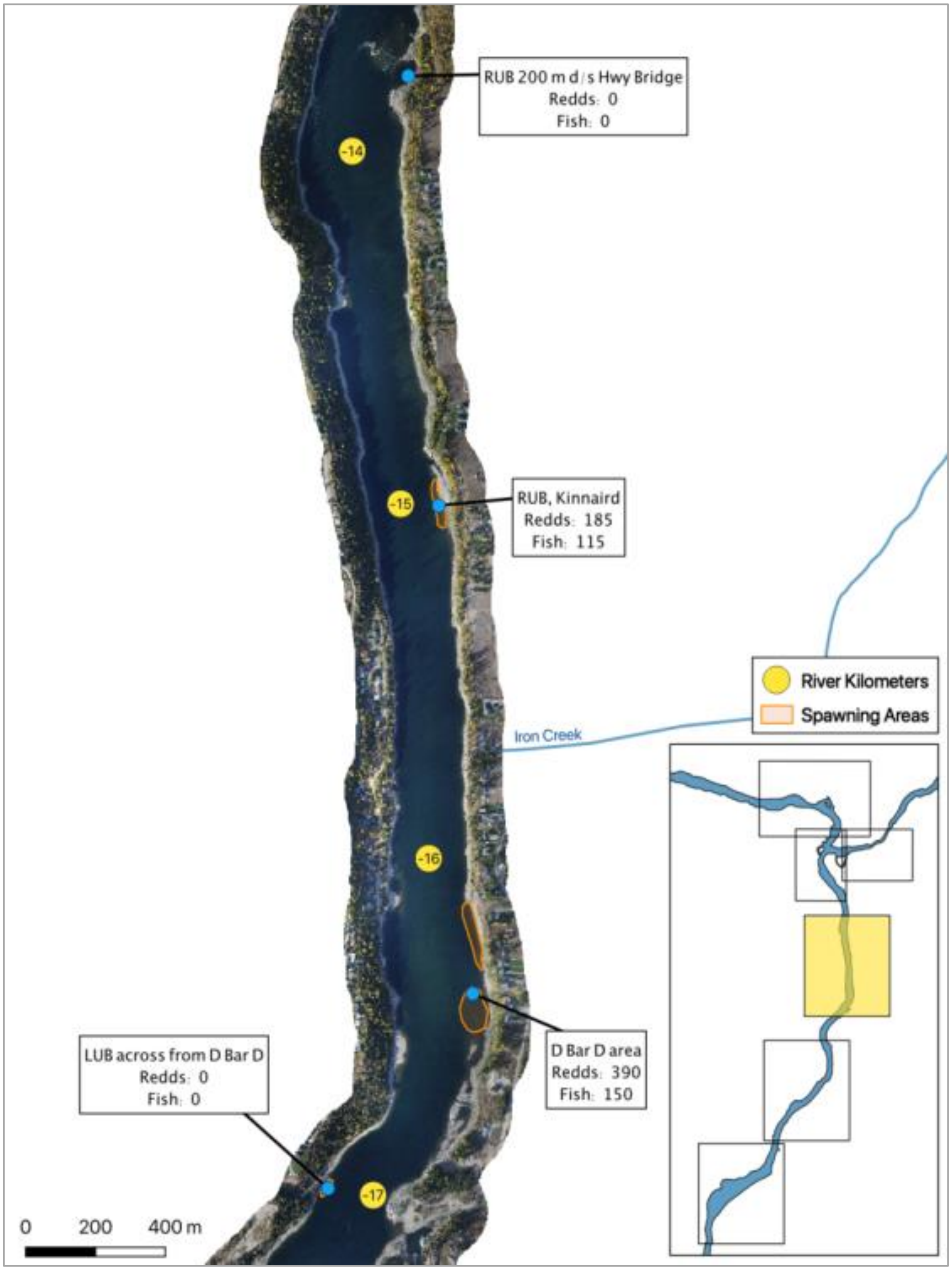


Figure A4 Fish and redd peak counts in the Kinnaird area.

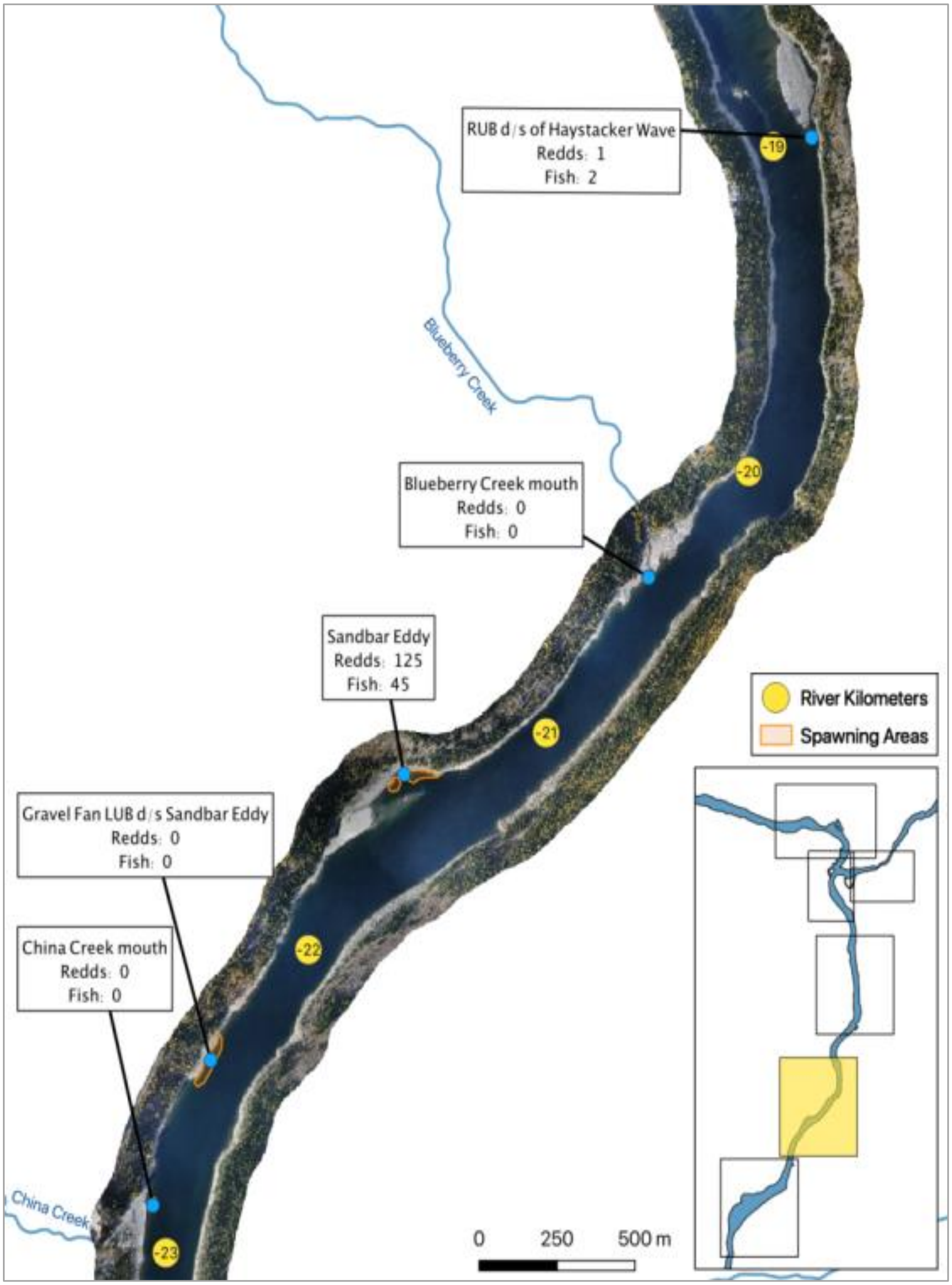


Figure A5 Fish and redd peak counts in the Blueberry and China Creek area.

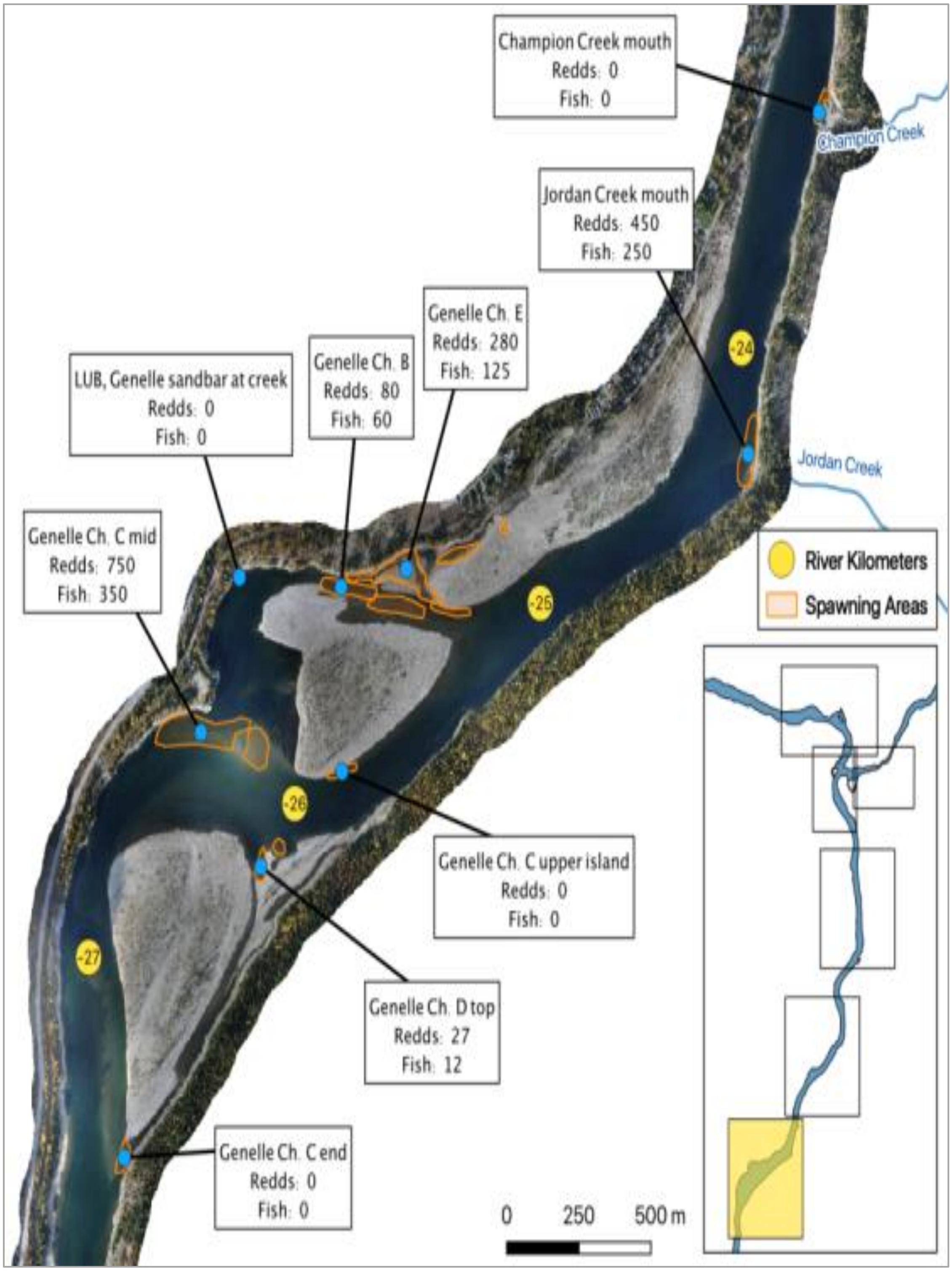


Figure A6 Fish and redd peak counts in the Genelle area.

