Columbia River Project Water Use Plan

CLBMON-46 LOWER COLUMBIA RIVER RAINBOW TROUT SPAWNING ASSESSMENT AND EGG MORTALITY STUDY

Reference: CLBMON-46 Implementation Year 3 (2021)

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March 2nd, 2022

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March 2nd, 2022

BC Hydro
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Attention: Teri Neighbour – Natural Resource Specialist, Environment

Dear Teri,

Re: CLBMON-46 Lower Columbia River Rainbow Trout Spawning Assessment and Egg Mortality Study-Year 3

Nupqu Limited Partnership, Mountain Water Research and Poisson Consulting Ltd. are pleased to provide you with an electronic copy of our technical report summarizing data analysis and field-based data collection results for the CLBMON-46 Lower Columbia River Rainbow Trout Spawning Assessment and Egg Mortality Study-Year 3 (2021) in relation to the BC Hydro CLBMON-46 Lower Columbia River Rainbow Trout Spawning Assessment (the Project).

We appreciate the opportunity to work with you on this Project, and we trust that this report meets your requirements for year 3 of the 5-year study period. In 2021, flows were managed with Rainbow Trout Spawning Protection Flows (RTSPF) enacted. Please feel free to contact the undersigned by phone or email regarding any questions or further information that you may require.

Report prepared by:

Poisson Consulting Ltd, Mountain Water Research and Nupqu Limited Partnership.

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EXECUTIVE SUMMARY

Since 1992, BC Hydro has implemented Rainbow Trout Spawning Protection Flows (RTSPF) at Hugh L. Keenleyside Dam on the Lower Columbia River (LCR). These flows are designed to provide stable or increasing flows during the spawning window for Rainbow Trout. 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 at current redd densities. The key operating decision that will be affected by this program is whether to continue the annual implementation of RTSPF in the LCR.

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 and LKR. The egg and alevin mortality are being assessed by opportunistically excavating redds at a range of intervals after redd dewatering to determine the percent mortality. This is in addition to continuing to track Rainbow Trout abundance, spawn timing and spatial distribution within the study area.

RTSPF were in place for 2021 resulting in the dewatering of only 10 redds (representing less than 0.1% of the annual total). No egg mortality surveys were conducted. Egg mortality in dewatered redds in 2019 and 2020 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.

Peak counts of redds in 2021 were highest at Genelle (1600), Norn's Creek Fan (1000), and left upstream bank at Norns Fan (800). These three areas have consistently provided the highest redd counts since 1999 when the surveys began. The analysis of the redd and spawner counts estimated that there were approximately 9,800 spawners in the mainstem of the LCR and LKR in 2021 (95% CIs from 7,900-13,000). Over the period of monitoring, there has been a nine-fold increase from the estimated abundance of 1,350 spawners in 1999 to a peak of 13,000 spawners in 2017. The number of spawners in Norn's Creek has shown a similar trend through time. Spawner abundance in the LCR has been relatively stable since 2013, a fact which together with the reduced growth and condition in adults suggests that population may have reached its carrying capacity in recent years, particularly in 2017 and 2018 (Golder et al. 2021).

In 2021 the first redd was observed on February 19th during initial boat surveys. Based on the redd counts the model estimated that 2.5% of the total number of redds had been constructed between the 3rd and 8th of March (depending on river segment). The model also estimated that peak spawning occurred on April 27th and that 97.5% of the total number of redds were constructed between the 16th and 21st of June. This spawn timing is similar to the previous 20 years of monitoring under CLBMON 46.

Spawner abundance has been estimated in Norn's Creek intermittently since 1999 by a crew of experienced snorkelers. The trend in the numbers of spawners in Norn's Creek has increased through time and the estimated abundance in 2021 was 2,966 spawners. This is the highest recorded year since surveys began in 1999.

To mitigate additional impacts to Rainbow Trout spawners and redds in 2021, an exclusion fence was installed in Channel E at Genelle for 46 days from on March 13th to April 28th as part of the BC Hydro CLBMON-42b Fish Habitat Recontouring Project.

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Version	Date	Issued by	Description
1.0	2021/12/21	Mark Fjeld	Draft report
2.0	2022/03/02	Mark Fjeld	Final Report

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ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	Definition
Assessment	Lower Columbia River Spawning Assessment
AUC	Area-Under-the-Curve
BRD	Brilliant Dam
CI	Confidence Interval
CRI	Bayesian Credible Interval
DO	Dissolved Oxygen
HLK	Hugh Keenleyside Dam
LCR	Lower Columbia River
LKR	Lower Kootenay River
Nupqu	Nupqu Limited Partnership
MWR	Mountain Water Research
Project	CLBMON-46 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
UAV	Unmanned aerial vehicle (drone)

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
MASL	Metres above sea level
MAF	Million Acre Feet = 1233.5m^3 volume of water

1.0 PROJECT OVERVIEW

1.1 Introduction

The primary objective of the current Rainbow Trout Spawning Assessment monitoring program is to reduce uncertainties pertaining to flow management effects on Rainbow Trout (*Oncorhynchus mykiss*) egg mortality in the LCR and LKR 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 the 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 (six-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 can accommodate other values without significantly altering Rainbow Trout population status.

In 2018, a Technical Committee consisting of representatives from First Nations, Provincial and Federal government agencies, consultants, 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. To test this possibility, 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. Although RTSPF were not implemented in 2019, less than 1% of the redds were dewatered. RTSPF were originally scheduled for 2020, but exceptional environmental conditions required minor flow reductions within the spawning period. This mixture of stable or increasing flows and reductions defines 2020 as an RTSPF hybrid year, which resulted in a total of 1.1% of the redds being dewatered. As RTSPF were not officially in place for 2020, the yearly alternation of flow protocols was shifted. In accordance with this shift, 2021 was re-designated as an RTSPF ‘on’ year with stable or increasing flows throughout the spawning period, resulting in less than 0.1% of redds being dewatered.

The current study was also 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.

1.2 Study Area

The geographical scope of the monitoring program is the LCR downstream of Hugh L. Keenleyside 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 25.0); 6) Genelle (RKm 25 to 27.5).; 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 2021 analyses as historically these locations constituted less than 0.1% of the total aerial count. The remaining five sections were aggregated into three segments for analysis of spawn-timing. The three segments are the Lower Kootenay River (section 4), the LCR above LKR (sections 2 and 3) and the LCR below LKR (sections 5 and 6).

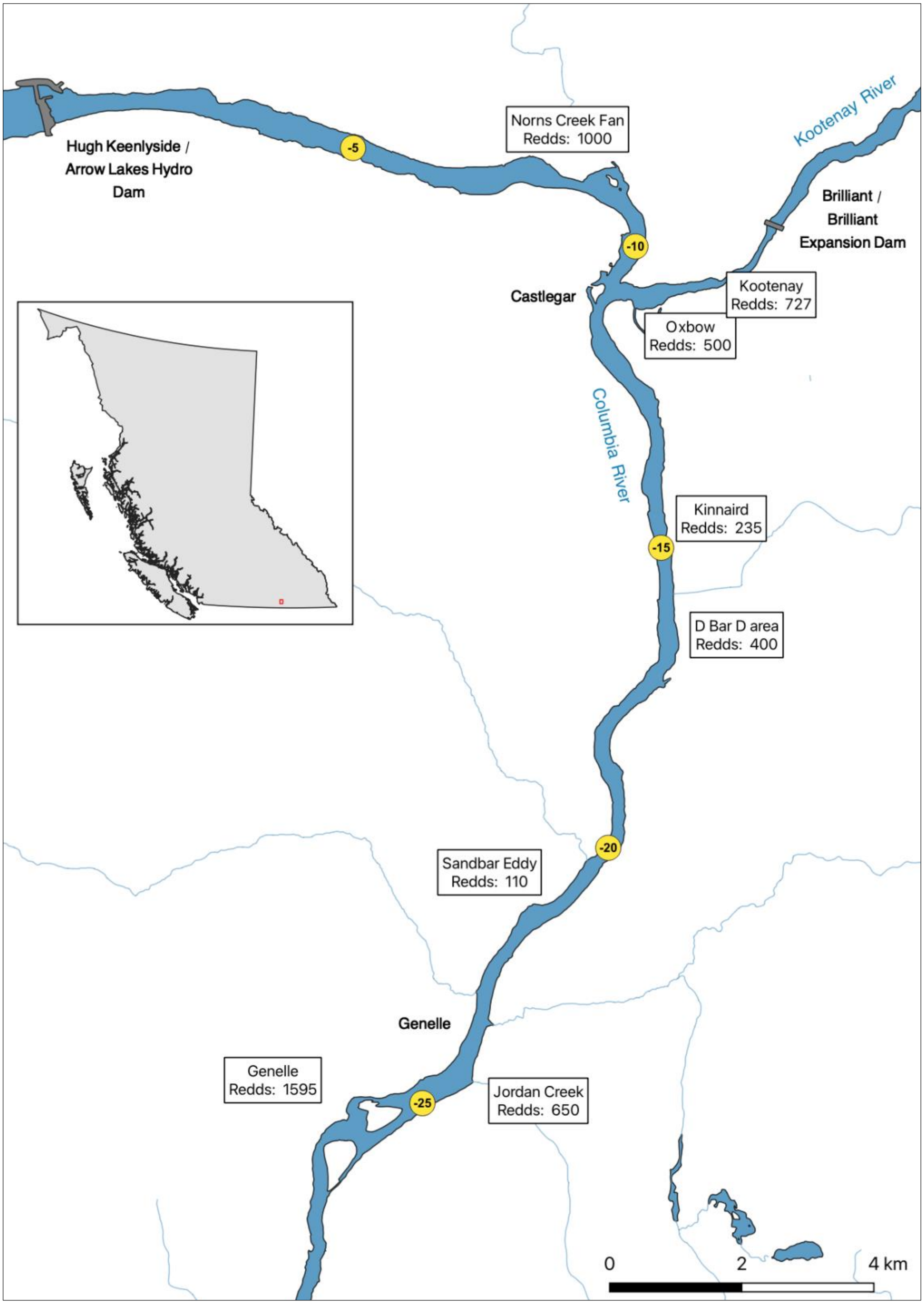

Figure 1. Overview map of the Lower Columbia River and Lower Kootenay River study area with peak count redd numbers by key areas. See Appendix A for detailed spawning maps.

2.0 METHODS

2.1 Rainbow Trout Redd and Spawner Surveys

Rainbow Trout redds and spawners were monitored in the Lower Columbia River with ground, boat, drone, and helicopter surveys. Prior to the first helicopter survey in 2021, boat surveys were completed to verify spawning had begun.

2.1.1 Helicopter Surveys

Helicopter surveys have been completed within the LCR since 1999 with varying frequency. Surveys commence once active spawning is determined either through boat surveys or utilizing the historical dataset for average spawn initiation timing. These surveys are conducted weekly throughout the Rainbow Trout spawning season covering the main spawning areas from Norn`s Creek Fan to Genelle, BC.

Aerial count sites were updated in 2020 to more clearly define the boundary between Norns Creek Fan and LUB Norns Fan (the opposing left-upstream bank and main stem). Although LUB Norns Fan is an important spawning site it is also deep, which means that the count can vary significantly based on visibility. Due to this variability, it is not included in the AUC analysis for redd abundance.

In 2021, a total of 11 helicopter surveys were carried out across the various sections during the Rainbow Trout spawning season as visibility permitted (Table 1). The spawners and redds were enumerated by two experienced observers with one person responsible for counting redds and the other for counting spawners. Viewing conditions were classified as Good or Poor depending on whether fish could be clearly seen on spawning gravels.

Table 1 Helicopter survey dates completed during active spawning including descending limb in 2021.