9.0 APPENDIX B - AREA-UNDER-THE-CURVE ANALYSES 2019

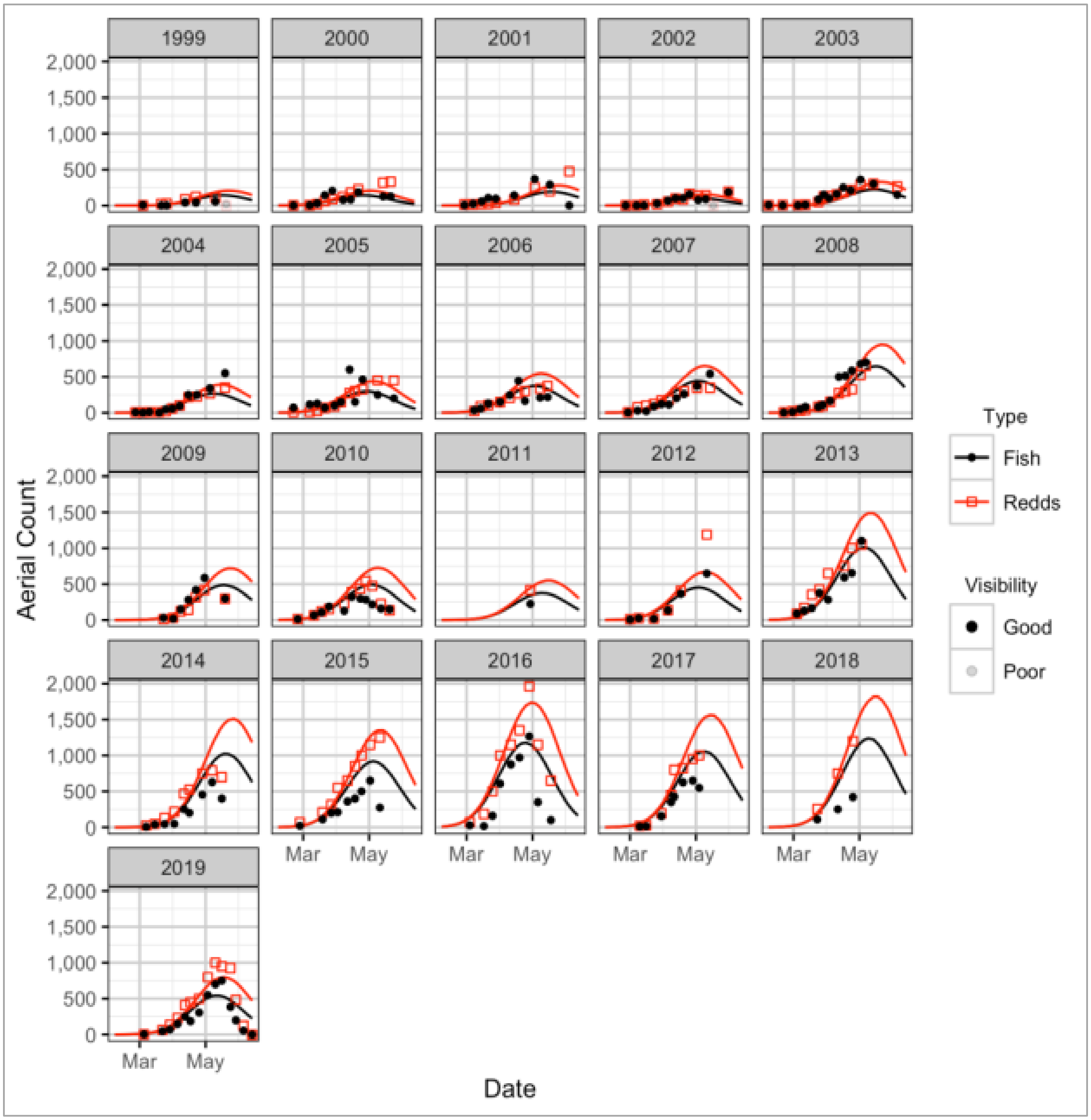


Figure B1 Predicted and actual aerial fish and redd counts at Norn's Creek Fan by date and year.

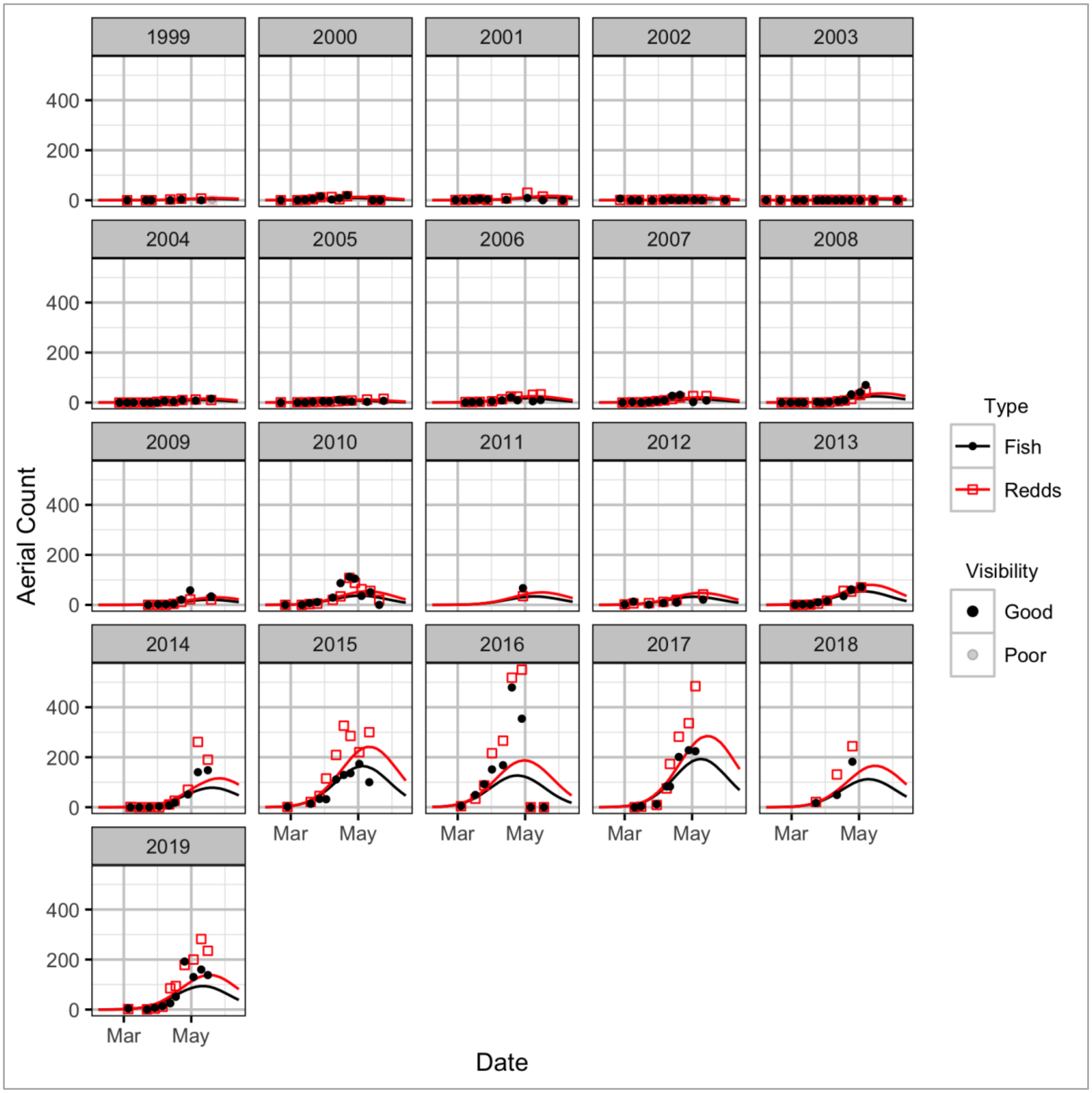


Figure B2 Predicted and actual aerial fish and redd counts in the section from Norn's Creek Fan to the Lower Kootenay River by date and year.

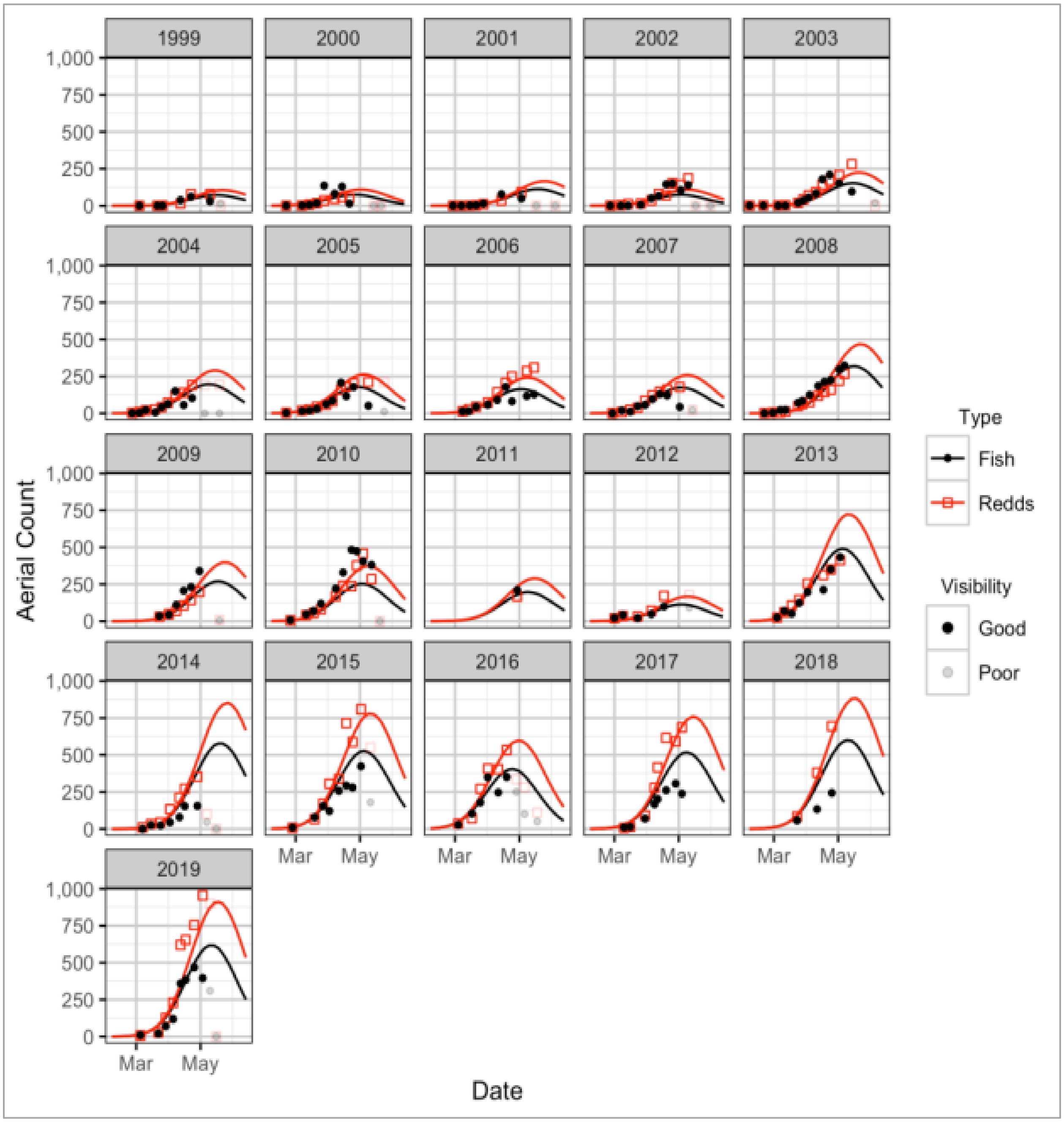


Figure B3 Predicted and actual aerial fish and redd counts at Lower Kootenay River by date and year.

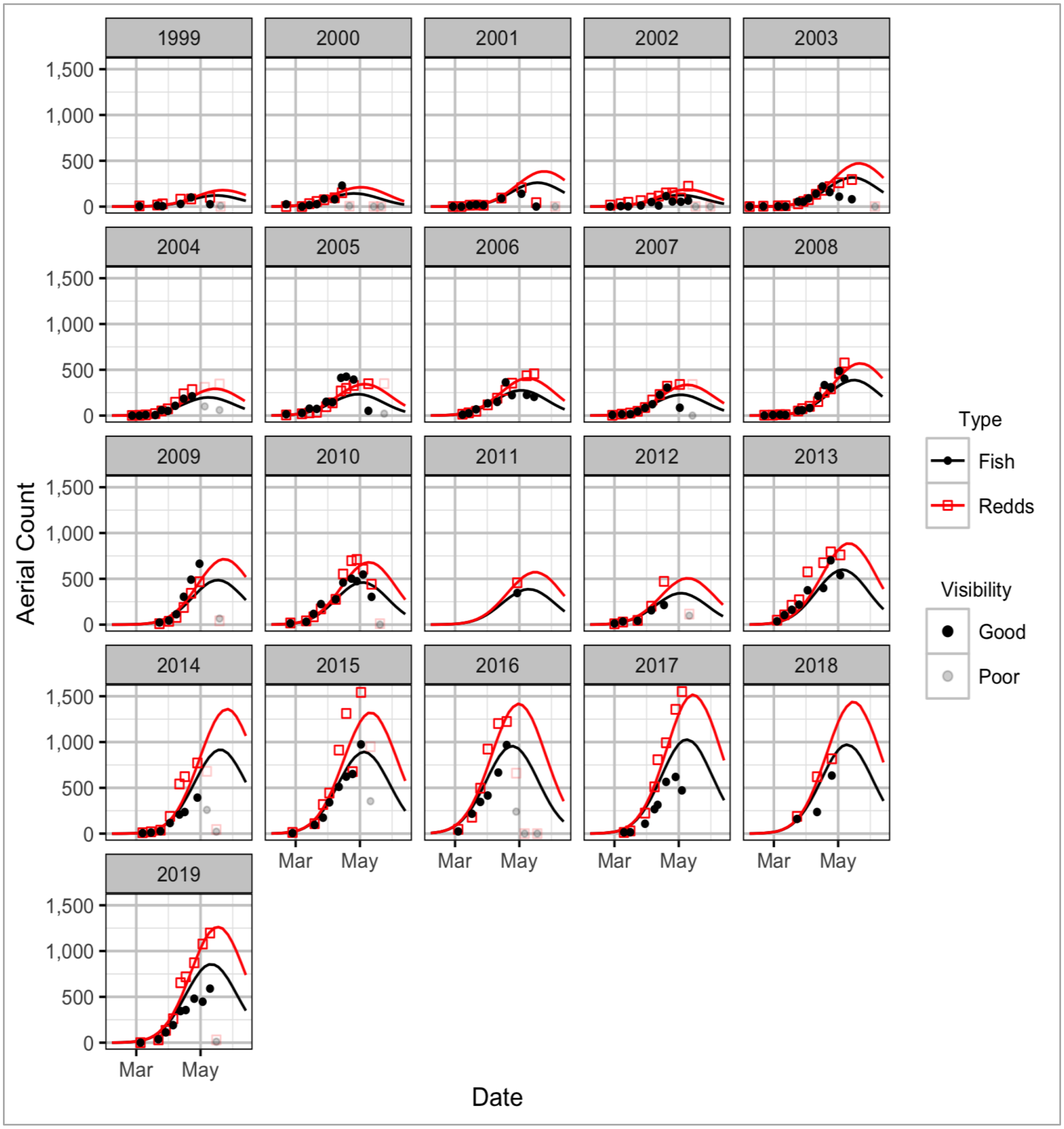


Figure B4 Predicted and actual aerial fish and redd counts in the section from Lower Kootenay River to Genelle by date and year.

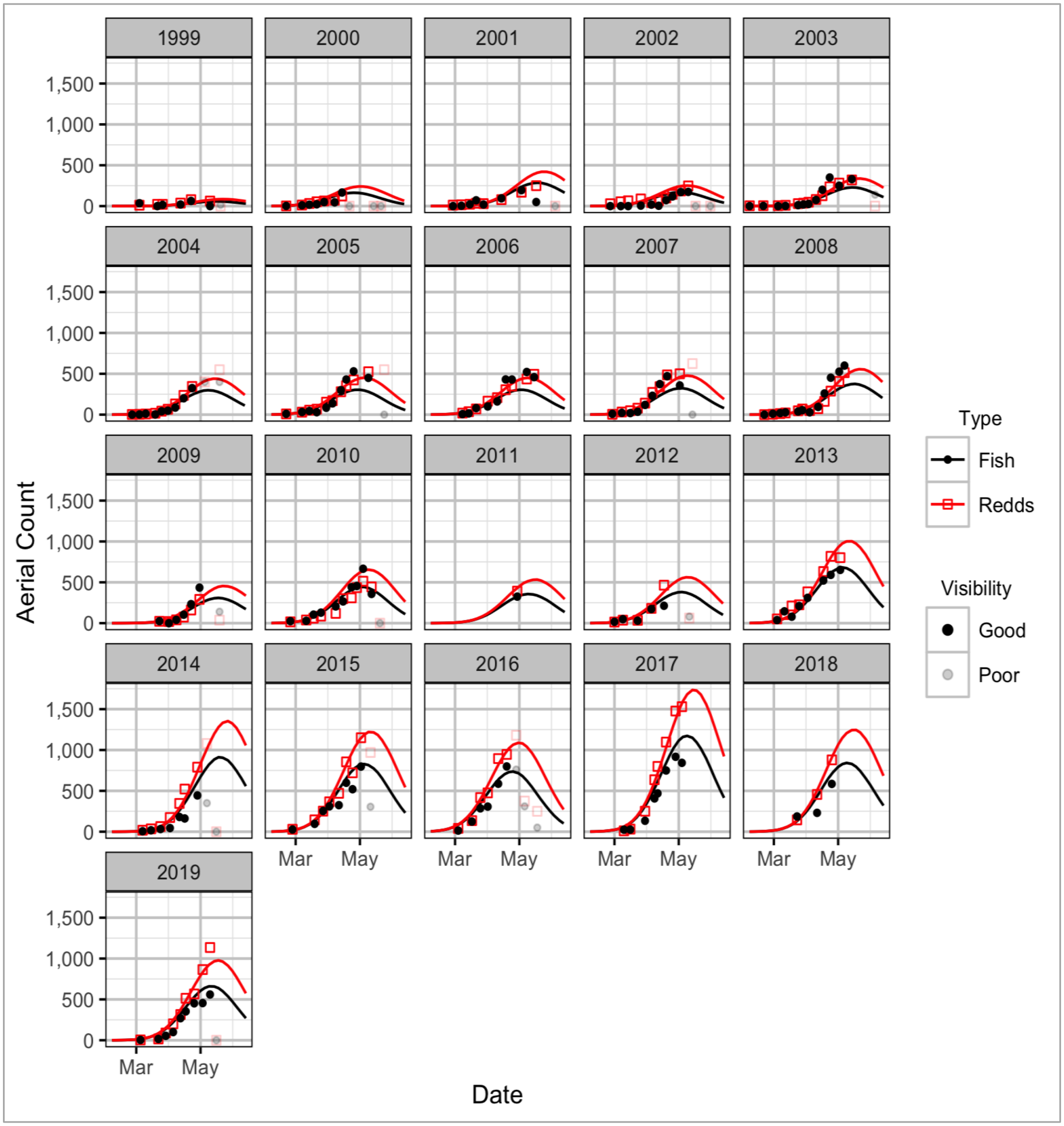


Figure B5 Predicted and actual aerial fish and redd counts at Genelle by date and year.

10.0 APPENDIX C - INTER-GRAVEL RELATIVE WATER TEMPERATURE

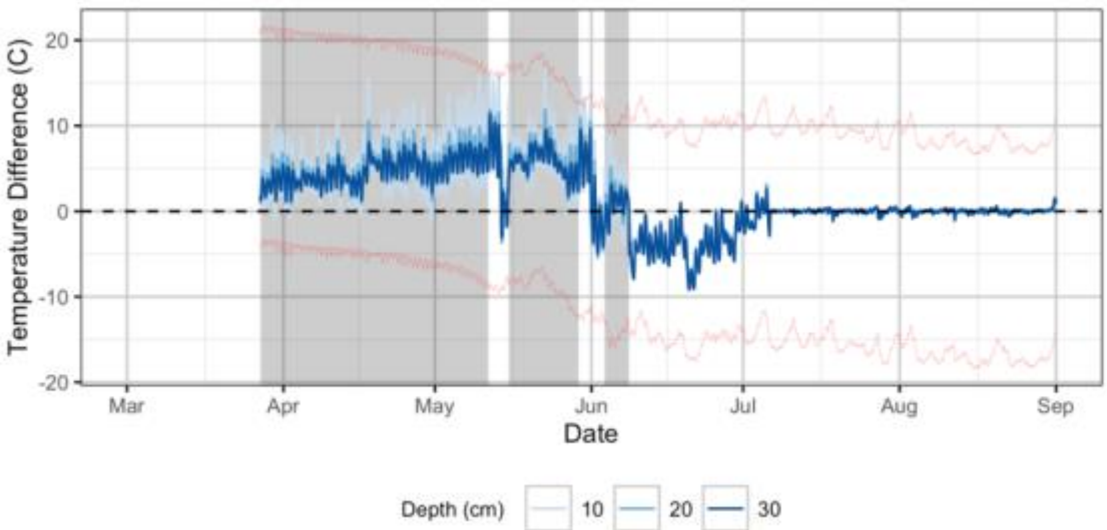


Figure D1 Station 2 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey Lower (0C and upper (25C) temperature egg mortality thresholds are shown in red.

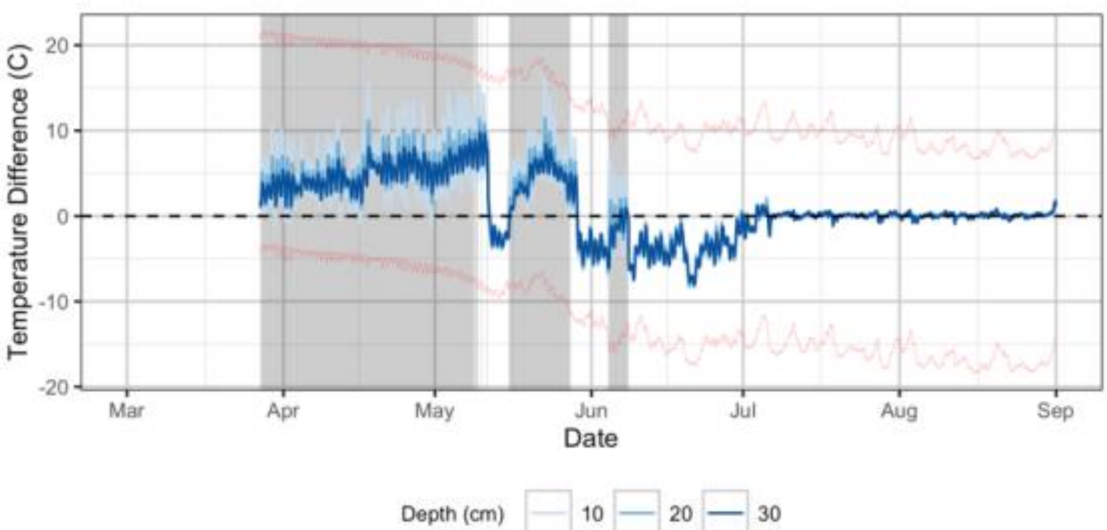


Figure D2 Station 3 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

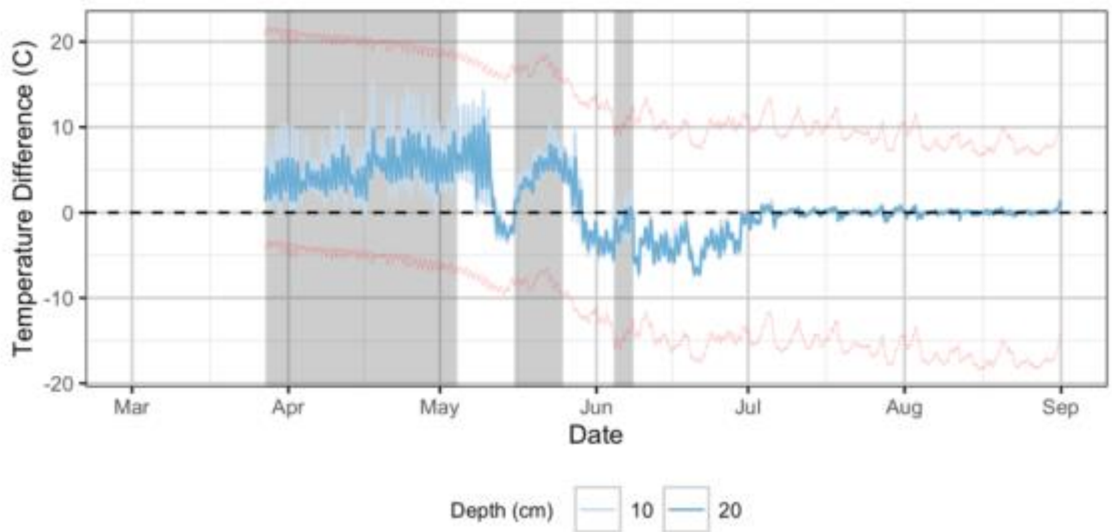


Figure D3 Station 4 at Norn’s Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

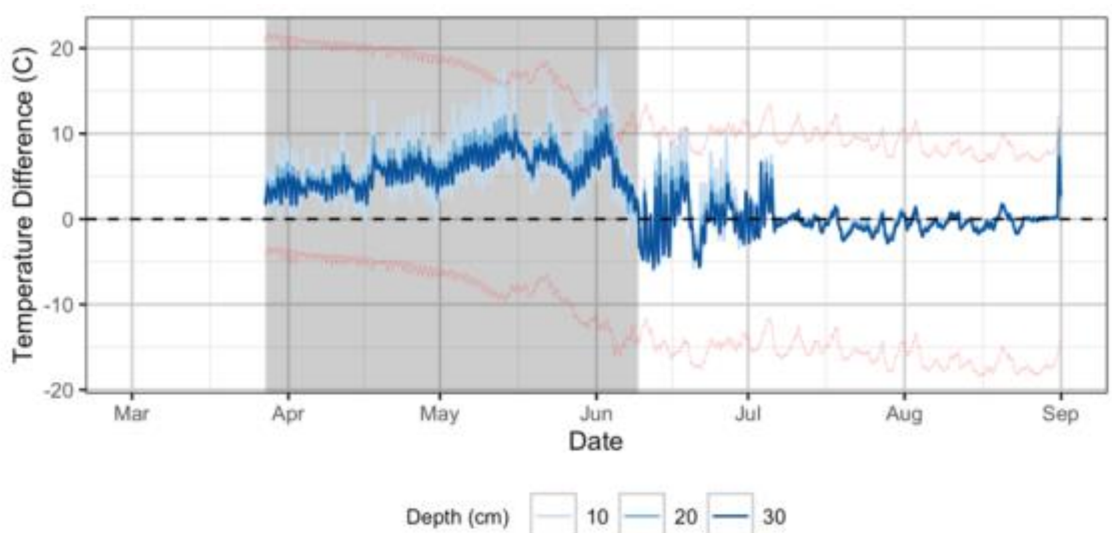


Figure D4 Station 5 at Norn’s Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