Survey Date (YY/MM/DD)	Survey Locations	Total Redd Count	Total Spawners
2021-03-04	LCR above LKR, LKR, LCR below LKR	156	166
2021-03-18	LCR above LKR, LKR, LCR below LKR	716	541
2021-03-25	LCR above LKR, LKR, LCR below LKR	1546	1306
2021-04-01	LCR above LKR, LKR, LCR below LKR	2206	1493
2021-04-07	LCR above LKR, LKR, LCR below LKR	3199	2275
2021-04-15	LCR above LKR, LKR, LCR below LKR	3943	2550
2021-04-21	LCR above LKR, LKR, LCR below LKR	4797	3415
2021-04-29	LCR above LKR, LKR, LCR below LKR	5608	3590
2021-05-06	LCR above LKR, LKR, LCR below LKR	6456	3092
2021-05-13	LCR above LKR, LKR, LCR below LKR	5602	2702
2021-05-21	LCR above LKR, LKR, LCR below LKR	1247	591

2.1.2 Boat Surveys

Helicopter surveys were supplemented by boat surveys which covered the main spawning areas from Norn's Creek Fan to Genelle (sections 2-6). Boat surveys allow the verification of redds that cannot be clearly identified from the air, the documentation of redds in <1.0 m of water to monitor the risk of dewatering and the confirmation of possible new spawning areas seen from the air (Thorley and Baxter 2011). Boat-based shallow water surveys commenced February 19th and were completed April 21st. Hundreds of shallow redds were observed in 2021, but only 11 were identified as having the potential to dewater from subsequent flow reductions. Shallow redd surveys ended in late April as stable or increasing flows were scheduled for the remainder of the spawning period.

2.1.3 Drone Surveys

The use of drone surveying was introduced in 2020 as a supplementary method for counting redds at the Norn's Creek Fan area. A total of 12 drone surveys were conducted between April 21st and June 17th, 2021, by Harrier Aerial Surveys. An experimental survey was also conducted at the Kootenay River Oxbow on April 21st, 2021. During each survey the drone continuously captured high-resolution images along a predetermined set of transects, spanning the entire spawning habitat. The images were then processed and geolocated, and image analysis software was used to stitch together images to create georeferenced ortho-mosaics. These ortho-mosaics were then imported into mapping software (QGIS) to be spatially overlaid and compared. The exceptionally high resolution of the imagery (2.3 cm pixels) allowed for the identification of individual redds based on the size and shape of visible disturbances within the substrate. Images were compared through time to verify that disturbances were new and a spatial layer of points was then created to represent the locations and distribution of all redds and redd clusters identified within the habitat. High turbidity and surface disturbance prevented the digitization of redds for three out of the twelve drone surveys performed at Norns Creek Fan. The combined spatial layer of redds was joined to the digital elevation model (DEM) and water depth data from the River2D model produced by Ecoscape Environmental Consultants Ltd. (Plewes et al. 2020) to assign an elevation to each redd. The elevations were then related to changes in LCR stage to detect dewatering events. Redds that were newly constructed and then dewatered between drone surveys could not be confidently identified, with the exception of redds that had been visibly excavated by the field crew. Differences in lighting and shadows confounded the observer's ability to detect new disturbances when a given area of substrate transitioned from wetted to dry between images.

2.1.4 Boat and Shore Surveys

Locations of shallow water redds with the potential to dewater were recorded using a handheld Garmin GPS unit and marked with an individually numbered weighted tag by crews during 2021 boat surveys. A standard protocol was followed when reductions were 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 (Table 2).

Depending on the river stage, fish exclusion fencing is erected in Channel E (left upstream bank of Genelle section at RKm 25.3) to mitigate additional redd dewatering during RTSPF years. Observations from historical surveys estimate that approximately 100 additional redds may dewater without the installation of the exclusion fence (Thorley et al. 2017). In mid-March 2021, an area at Genelle upstream of Channel E was recontoured by BC Hydro as part of the CLBMON-42b Fish Habitat Recontouring Project. To mitigate additional impacts to Rainbow Trout spawners and redds in 2021, BC Hydro environmental staff decided [in consultation with the agencies (DFO and MOE)] that exclusion fences should be temporarily installed across the upstream and downstream ends of Channel E to force Rainbow Trout to spawn elsewhere in the river during the recontouring. The exclusion fence was in place for 46 days from on March 13th to April 28th, 2021.

Table 2 Reduction dates, magnitude of reduction, number, and general location of dewatered redds in 2021.

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
2021-02-20	1932	1653	514	513	0	Norns Creek Fan
2021-02-20	1932	1653	514	513	0	Oxbow
2021-02-20	1932	1653	514	513	0	Genelle
2021-02-23	1633	614	513	515	5	Norns Creek Fan
2021-06-07	960	784	1841	1742	5	Norns Creek Fan

**Both HLK and BRD discharge rates were provided by BC Hydro.*

2.1.5 Norn's Creek Spawner and Redd Count Snorkel Survey

Norn's Creek is the highest use spawning tributary to the LCR after the Kootenay River. To estimate spawner abundance in Norn's Creek, snorkel surveys are conducted once a year when time, resources and conditions permit. Norn's Creek contains a side channel which is included in the surveys when it has enough flow for spawning. In 2021 the snorkel survey was completed on April 27th. The survey was conducted during daylight hours by three snorkelers who counted spawners, with 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 behind the snorkel team surveying both banks. . 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 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.

2.2 Egg and Alevin Mortality Surveys

Egg and alevin mortality surveys were initiated in 2019 and took place opportunistically throughout 2019 and 2020 when significant redd dewatering occurred. Mortality surveys were not scheduled in 2021 as flows remained stable or increasing and no significant redd dewatering was anticipated. Further details regarding egg and alevin mortality surveys can be found in Appendix D.

2.3 Environmental Data

In March 2019 real-time Onset Hobo RX3000 monitoring stations were installed in the LCR adjacent to Norn's Fan and in the LKR near the Kootenay River Oxbow (Figure 2 and 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 March 2019, 15 gravel temperature monitoring stations were installed at Norn's Fan (Figure 2) and seven were installed at the Kootenay River Oxbow (Figure 3). Each spawning gravel temperature monitoring station was equipped with three Onset Hobo MX2201 temperature loggers at gravel depths of 10 cm, 20 cm and 30 cm. These loggers were affixed to a wooden survey stake to facilitate installation. The gravel temperature logger stations were deployed at a range of elevations between 418.73 and 420.73 MASL at Norn's Creek Fan and between 415 and 415.8 MASL at the Kootenay Oxbow.

In October 2021, the MX2201 loggers were replaced by Tidbit V2 loggers and re-deployed at the same established gravel temperature monitoring sites at Norns Creek Fan (Figure 2). The two logging stations of lowest elevation are yet to be deployed and will be installed prior to the beginning of the 2022 spawning period, if water levels allow. The Tidbit V2 loggers are made from sealed epoxy and are further protected by a plastic housing and joined together using a 100 lb nylon strap to minimise thermal conductance. To reduce the chances of vandalism, the stations are no longer visible from the surface and are marked by a metal bolt which can be located using a metal detector. No gravel temperature loggers were redeployed at the Kootenay River Oxbow, as relatively low redd dewatering tends to occur there in comparison to Norn's Creek Fan.

2.4 Elevational Data

In December 2020, a federal geodetic benchmark at the Robson boat launch near Castlegar, BC (Geodetic Control Marker 533570) was located, and its elevation verified. On December 12th, 2020, the benchmark was used to recalibrate the RX3000 LCR water level reading. The field crew measured the vertical distance from the benchmark to the water's edge using a high precision Leica Disto D810 hypsometer. This measurement was then compared to the recorded logger elevation at the time of the measurement. The benchmark and hypsometer are used to ensure the accuracy of all elevational data for Norn's Creek Fan. In October 2021, additional elevation benchmarks were installed at Norn's creek fan and tied into the federal benchmark for additional measurement reference in future surveys.

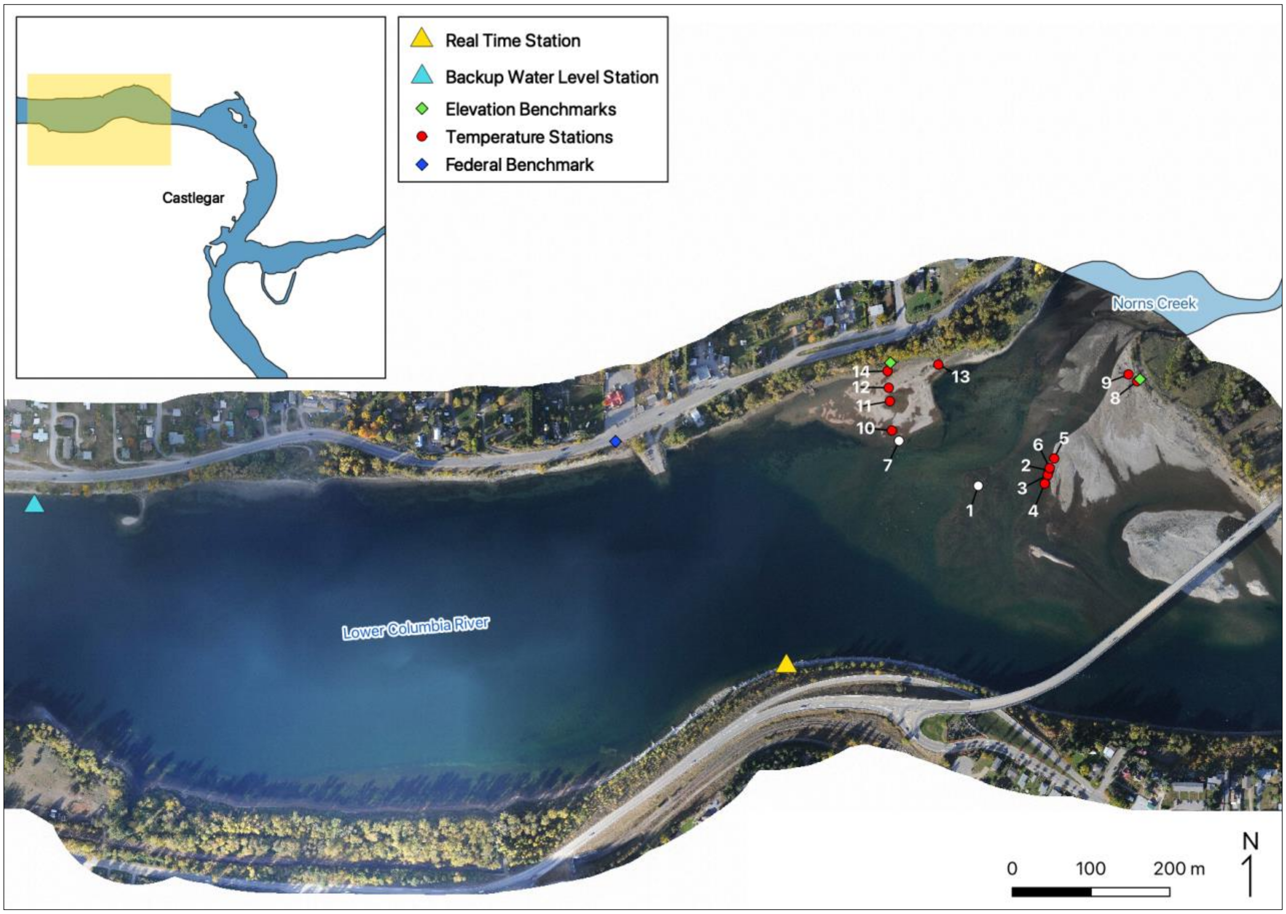

Figure 2. Monitoring stations on the Lower Columbia River at Norn's Creek Fan. White points are locations for temperature stations still to be deployed at low water.