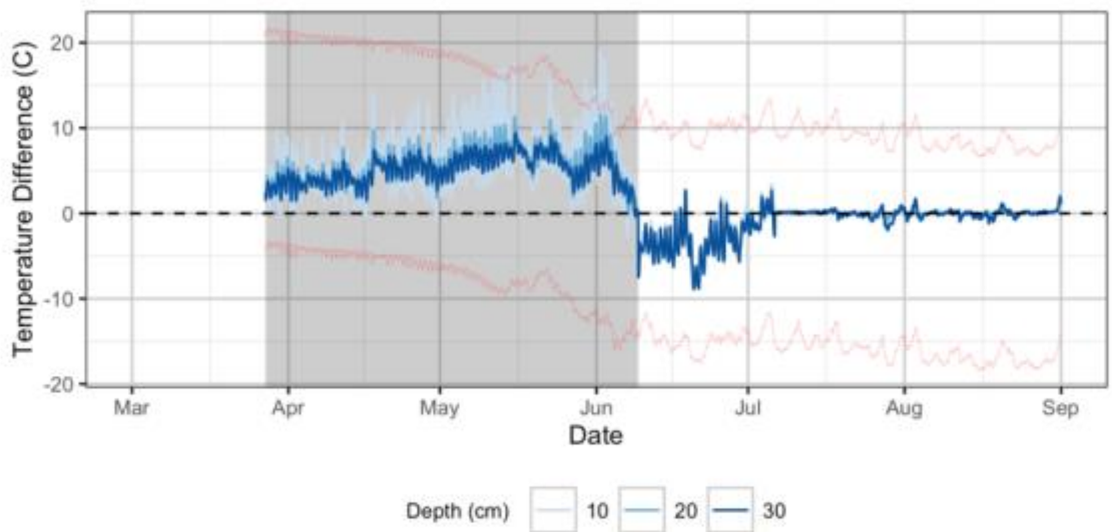


Figure D5 Station 6 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

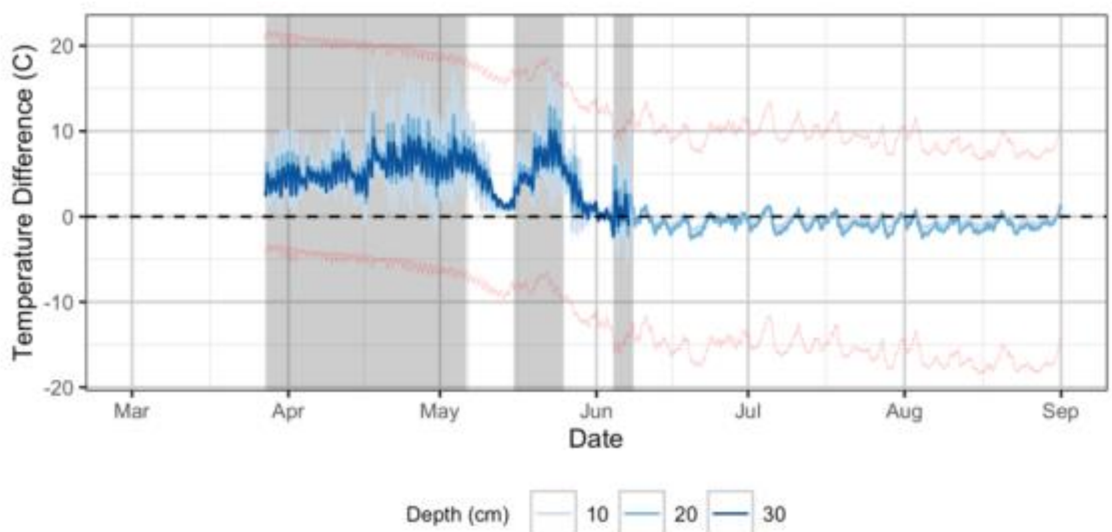


Figure D6 Station 7 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

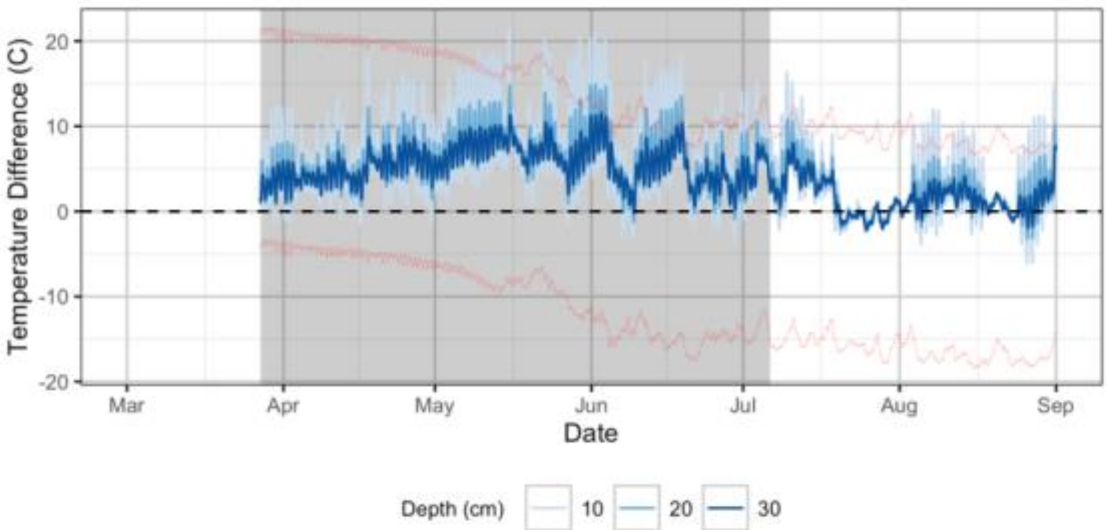


Figure D7 Station 8 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

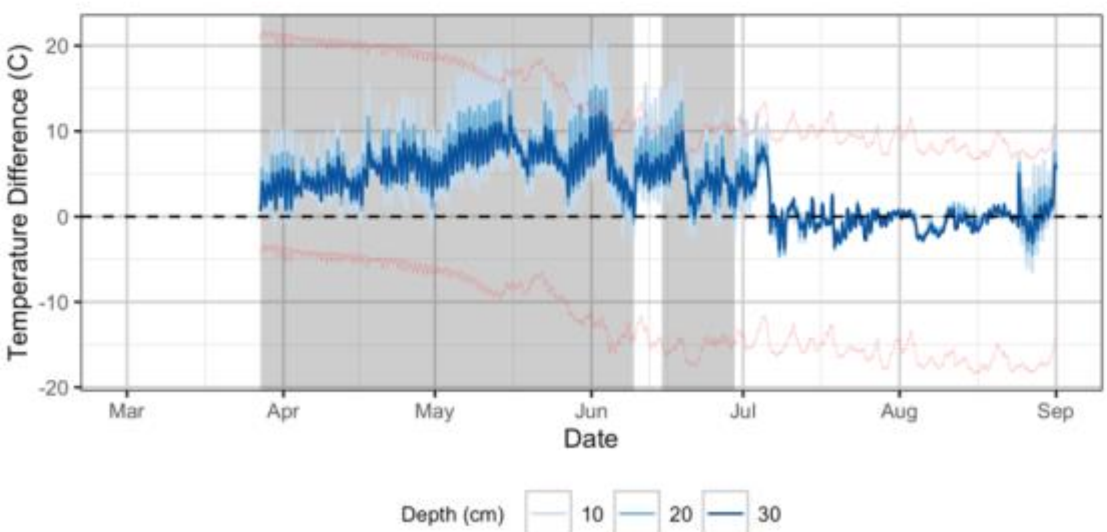


Figure D8 Station 9 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

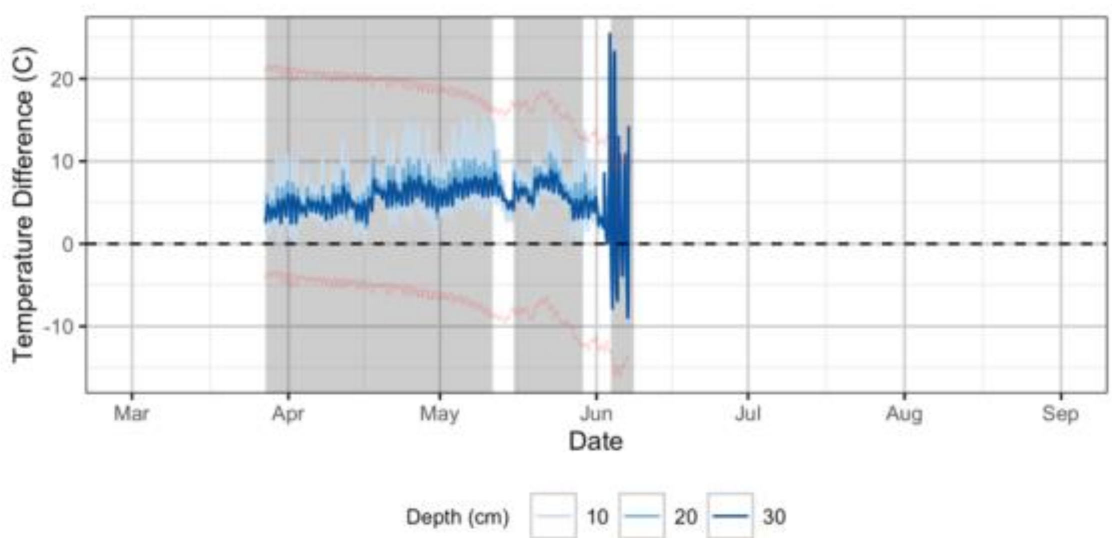


Figure D9 Station 10 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

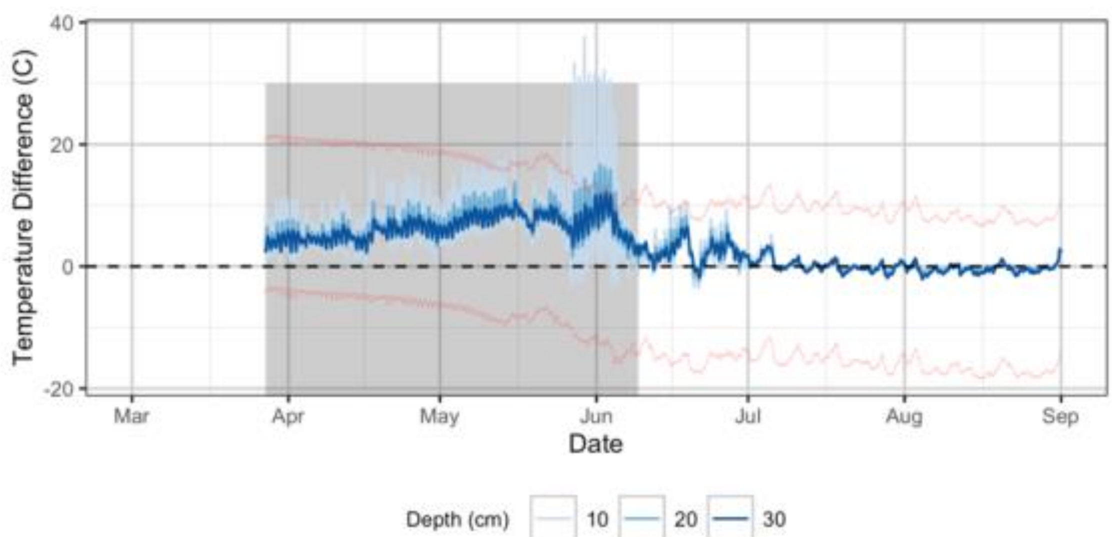


Figure D10 Station 11 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

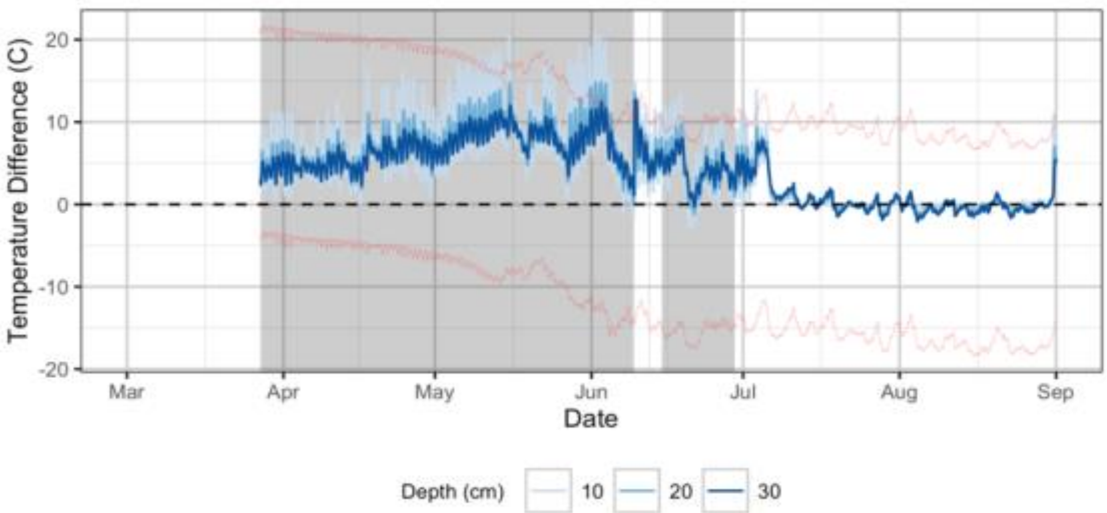


Figure D11 Station 12 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

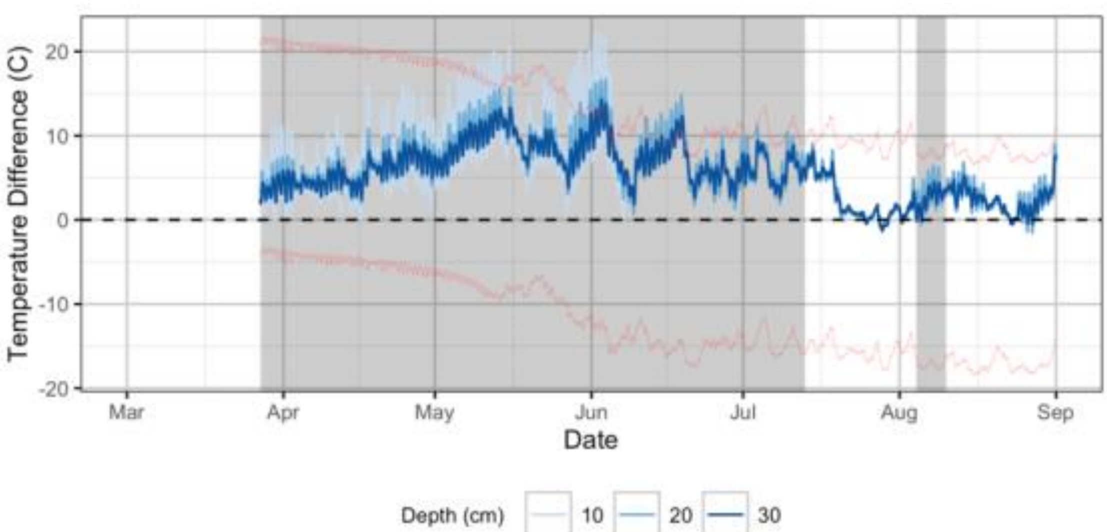


Figure D12 Station 13 at Norn's Creek Fan. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

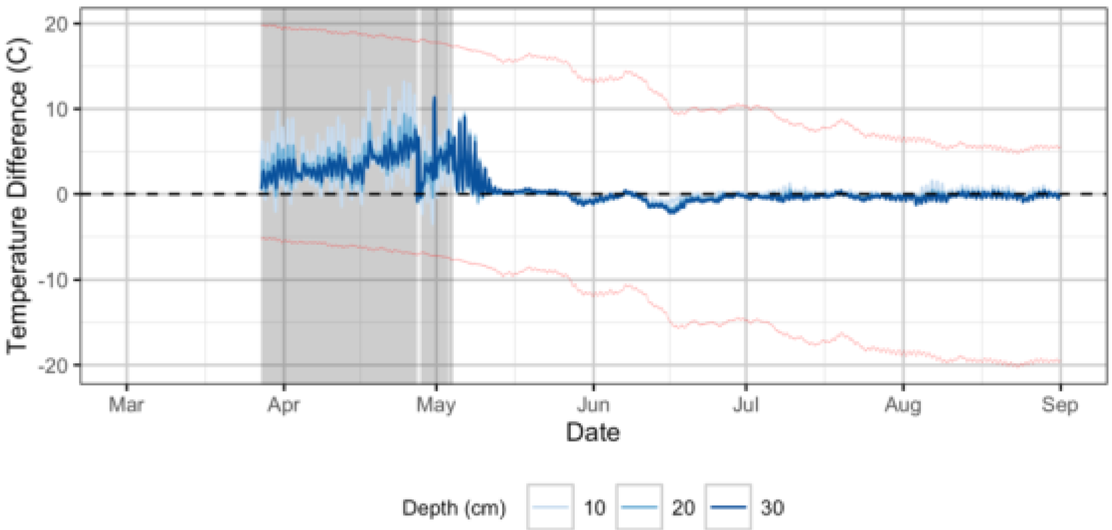


Figure D13 Station 16 at The Oxbow. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

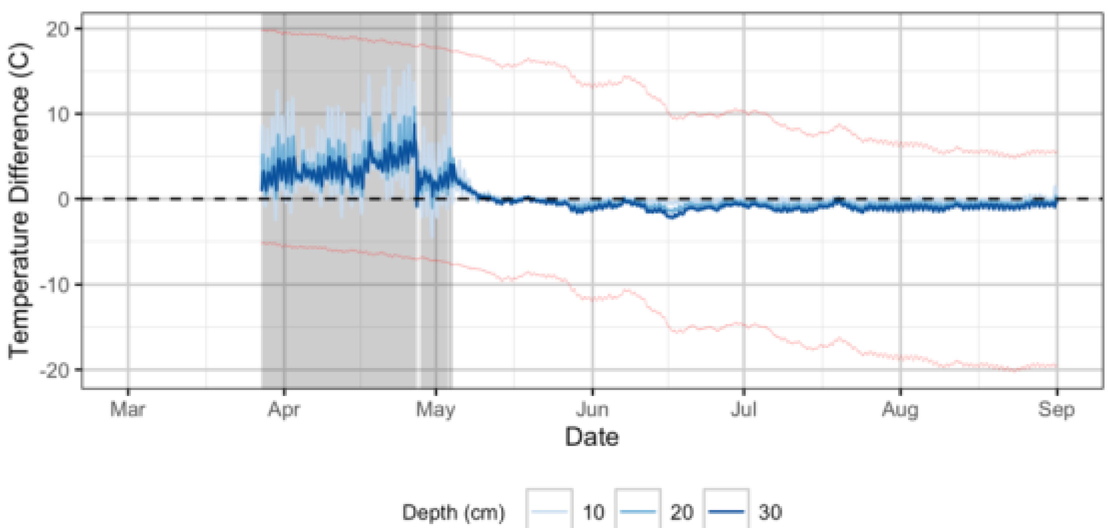


Figure D14 Station 17 at The Oxbow. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

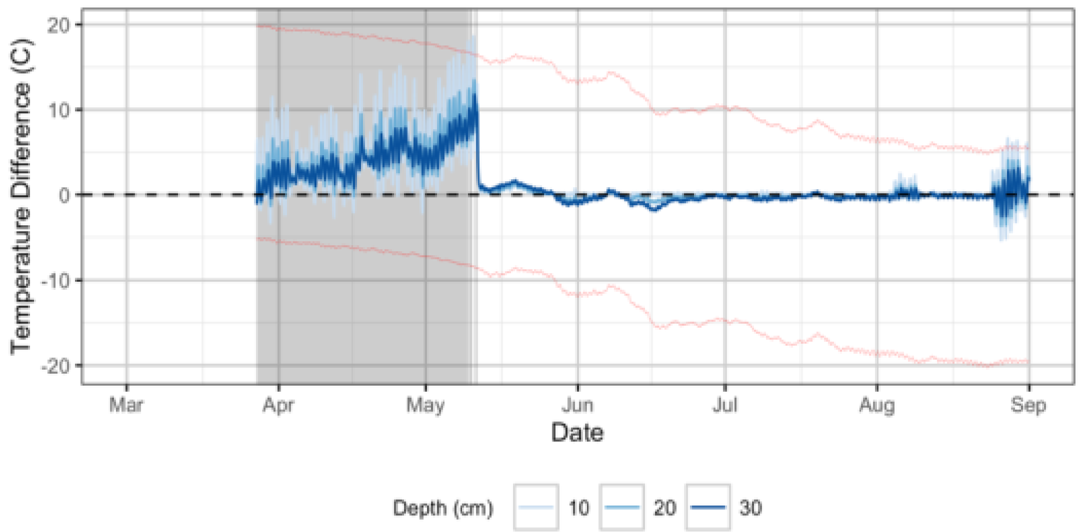


Figure D15 Station 18 at The Oxbow. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

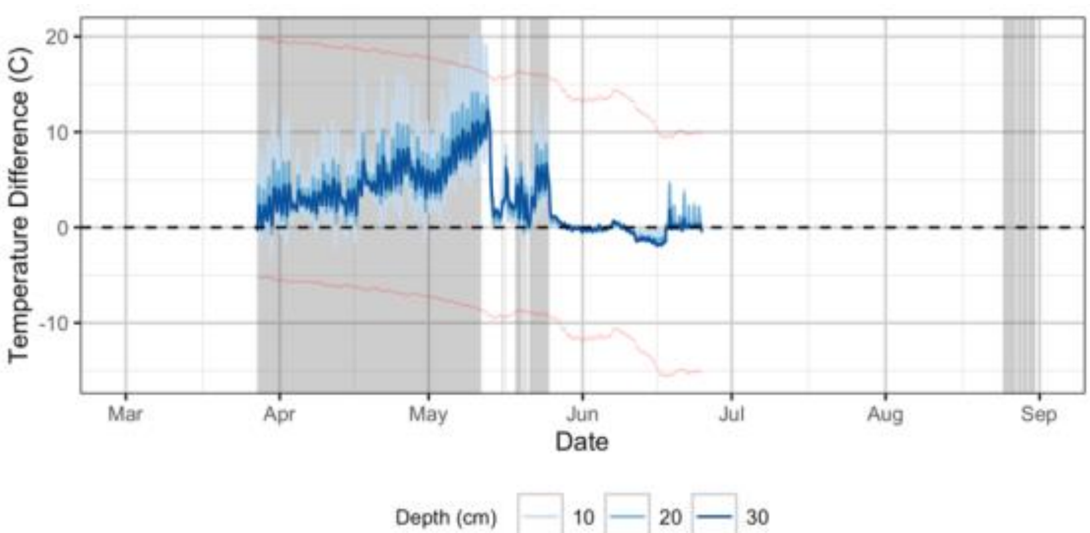


Figure D16 Station 19 at The Oxbow. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

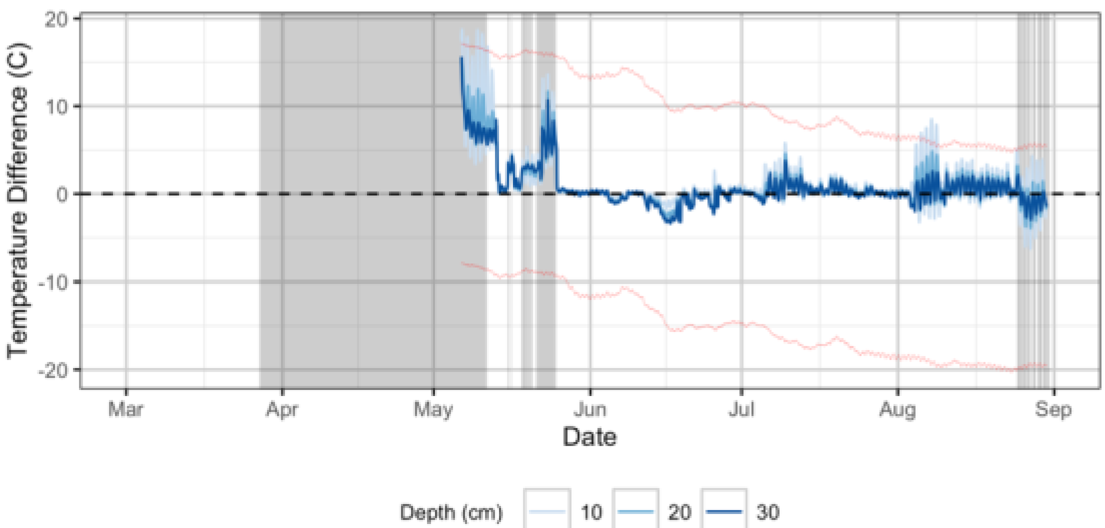


Figure D17 Station 21 at The Oxbow. Relative difference of gravel temperature to water temperature by sensor depth. Periods of dewatering (for 10cm sensor) are shaded in grey. Lower (0C) and upper (25C) temperature egg mortality thresholds are shown in red.

11.0 APPENDIX E – INTER-GRAVEL ABSOLUTE WATER TEMPERATURES

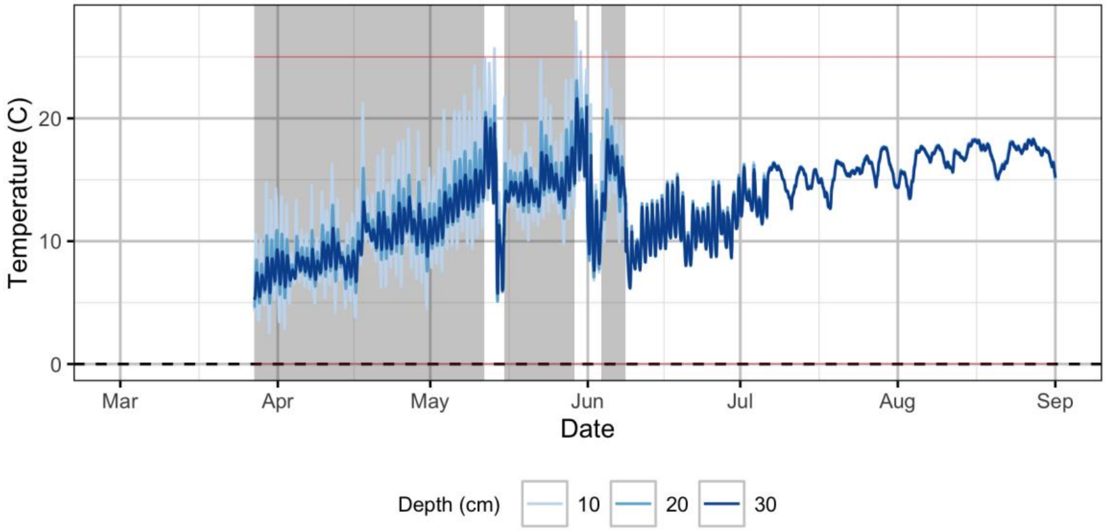


Figure E1 Station 2 at Norn’s Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

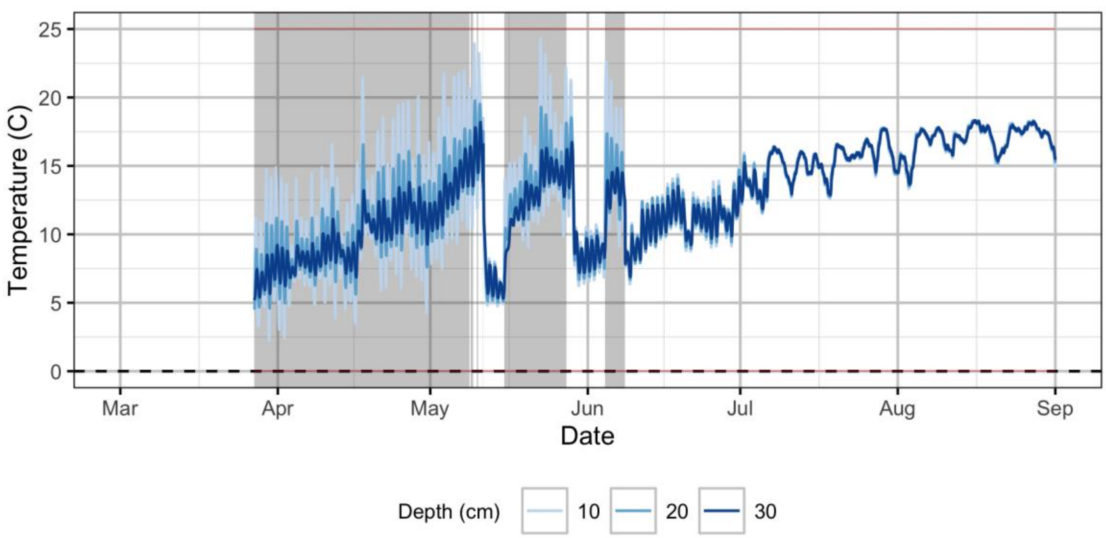


Figure E2 Station 3 at Norn’s Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