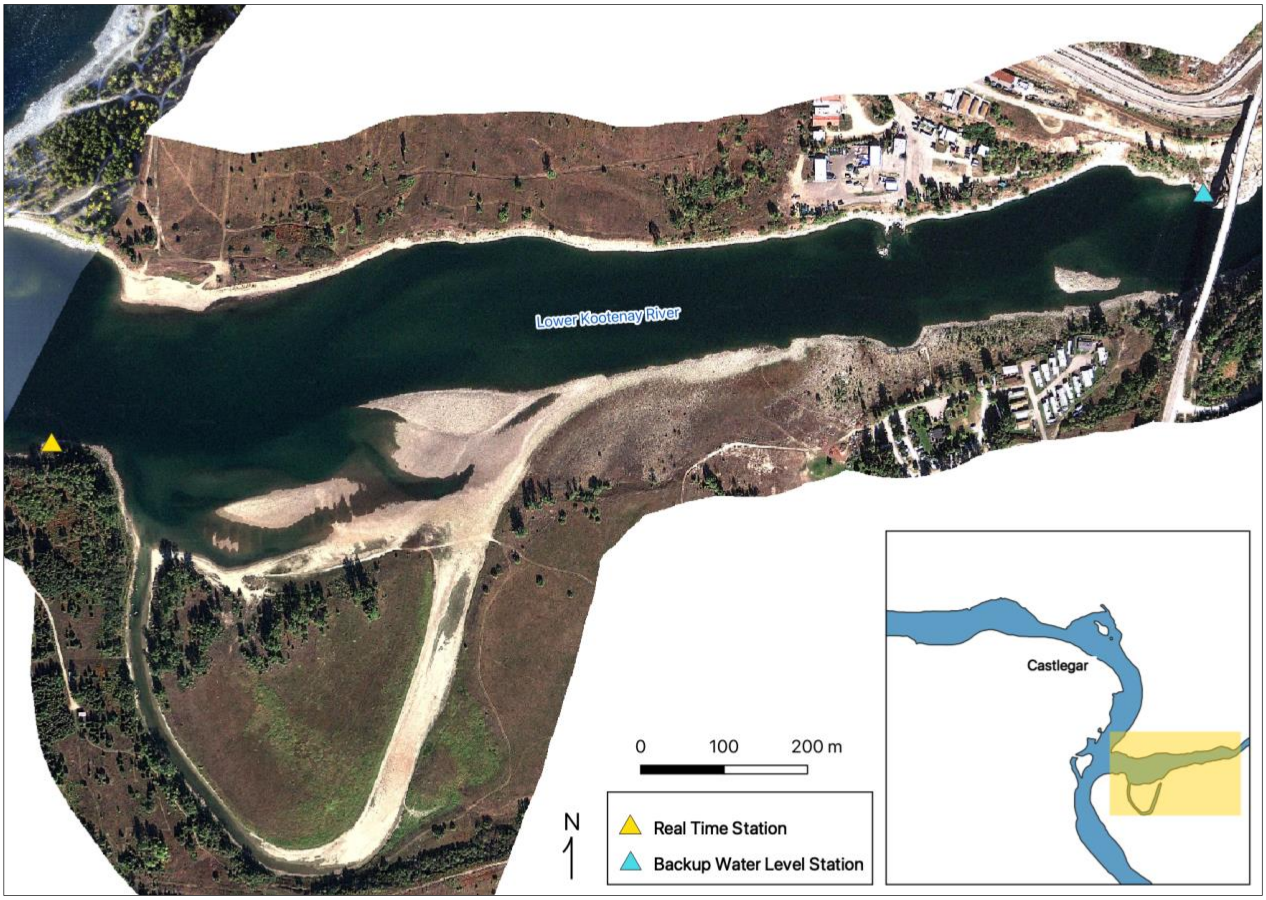

Figure 3. Monitoring stations on the Lower Kootenay River at the Oxbow.

2.5 Data Sources and Preparation

The redd and spawner surveys were conducted by Mountain Water Research. The age-1 Rainbow Trout abundance estimates were provided by the CLBMON-45 Large Fish Population Indexing Program conducted by Okanagan Nation Alliance (ONA) in conjunction with Golder Associates and Poisson Consulting. The DEM and velocity model data were provided by Ecoscape Environmental Consultants Ltd. The remaining data were collected by Mountain Water Research and Poisson Consulting.

The real-time stations continuously transmitted all sensor data to a project specific HOBOlink account where it was securely stored online. 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 4.0.3 (R Core Team 2020) 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 three 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 4.0.3 (R Core Team 2020) and the mbr family of packages.

2.6.1 Area-Under-the-Curve

The number of spawners, 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.

For the historical data information on the viewing conditions was not available, consequently 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.

2.6.2 Stock-recruitment Relationship

2.6.2.1 Spawners

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 strength of the density-dependence.

Key assumptions of the stock-recruitment model include:

- The prior probability for the recruits per spawner at low density (α) is zero truncated normal distribution 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 (Allen and Sanger 1960; Hildebrand and McKenzie 1995; Thorley 2009). The carrying capacity is α/β.

2.6.2.2 Eggs

The relationship between the total egg deposition and the number of age-1 fish the following fall was also estimated using a Beverton-Holt stock-recruitment. The first assumption was replaced with the assumption that:

- The prior probability for the egg to age-1 survival at low density (α) is a zero truncated normal distribution with a mean of 0.0625 and a SD of 0.03.

The mean of 0.0625 is based on 50% egg survival, 50% post-emergence fall survival, 50% overwintering survival and 50% summer survival.

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 *https://www.poissonconsulting.ca/f/563845962*.

3.1 Redd and Spawner Abundance

As in previous years, the areas with the most spawning in 2021 were Genelle (1,595 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 9,800 fish spawned in the LCR and LKR mainstem in 2021 (95% CIs from 7,893-12,911). Over the period of monitoring, there has been a six-fold increase from an estimated abundance of 1,350 spawners in 1999 to the 9,800 spawners in 2021. The abundance has been relatively stable since 2013 with broadly overlapping CIs among years. (Figure 4).

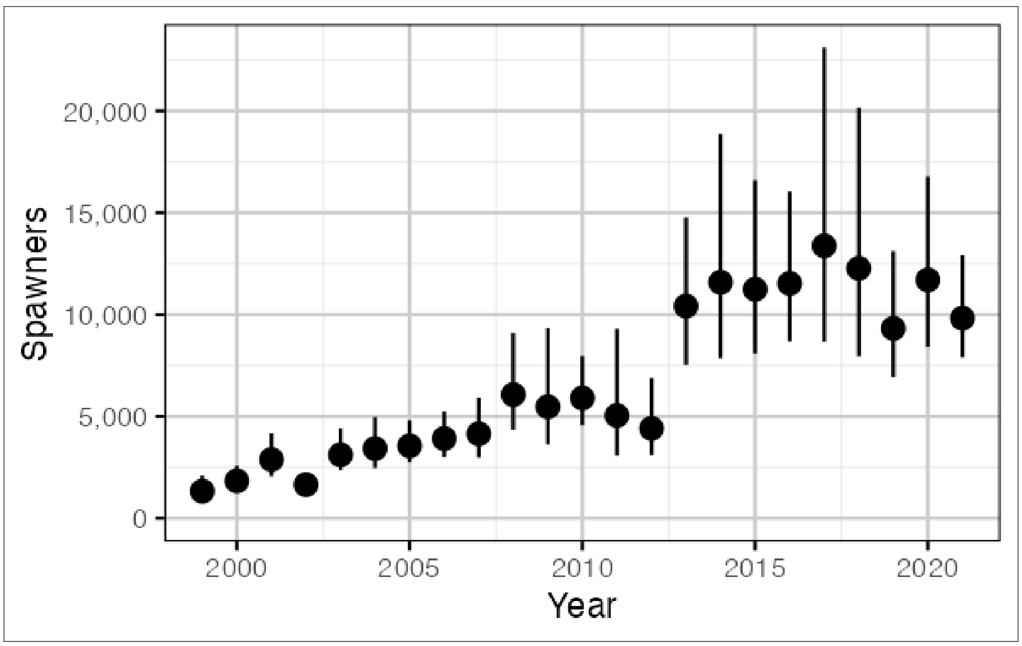

Figure 4. Estimated total spawner abundance by year with 95% CIs.

3.2 Norn's Creek Snorkel Surveys

A total of 2,966 spawners were enumerated during the snorkel and shore-based survey of Norn's Creek on April 27th, 2021 (Figure 5). This year's estimated spawner abundance was slightly higher than the previous peak observed in 2017. The 2021 estimate represents a five-fold increase since surveys began in 1999.

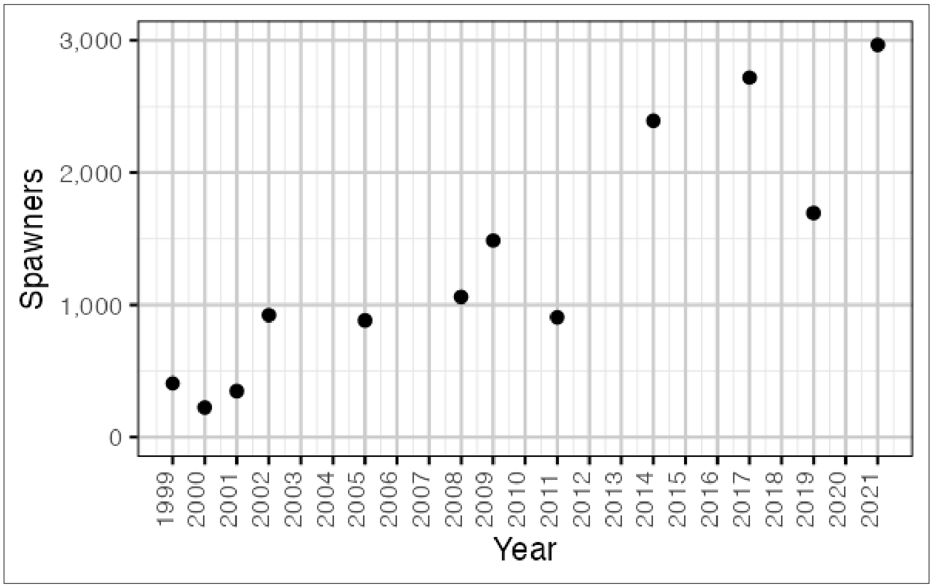

Figure 5. Total spawner abundance in Norn's Creek by year.