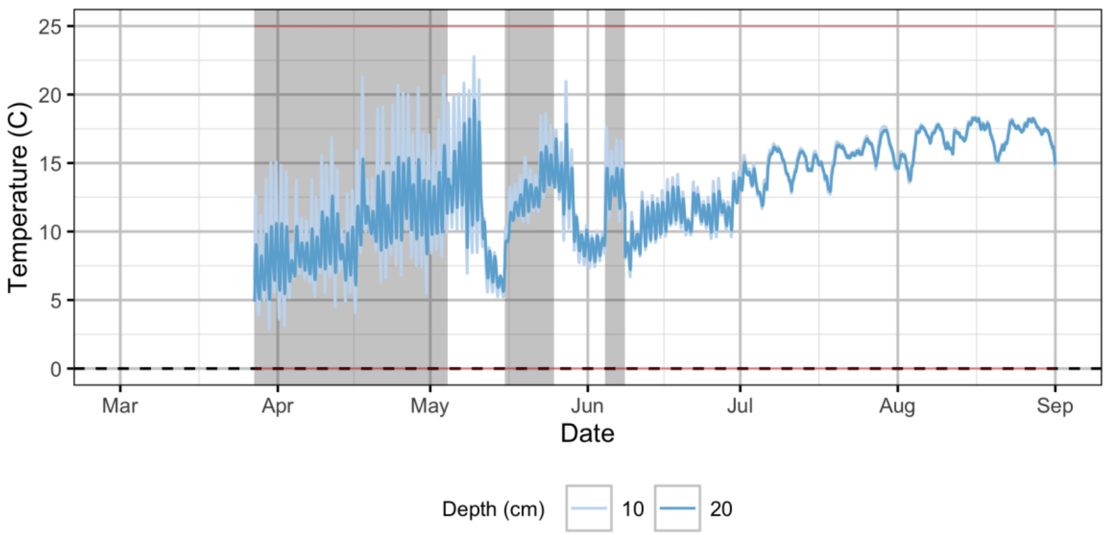


Figure E3 Station 4 at Norn's Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

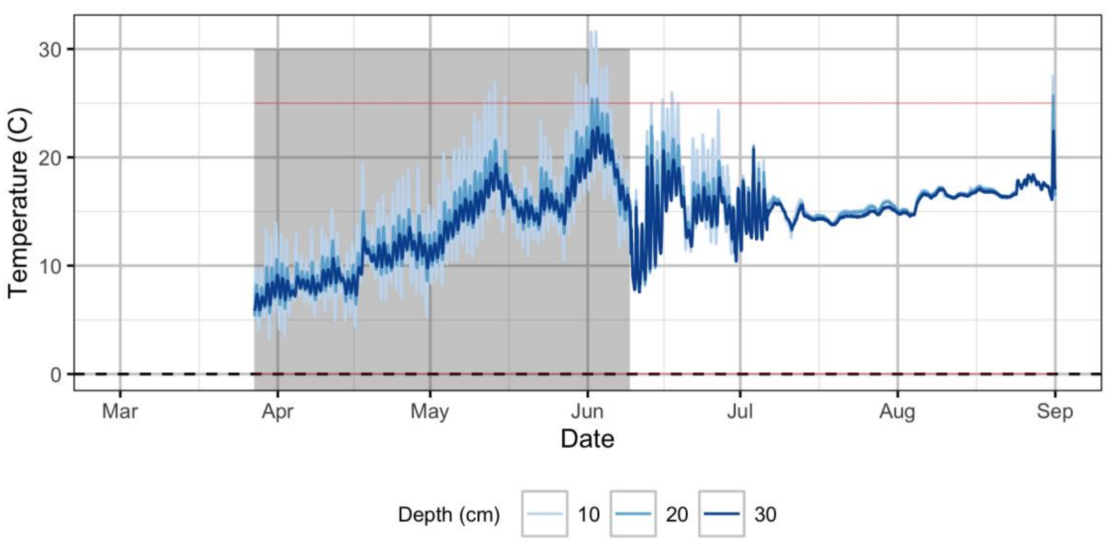


Figure E4 Station 5 at Norn's Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

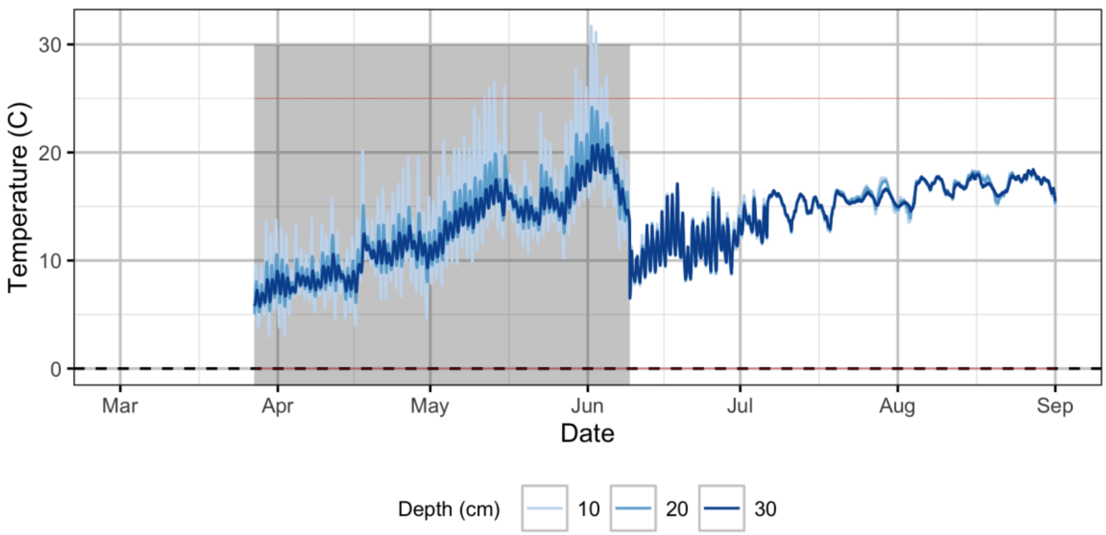


Figure E5 Station 6 at Norn's Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

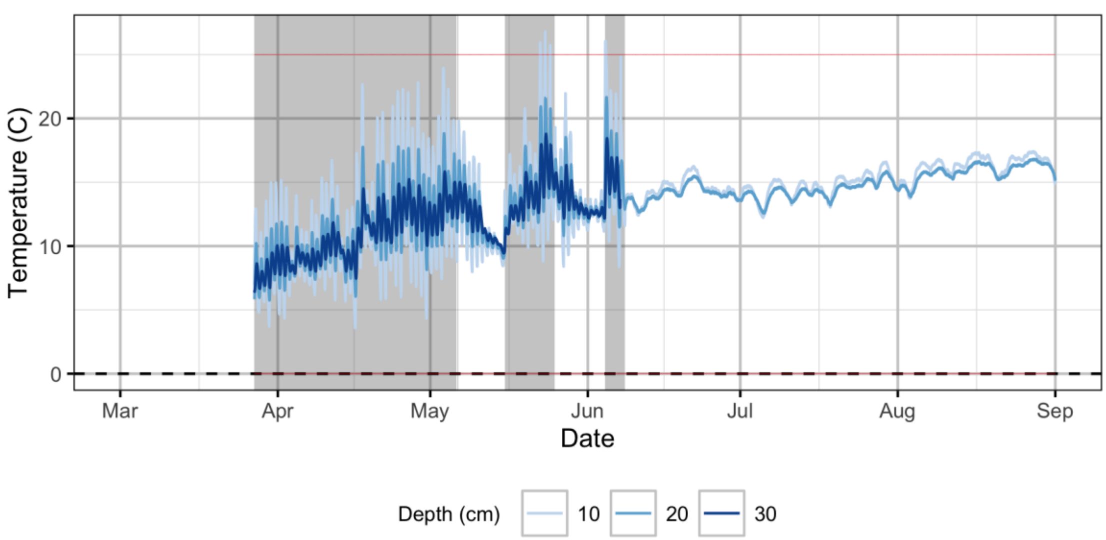


Figure E6 Station 7 at Norn's Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

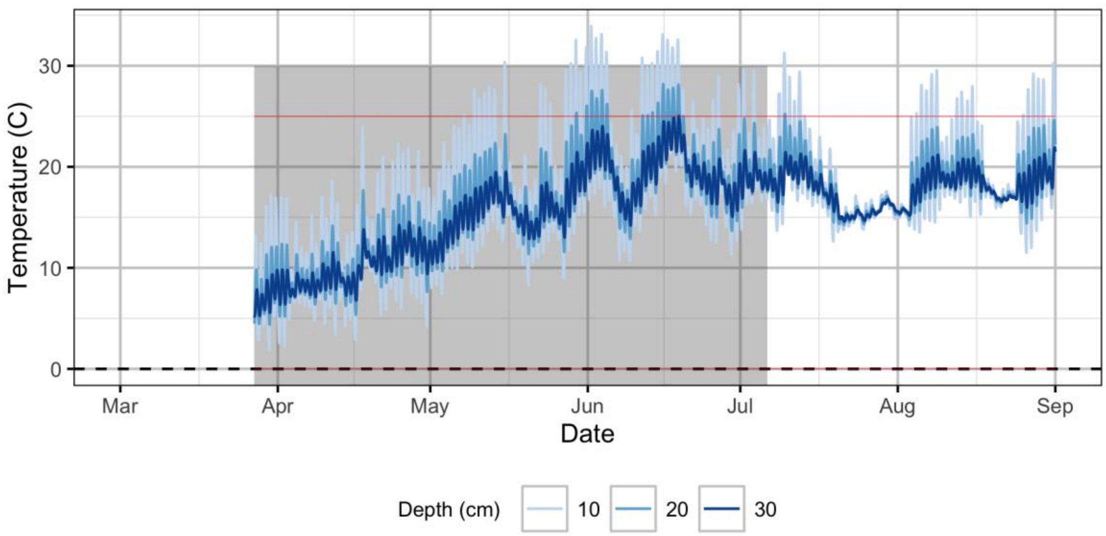


Figure E7 Station 8 at Norn's Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

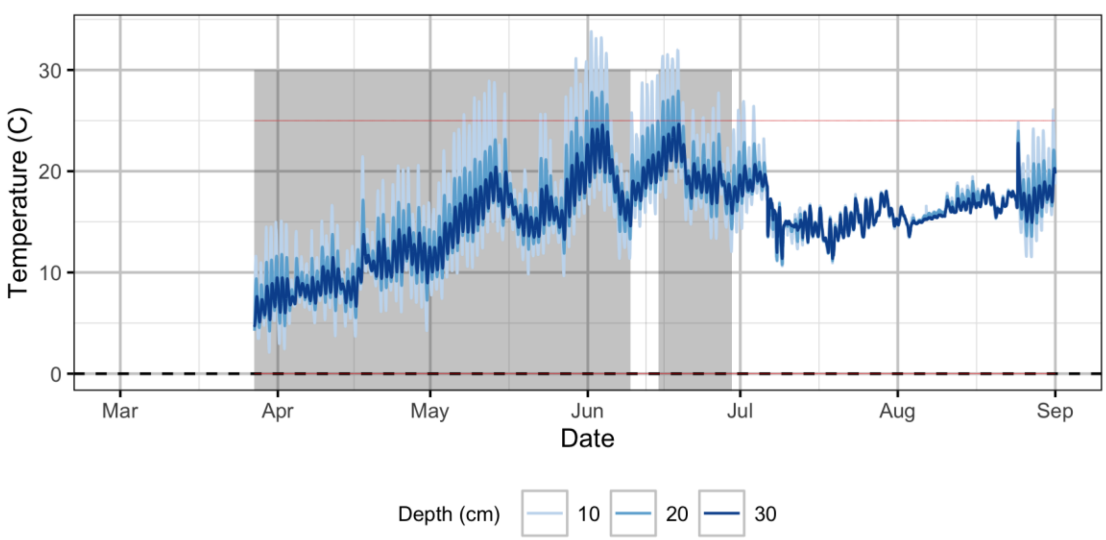


Figure E8 Station 9 at Norn's Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

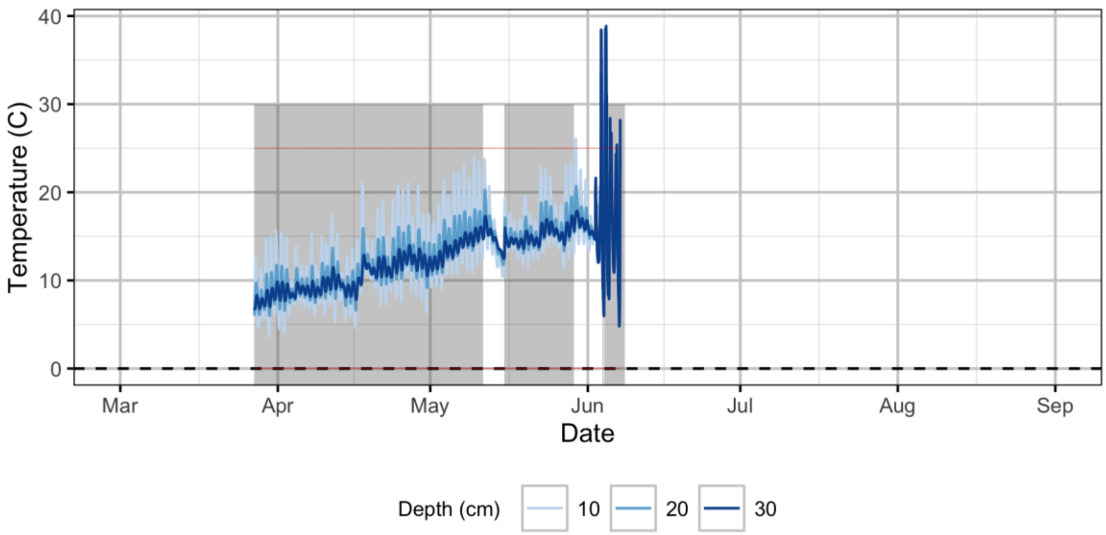


Figure E9 Station 10 at Norn’s Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

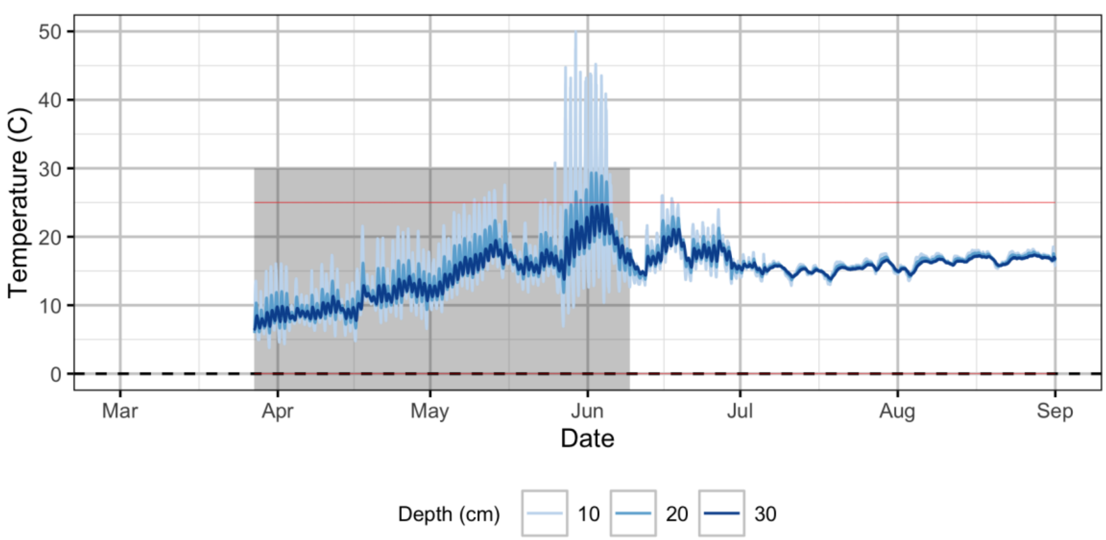


Figure E10 Station 11 at Norn’s Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

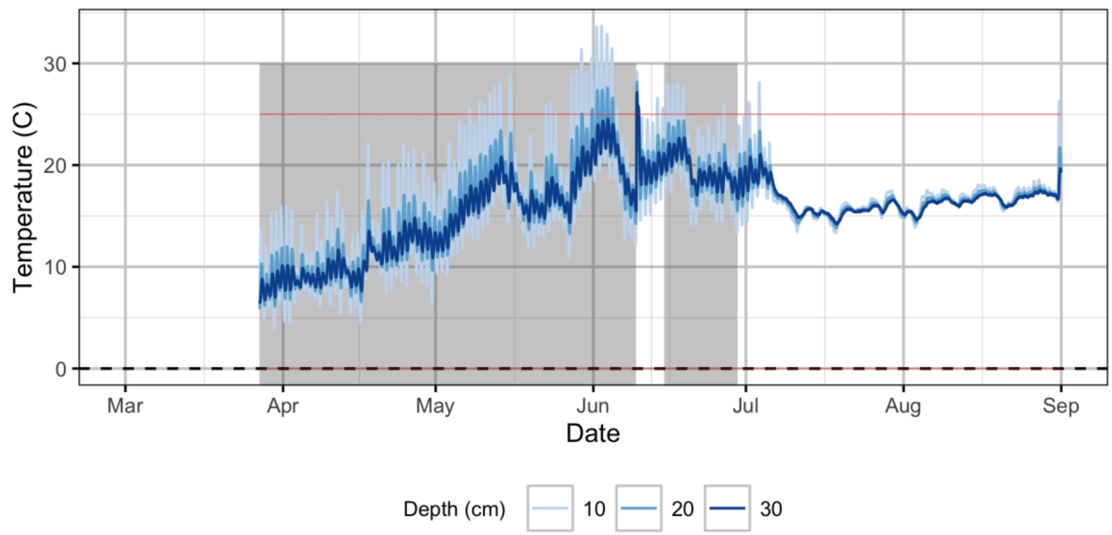


Figure E11 Station 12 at Norn’s Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

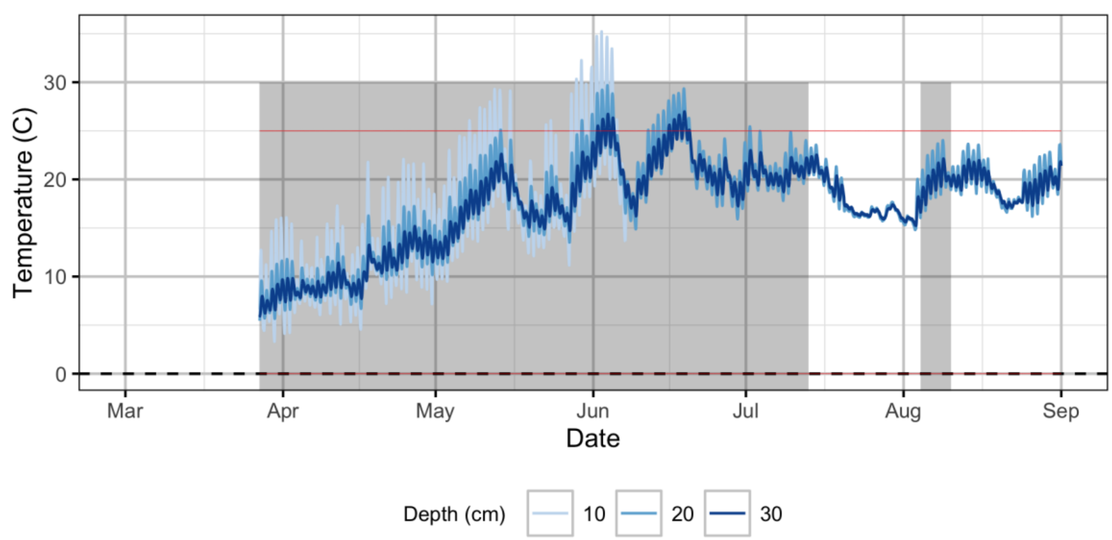


Figure E12 Station 13 at Norn’s Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

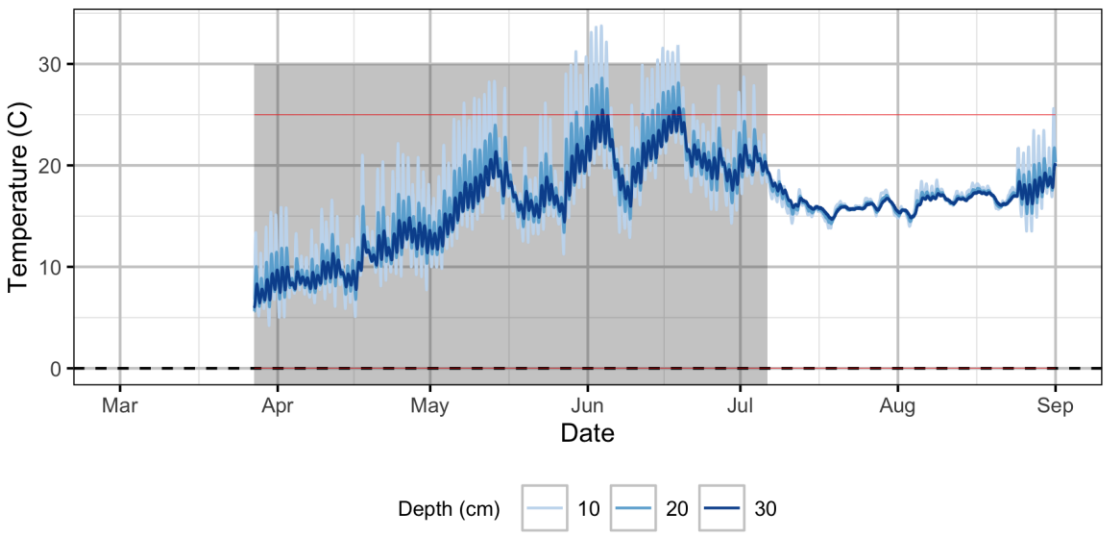


Figure E13 Station 14 at Norn's Creek Fan. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

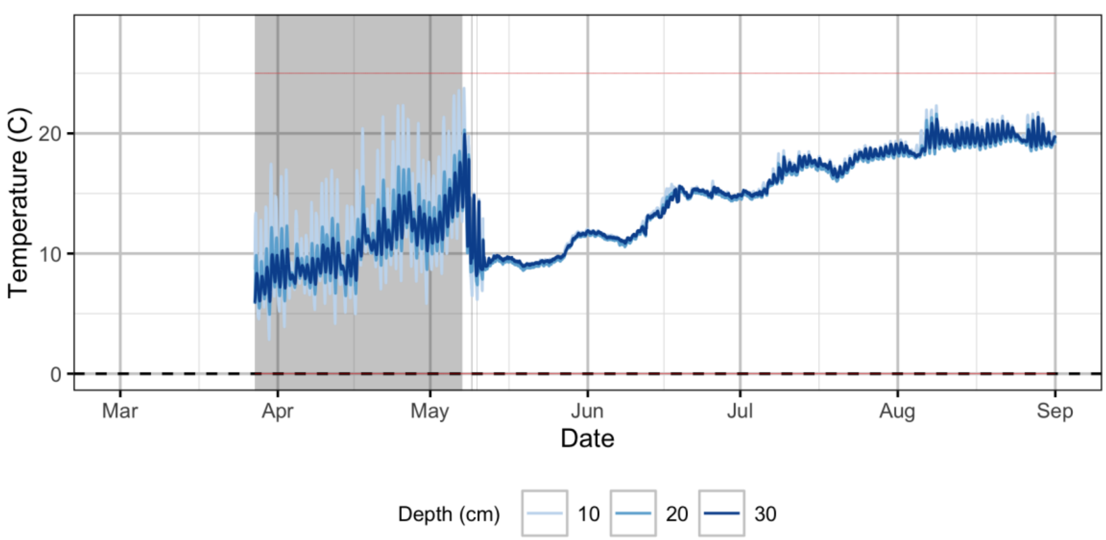


Figure E14 Station 15 at The Oxbow. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

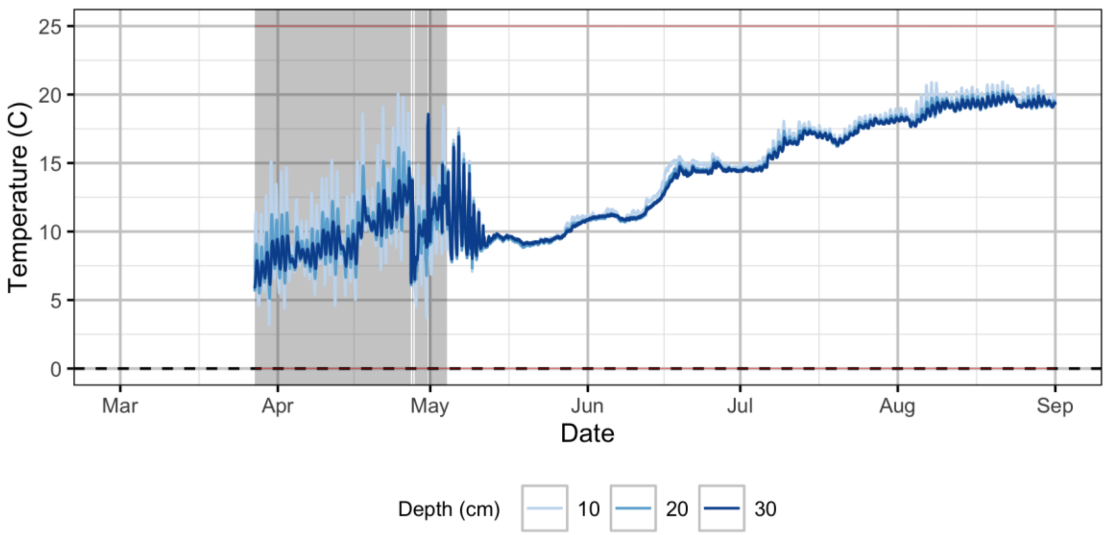


Figure E15 Station 16 at The Oxbow. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