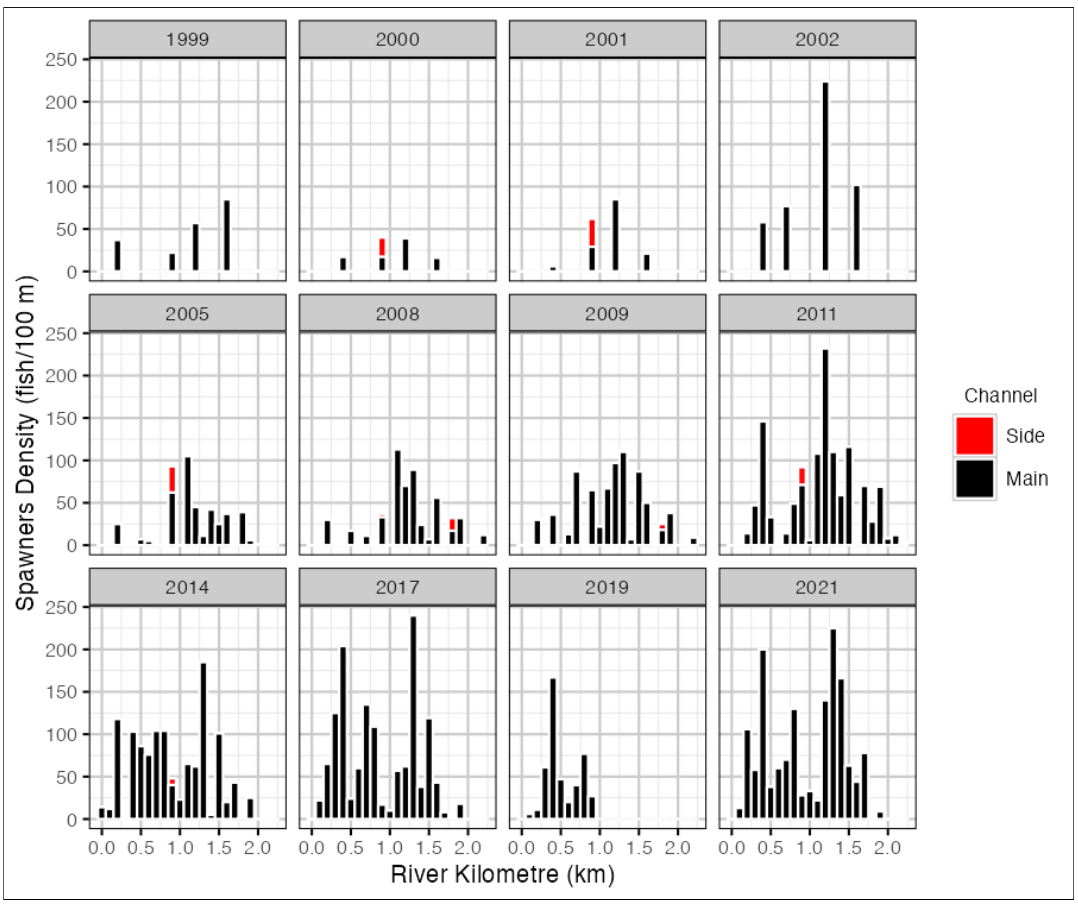

Figure 6. Distribution of spawning fish in Norn's Creek by year.

3.3 Redd Dewatering

The discharge from HLK dam in 2021 underwent reductions that caused redd dewatering on the LCR in late February and early June 2021 (Figure 7). A total of 10 redds (Figure 8) were dewatered by these reductions corresponding to 0.07% of the estimated total number of redds (95% CI 0.04-0.1%; Figure 8 and Figure 9). This is the lowest percentage of redds dewatered since annual record keeping began in 1999. Redd dewatering in 2021 only occurred at Norn's Creek Fan. The exclusion fence at Genelle in Channel E prevented an estimated two hundred additional redds from being constructed downstream of the recontouring area. The exclusion fence also prevented spawners from being stranded when load factoring from the Kootenay River in April caused significant water level fluctuations in Channel E. The current and historical discharge time series for HLK dam are available in Appendix C. There was no redd dewatering recorded on the LKR in 2021.

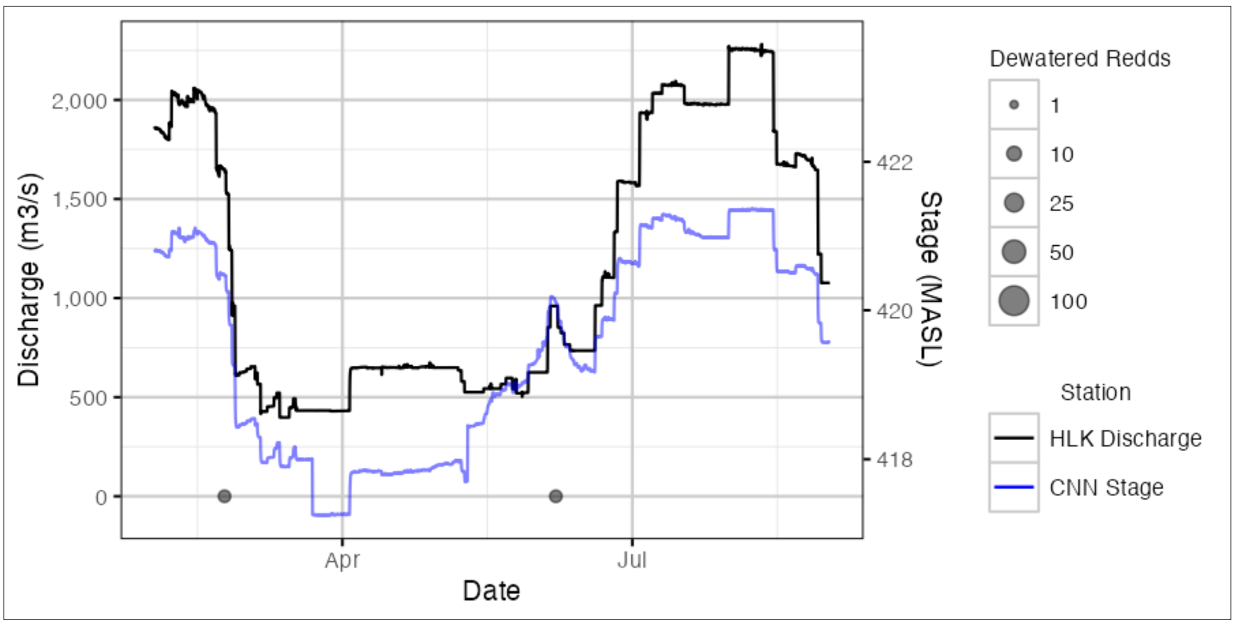

Figure 7. Discharge at HLK and stage at CNN and number of dewatered redds by date for 2021.

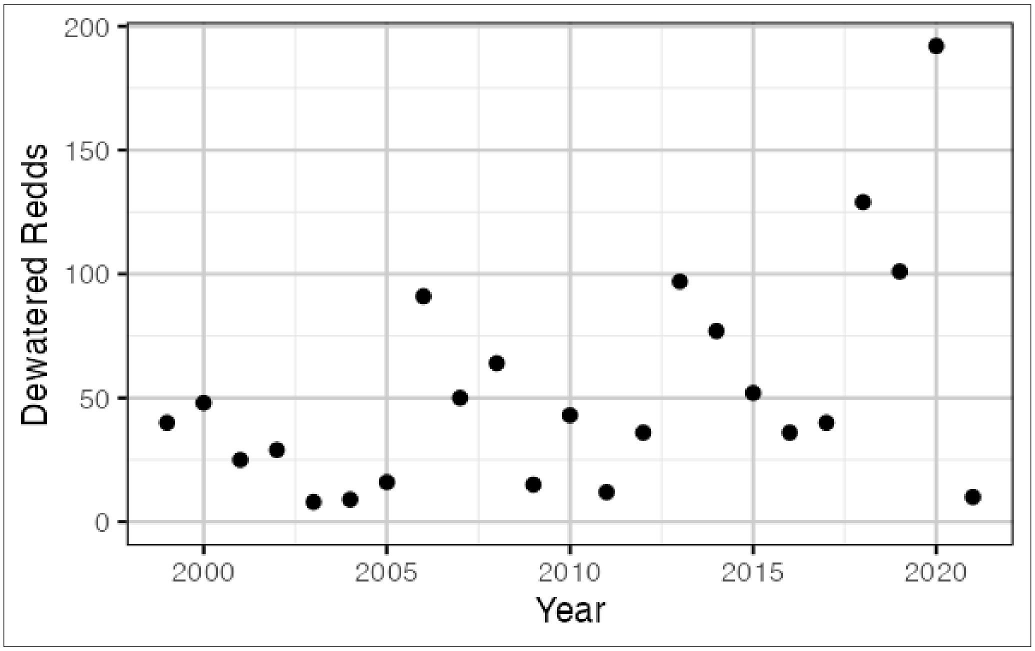

Figure 8. Actual number of enumerated dewatered redds by year.

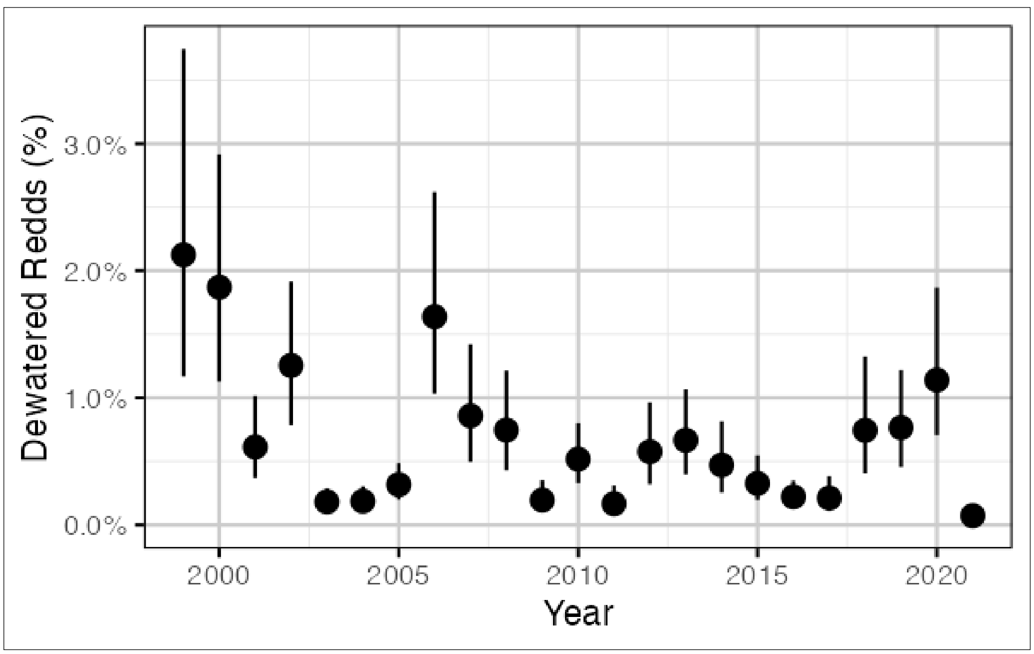

Figure 9. Estimated percentage of redds dewatered by year with 95% CIs.

3.4 Drone Based Monitoring

Redds identified from drone imagery were mapped against water depth as a supplementary method of assessing dewatering, and to provide a measure of the spatial and elevational distribution of redds within the habitat (Figure 10). Weekly drone surveys were carried out at Norn`s Creek Fan throughout the spawning period. Turbidity and surface disturbance on the LKR prevented the digitization of redds following the experimental survey at the Oxbow. Given that weather conditions were close to ideal at the time of the survey, it was determined that the Oxbow and other turbulent sites are not suitable for future drone surveys to map or enumerate redds.