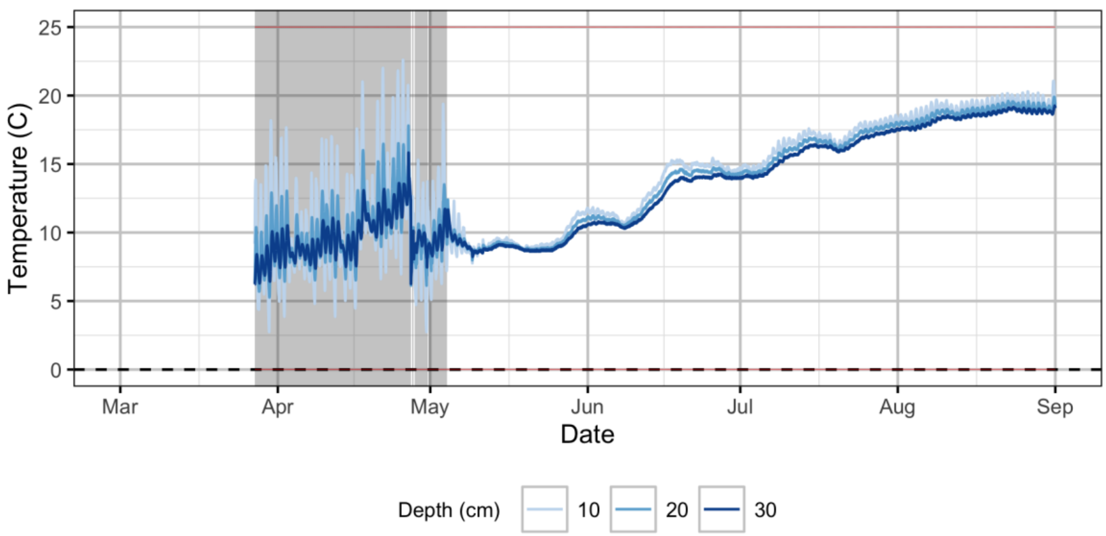


Figure E16 Station 17 at The Oxbow. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

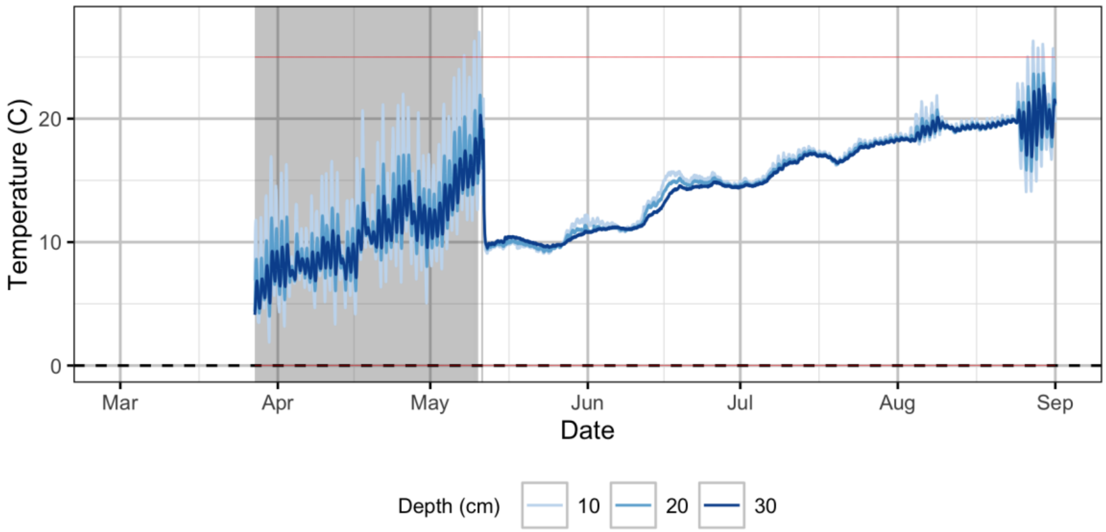


Figure E17 Station 18 at The Oxbow. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

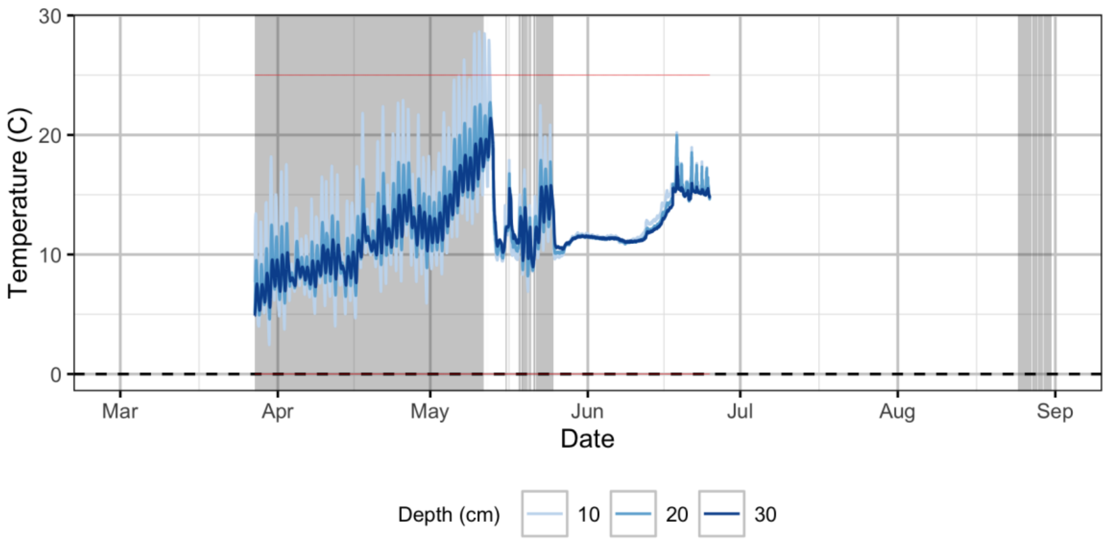


Figure E18 Station 19 at The Oxbow. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

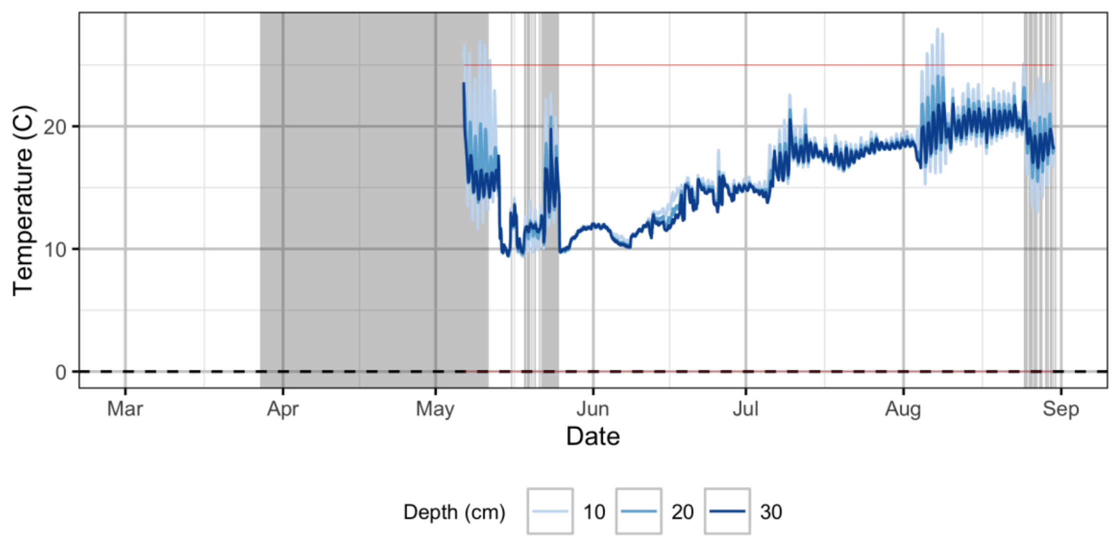


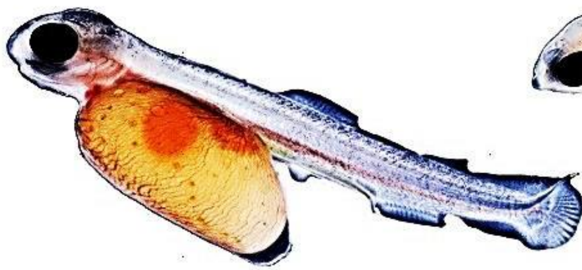
Figure E19 Station 21 at The Oxbow. Absolute gravel temperature by sensor depth. Periods of dewatered for 10 cm sensor are shaded in grey. Lower (0°C) and upper (25°C) thresholds are shown in red.

12.0 APPENDIX F - RAINBOW TROUT EGG STAGING GUI

Rainbow Trout Egg and Alevin Development Field Guide

Mountain Water
RESEARCH
Jeremy Baxter
107 Viola Cres., Trail, BC, V1R 1A1
Tel: 778-456-4566
Mobile: 250-505-9887
jeremy@fishtech.ca

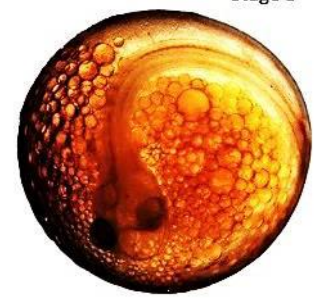
Stage 8



Stage 7

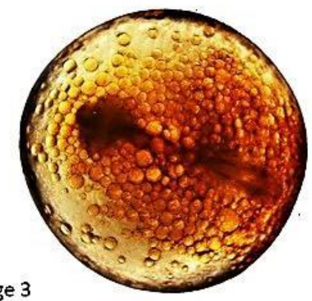
Stage 6

Stage 5



Stage 1

Stage 2



Stage 3

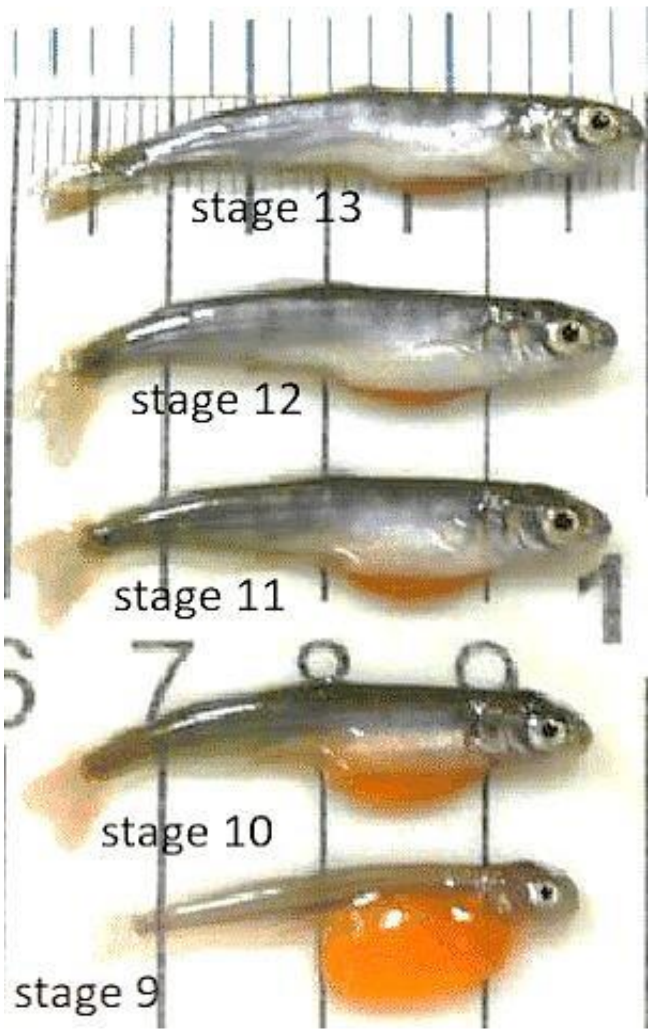
Stage 4

Stage	Description & development time based on 10°C (Days since fertilization)
1	Fertilization-Early Blastula (hours)
2	Blastula-Gastrula (12 hours to 6 days)
3	Embryo with ocular development (7 days)
4	Embryo with faint pigmentation of eyes (12 days)
5	Eyed - Full pigmentation of eyes (20 days)
6	Ready to Hatch. Body developed (30 days)
7	Hatching, when the larva is about 14–14.5 mm (32 days)
8	Alevin (Larvae)- Hatched (34 days) no adipose yet (picture at stage 9 to 10)

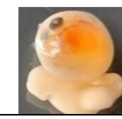
Use Stage 9 to 13 for Alevin (Larvae) development

Rainbow Trout eggs can have different concentrations of carotenoid pigments

Stage	Description and development time based on 10°C (Days since fertilization)
9	Larva is about 18 mm and the initiative of adipose fin appears (42 days),
10	2/3 of the yolk sack has already been consumed and larvae gulp air (52 days),
11	Edge of pectoral, pelvic and caudal fins become serrated (59 days),
12	Yolk-sack is almost entirely pigmented (70 days),
13	Fry - yolk-sack is fully absorbed (85 days).



Development of hatched alevin (larvae) to fry at about 10°C

Dead Egg Types	Description	Example
Opaque	Not transparent	
Fungus	Fungus or disease present	
Desiccated	Dried up (wrinkled)	
Decayed	Rotted or decomposed (can have fungus)	

Dead Eggs

Healthy Eggs (one or two dead)