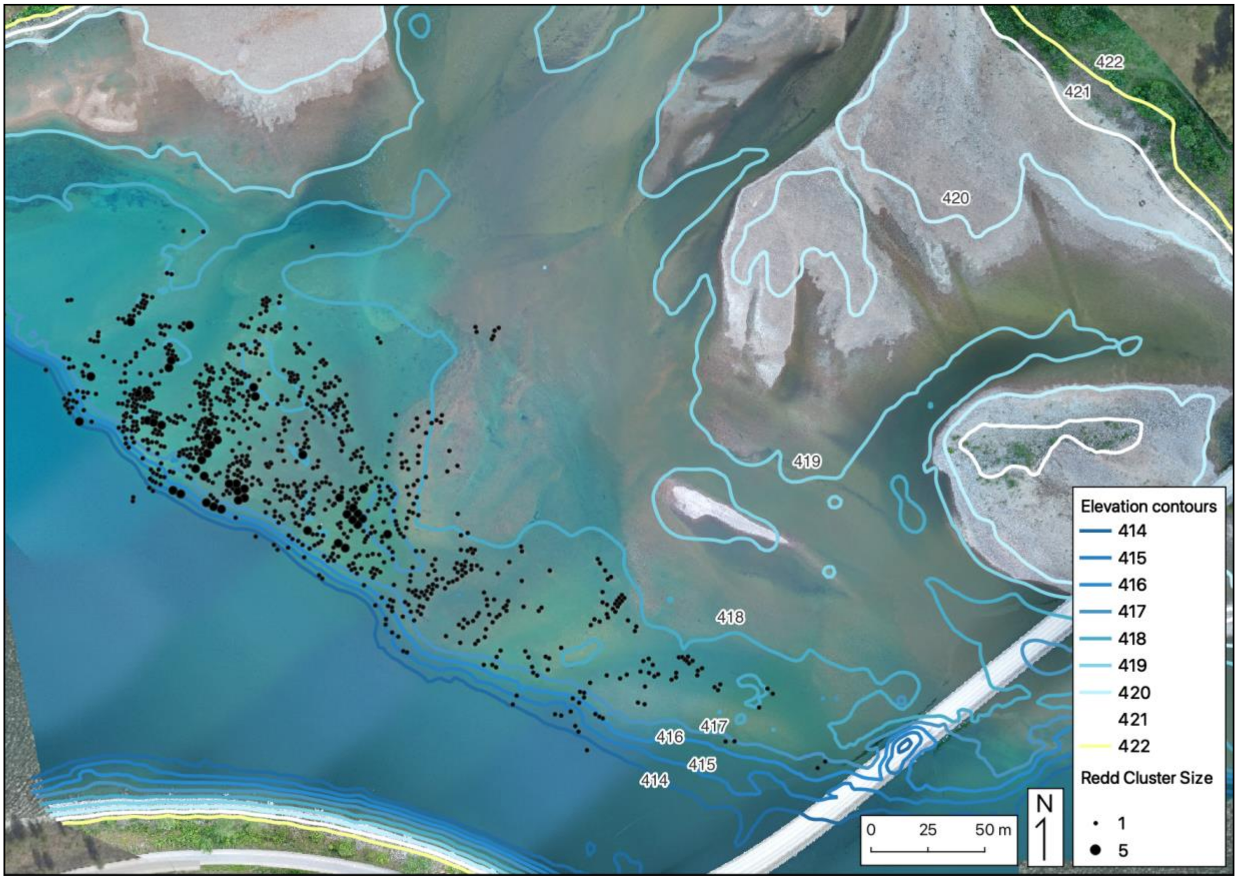

Figure 10. Cumulative redds identified over 9 drone surveys at Norn's Creek Fan, and adjacent main channel in 2021.

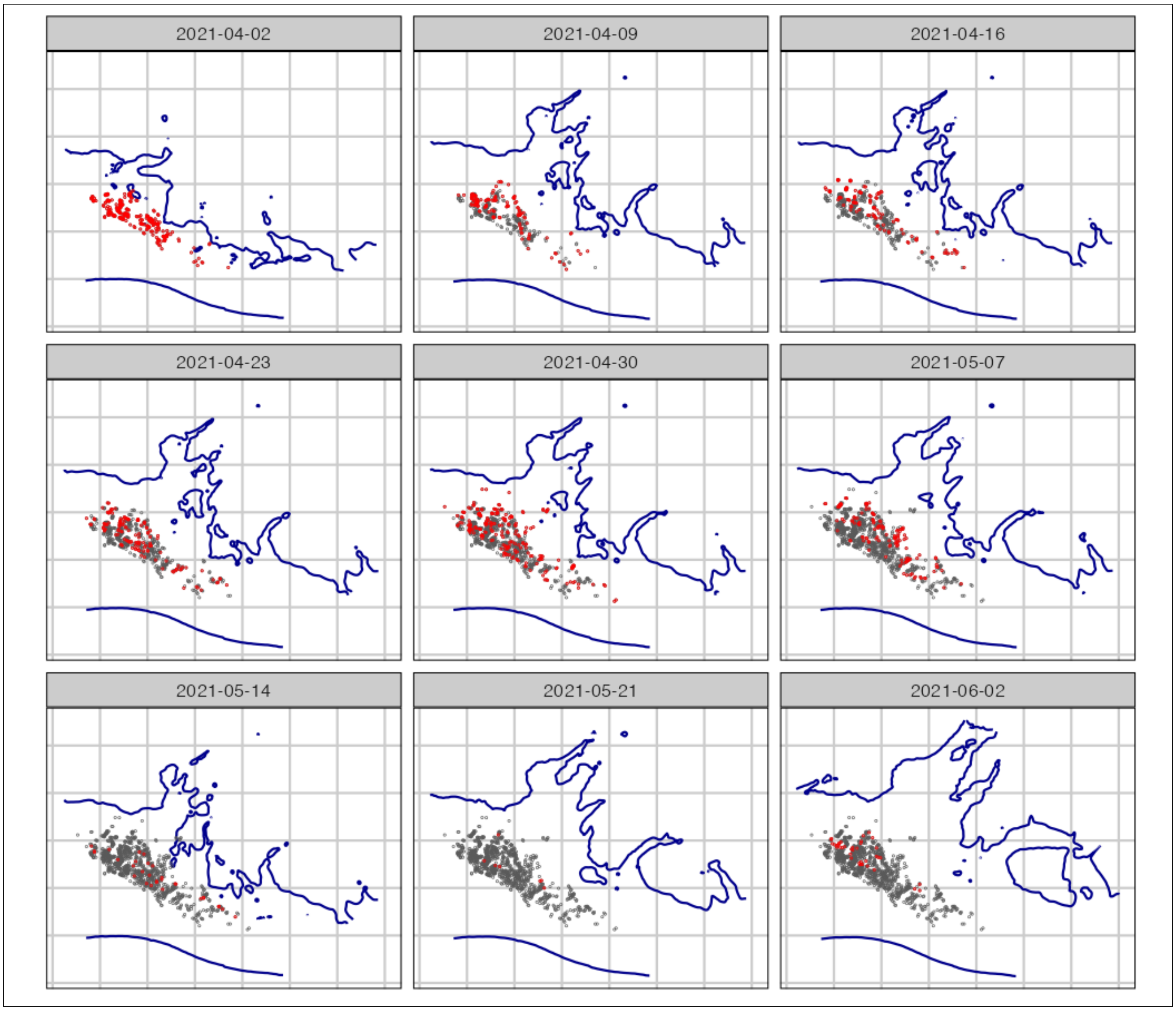

Figure 11. Accumulation of drone counted redds by date in 2021, with new redds highlighted in red. The wetted edge elevation contour is shown for each survey date.

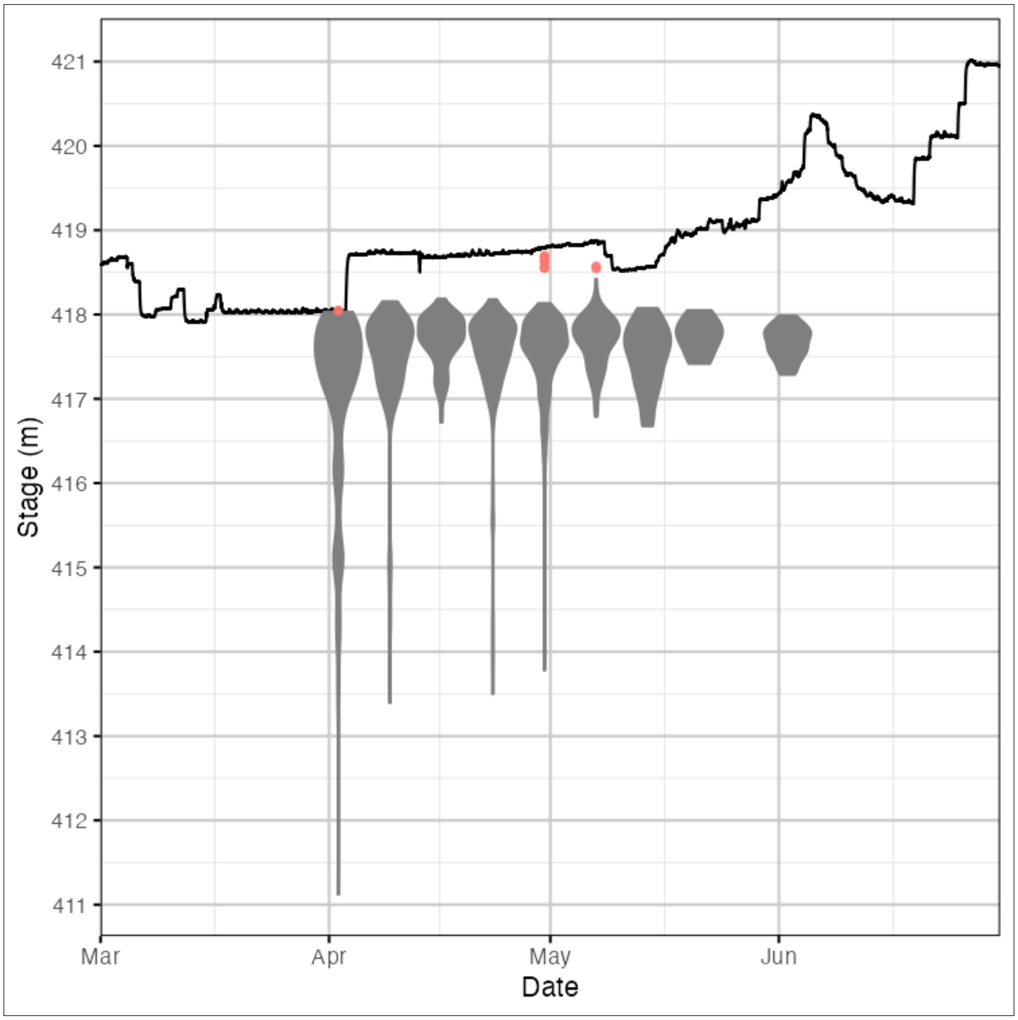

Figure 12. Elevational distribution of newly detected drone surveyed redds at Norn's Creek Fan by survey date in 2021. Redds that were estimated to be dewatered based on LCR stage are marked in red.

3.5 Egg Mortality

As RTSPF were in place in 2021 and only minimal dewatering occurred, no mortality surveys were conducted. Mortality surveys took place opportunistically in 2019 and 2020 and field crew observed low rates of mortality (< 25%) in most redds over short periods (< 9 days) of dewatering (Figure 13). A modelling approach will be implemented once there are sufficient data to determine the effect of longer periods of dewatering and more extreme environmental conditions on the mortality.

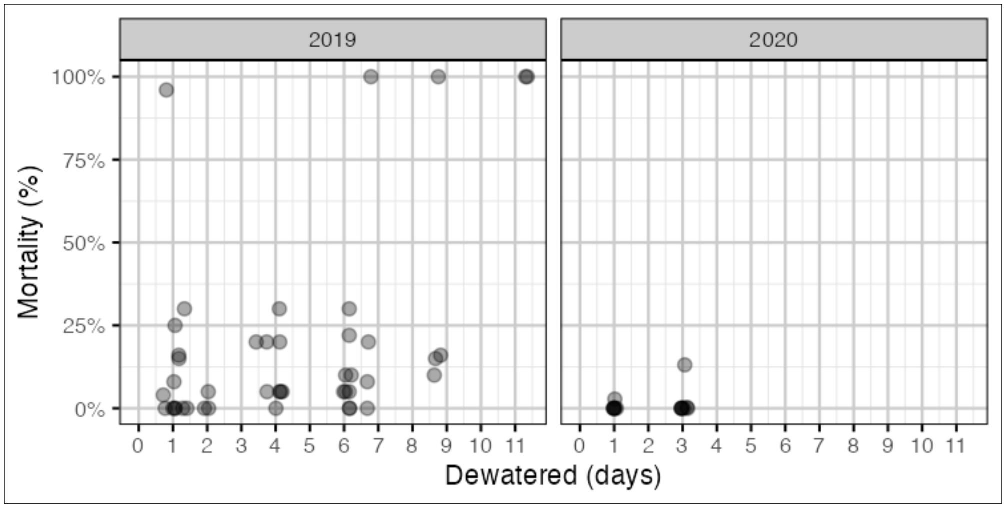

Figure 13. Observed egg mortality in natural redds by days dewatered in 2019 & 2020.

3.6 Spawn Timing

Spawn timing has been generally stable through the period of monitoring with minor fluctuations among years (Figure 14). The 2021 spawn timing window was slightly earlier and more compressed than an average year, and had an estimated duration of 100 or 110 days depending on the river segment. Spawning was estimated to 'start' (2.5% of spawning) on the 3rd or 8th of March depending on river segment, peak on April 27th (95% CIs ranged from the 23rd of April to the 2nd of May), and 'end' (97.5% of spawning) on the 16th or 21st of June depending on the river segment (Figure 14).

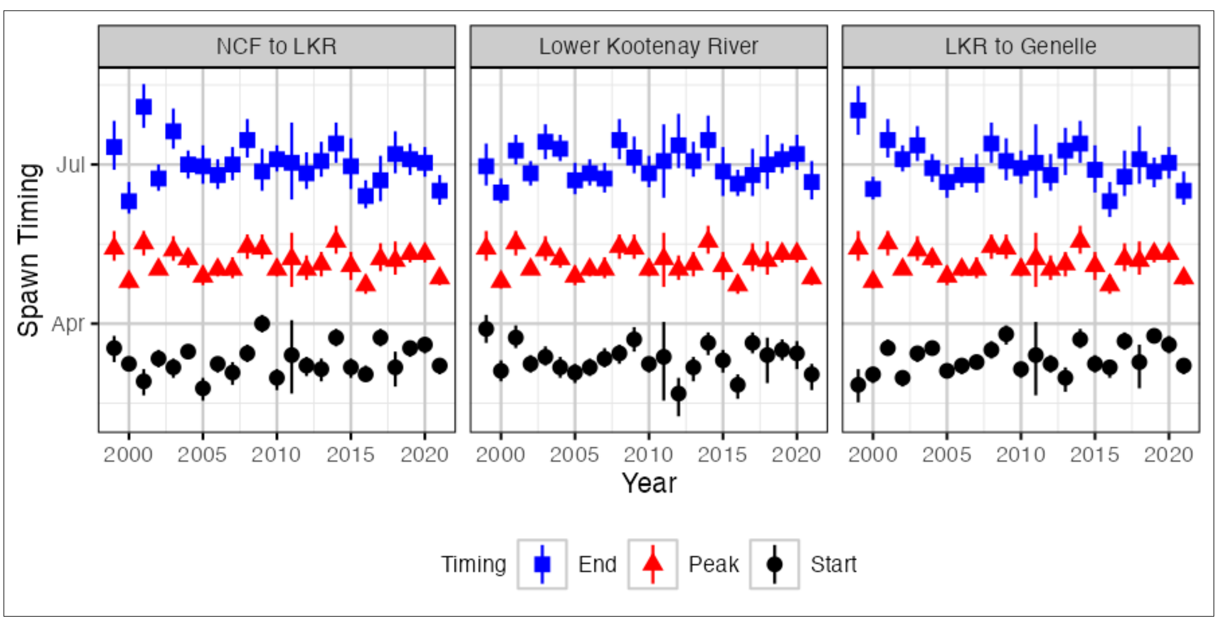

Figure 14. Estimated start (2.5% of spawners arrived), peak and end (2.5% of spawners remaining) spawn timing by year and segment with 95% Cis

3.7 Stock Recruitment

The Beverton-Holt stock recruitment models fitted to age-1 Rainbow Trout abundance suggest density-dependent survival (Figure 15 and Figure 16). The models assume that the age-1 abundance estimates are representative of the juvenile densities. There were no data pertaining to the slope of the lines through the origin at low densities, so the slope of the initial portion of the curve was informed based on professional judgement about the biology of the species.

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 (Golder et al. 2019) was highest for the 2000, 2001, 2006 and 2010 spawn years. The number of recruits tended to decrease with higher stock abundance.

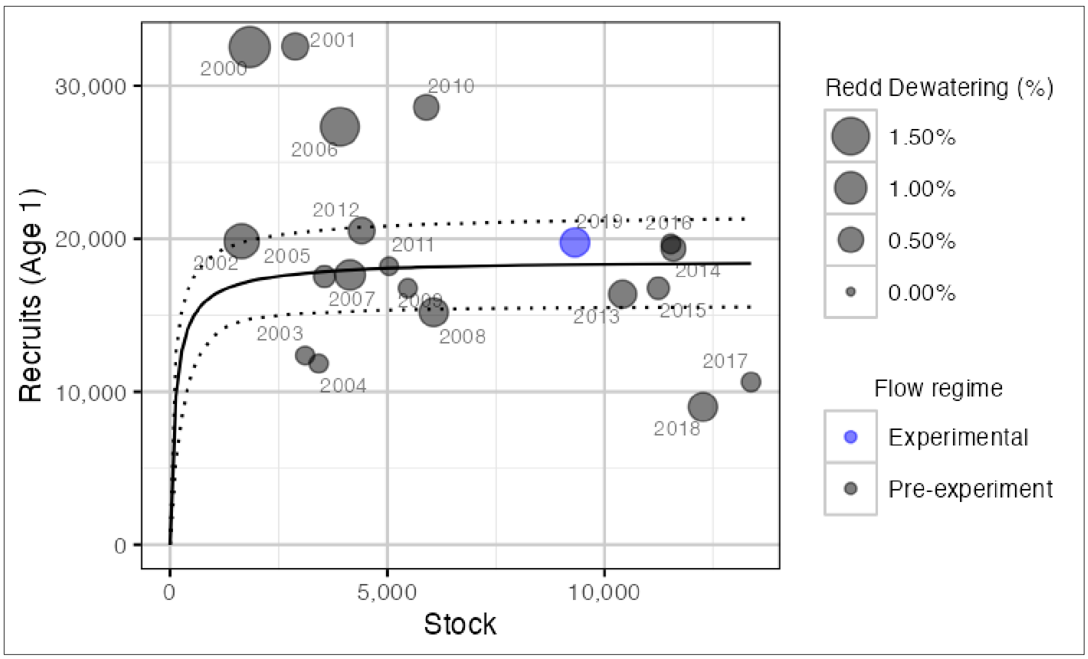

Figure 15. Predicted stock-recruitment relationship from spawners to subsequent age-1 recruits by spawn year with 95% CIs.

The number of age-1 recruits was positively correlated with number of dewatered redds (Figure 15) which taken at face value suggests that higher redd dewatering is associated with increased recruitment success. The correlation may just represent the fact that both redd dewatering and the number of recruits have declined overtime.

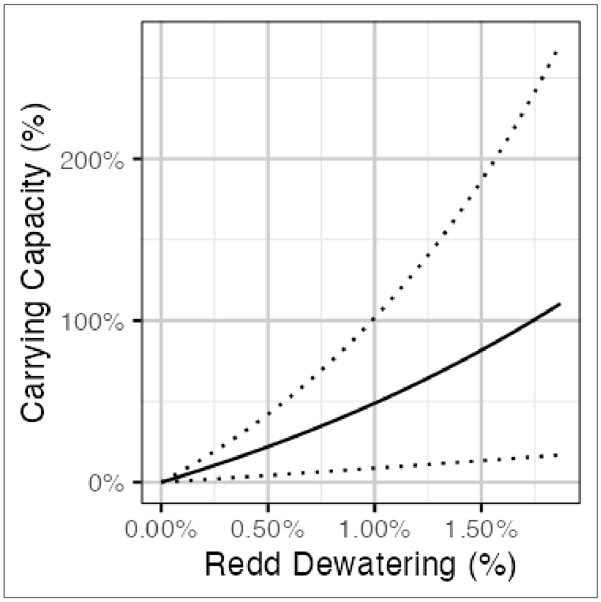

Figure 16. Predicted change in the age-1 recruits carrying capacity vs. percentage egg dewatering with 95% CRIs.

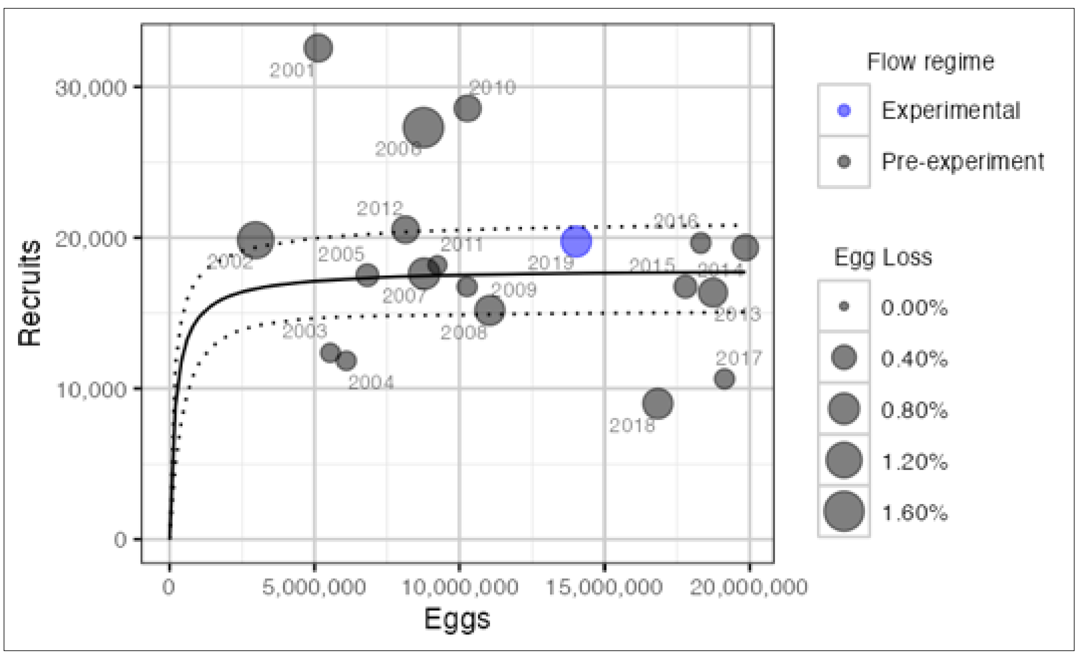

Figure 17. Predicted eggs to age-1 recruits stock-recruitment relationship by spawn year (with 95% CRIs)

The stock recruitment curve for eggs shows a similar relationship, with the additional benefit that it accounts for spawner fecundity (Figure 17). A similar positive correlation between dewatering and change in the carrying capacity is also observable (Figure 18).

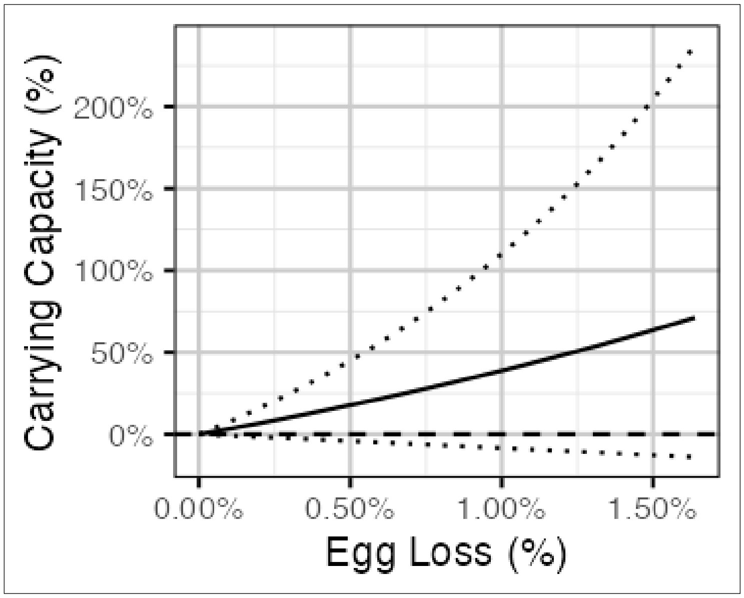

Figure 18. Predicted effect of egg loss on the age-1 carrying capacity (with 95% CRIs)

4.0 DISCUSSION

Salmonids like most fish have a high fecundity which at least partially compensates for the high mortality at the egg and larval stages. Mortality effects on eggs include siltation, predation, overheating, freezing 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 the 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 *in situ* 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 eggs have hatched, alevins absorb oxygen through their gills and require immersion in water. As a result, they are much more sensitive to dewatering.

Table 3 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)
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 mortality conditions for Atlantic salmon eggs occur when air temperatures are below 0°C and redds are dewatered for three or more hours, and that mortality 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 Associates Ltd. 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 may 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 and specific heat capacity of the gravels together with the burial depth.

On September 17th, 2021, the LCR Rainbow Trout Technical Committee met to review the RTSPF protocols and experimental design for egg mortality. Three hypothetical flow regimes were proposed, each designed to dewater a significant number of redds, creating the conditions necessary for in-depth study of egg mortality. Representatives from BC Hydro indicated that limitations in water supply and obligations to the Columbia River Treaty would not allow for the implementation of any of the proposed flow regimes (Casselman and Thorley 2021). Future mortality surveys will take place opportunistically but may therefore be limited in their capacity to capture data that represents a true picture of mortality in dewatered redds. If possible, mortality surveys will be targeted to higher elevation areas of the habitat that are more likely to have gravels exposed for longer periods when dewatering does occur. Climate conditions such as air temperature and humidity will continue to be monitored so that additional mortality surveys are initiated when short term dewatering is paired with extreme conditions and mortality is anticipated to occur more quickly.

Results from redd excavations completed for the period of 2019-2020, albeit minor in overall sampling, did not show 100% mortality immediately after dewatering as had previously been assumed. Egg mortality in 2019 was less than 25% in 79% of the samples while egg mortality in 2020 (n = 10) was 0% in 80% of the samples and averaged 7.8% in 20% of the samples. Additional redd excavations are required to determine the effect of longer periods of dewatering and environmental conditions on egg mortality. Additional field data will be paired with a modelling approach assessing the impact of water temperature, time since dewatering and other measured variables that effect egg mortality. To effectively test what combination of environmental conditions constitutes an incipient threshold temperature for egg mortality, redds need to remain unwetted coupled with extreme ambient and water temperatures until high levels of mortality occur. To date, extreme temperatures coupled with prolonged dewatering events have not been present in the LCR to test or quantify thresholds found within background literature.

For the purposes of estimating when eggs would be impacted by environmental conditions, upper threshold limits of 25°C and lower limits of 0°C were compared to the temperatures recorded by the loggers in the gravels at each of the permanent location at Norn's Creek Fan and Oxbow on the LKR. In 2019 of the 13 stations retained throughout the monitoring season on Norn's Creek Fan, 10 exceeded the 25°C threshold (Appendix C). For the six stations on the Kootenay Oxbow, three exceeded the 25°C limit (Appendix C).

5.0 RECOMMENDATIONS

- Conduct opportunistic redd excavations to collect additional information on the dewatering mortality of eggs and alevins in the LCR. Target surveys to capture freezing or hot conditions when mortality is likely to occur sooner.

- Do not install the Genelle channel E exclusion fence in 2022 to allow spawning at the site and conduct redd excavations at channel E to assess the effects of intermittent dewatering caused by load shaping in the LKR. This recommendation also requires the installation of an environmental monitoring station at Genelle to record water elevation and temperature, as well as the implementation of spawner salvage operations to prevent fish stranding in channel E.

- If conditions allow, deploy the fry emergence trap over shallow redds at Genelle early in the spawning period and use real-time water temperature data to assess emergence timing based on ATUs.

- Continue with aerial drone flights over Norn's Creek fan during RB spawning window to supplement helicopter redd counts.

6.0 CLOSING

On behalf of Nupqu Limited Partnership and the study team we would like to thank BC Hydro for this opportunity. If there are any questions related to the information provided in this report, please feel free to contact the undersigned.

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APPENDIX A

MAPS OF PEAK FISH AND REDD COUNTS 2021

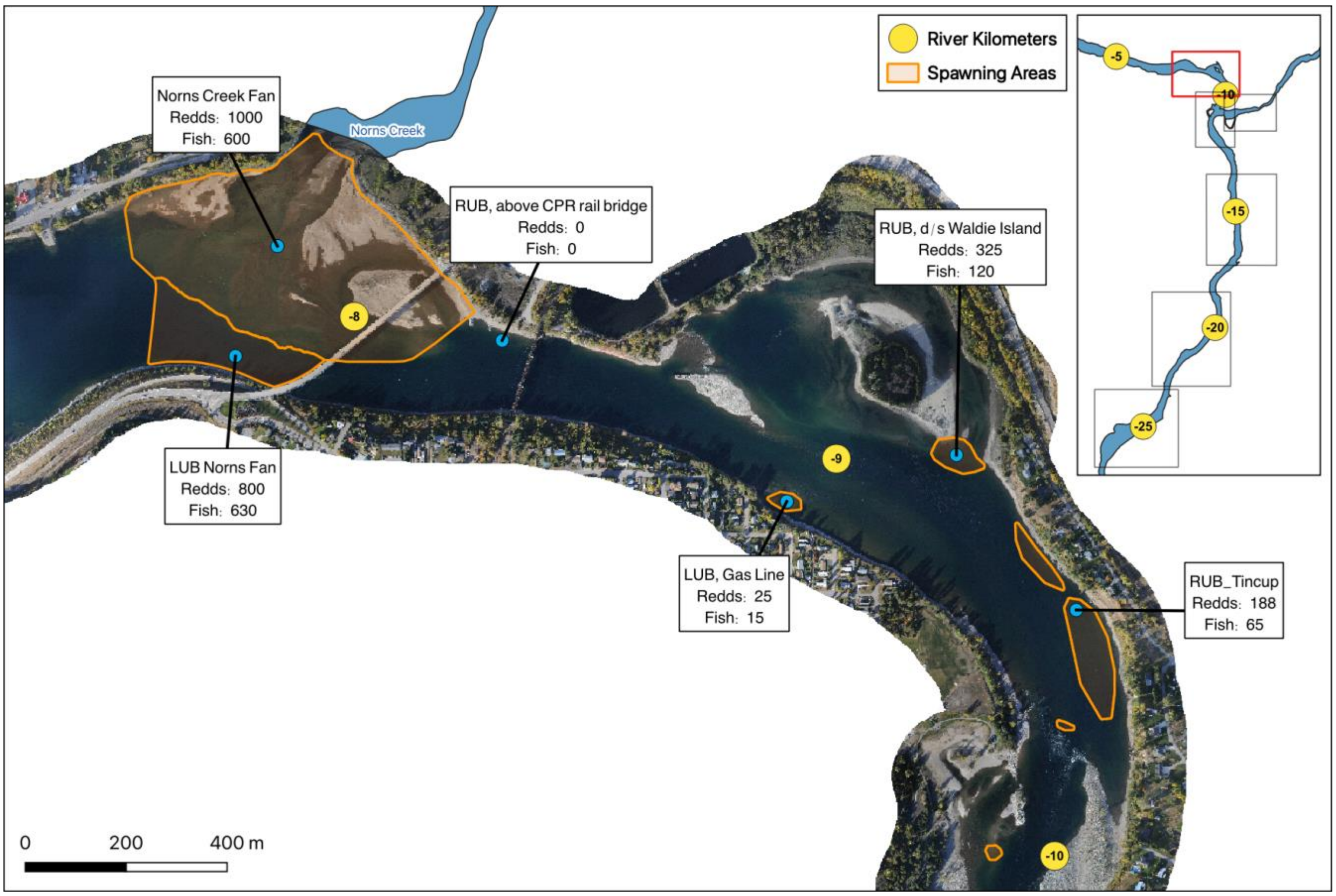

Figure A1. Fish and redd peak counts in the Norn's Creek Fan and Robson Bridge area.

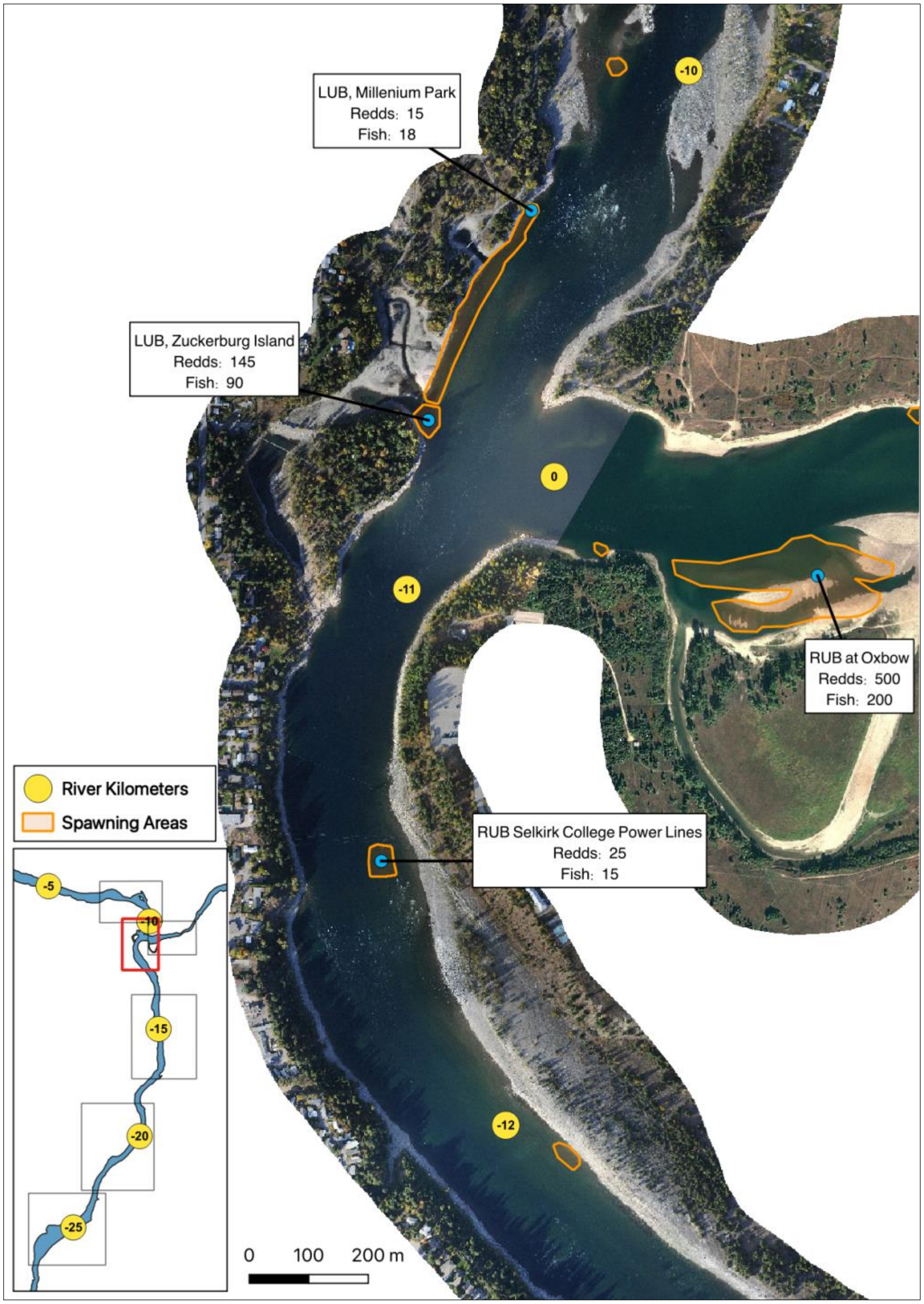

Figure A2. Fish and redd peak counts in the Zuckerberg and Millennium Park area.

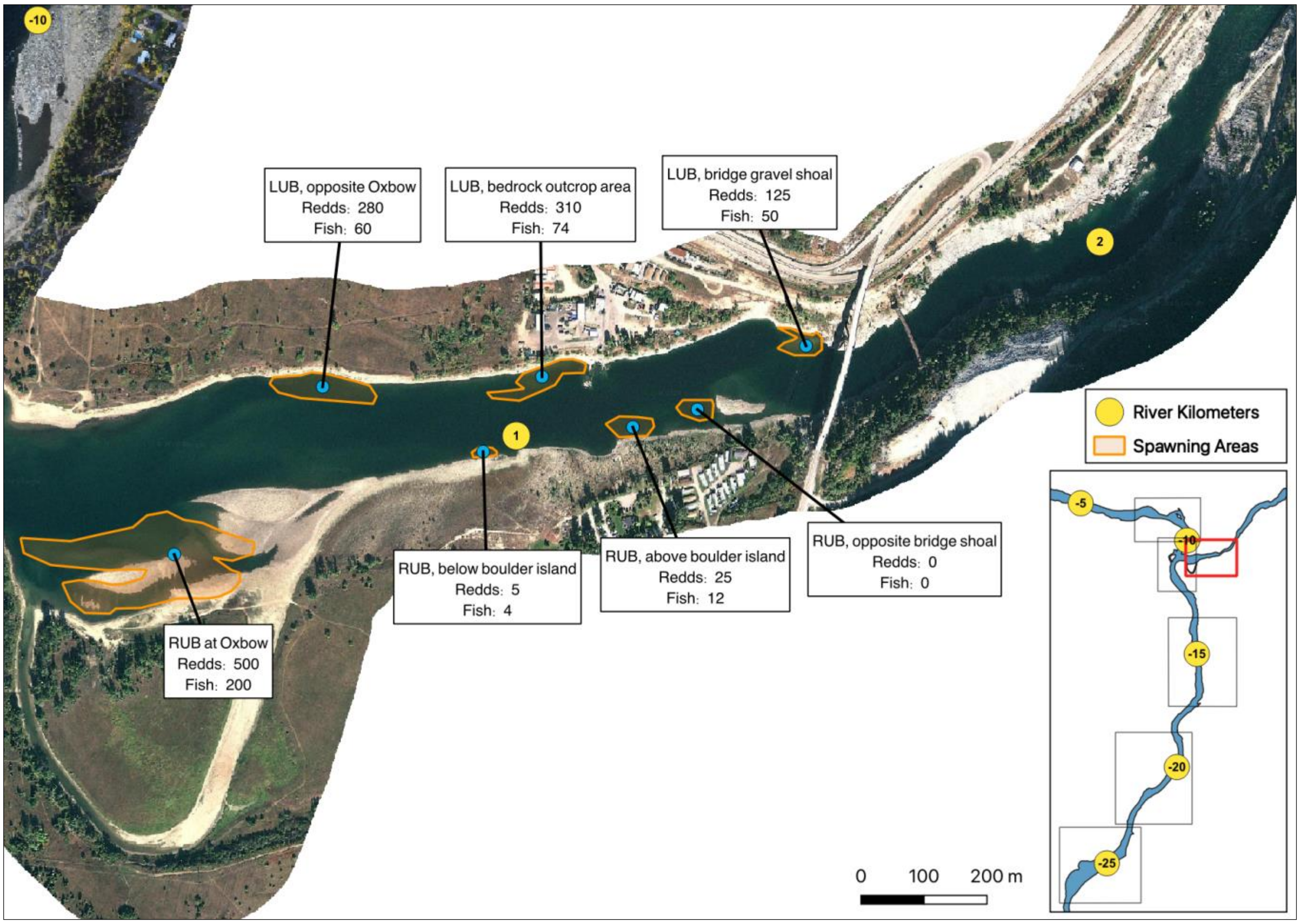

Figure A3. Fish and redd peak counts in the Lower Kootenay River area.

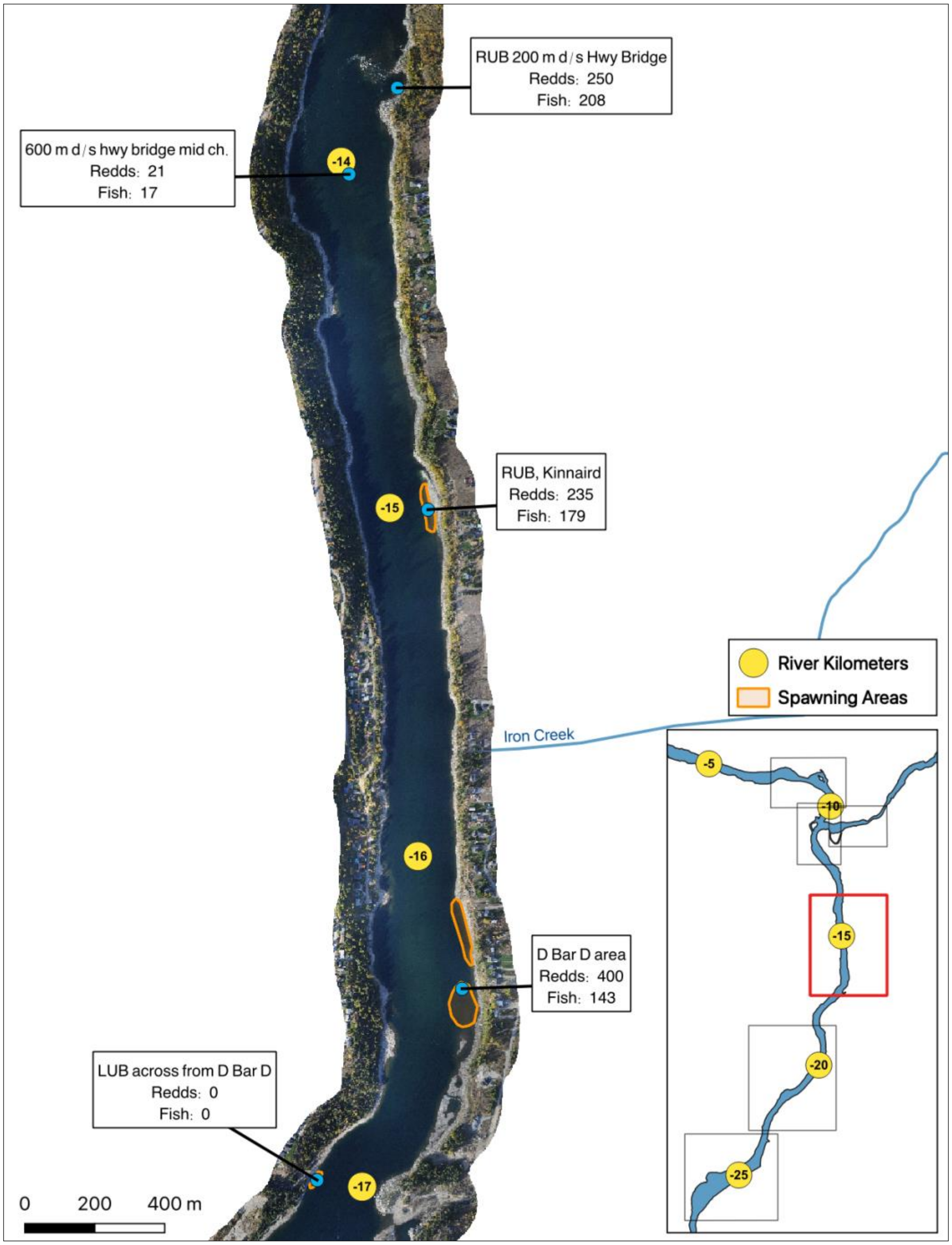

Figure A4. Fish and redd peak counts in the Kinnaird area.

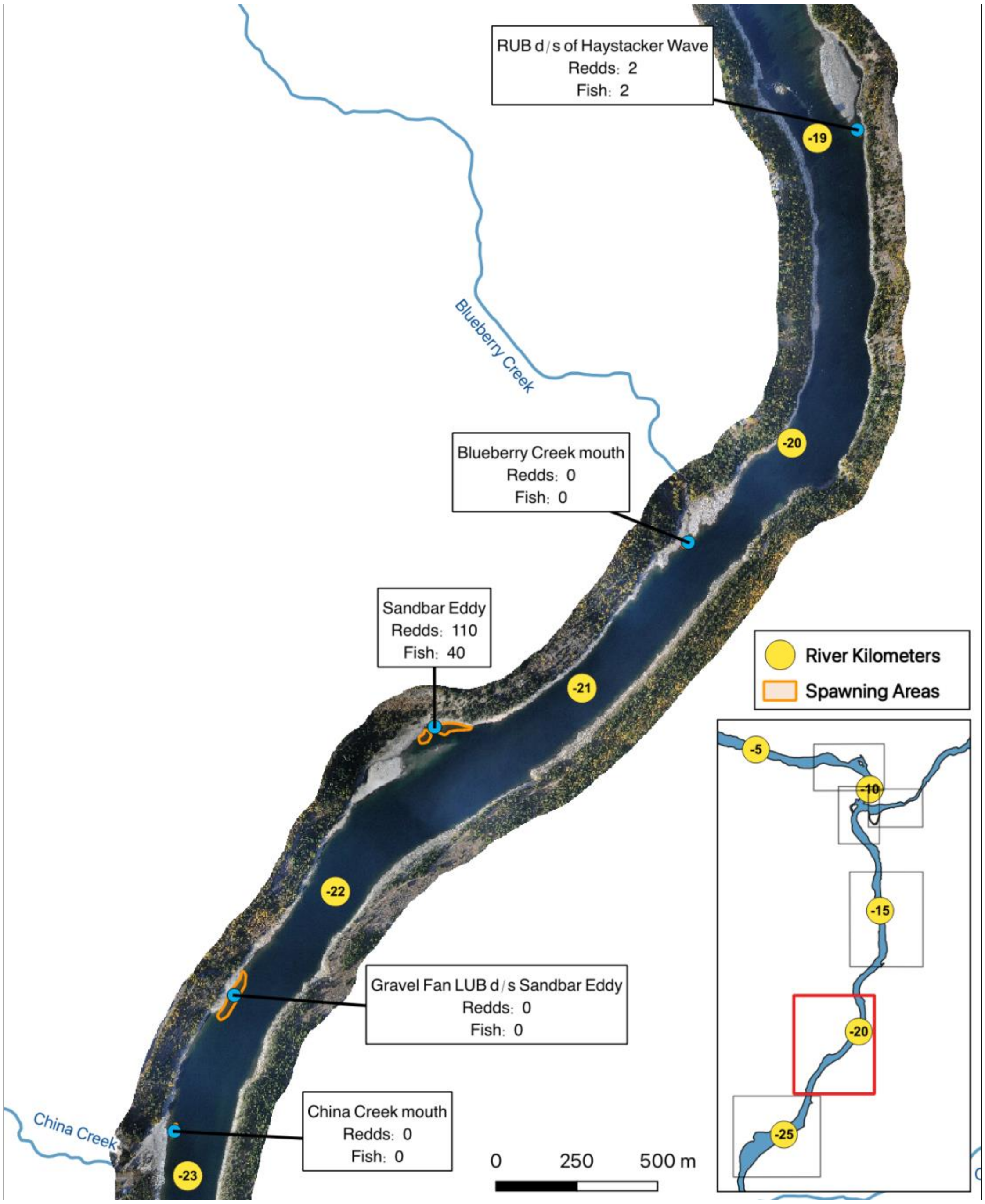

Figure A5. Fish and redd peak counts in the Blueberry and China Creek area.

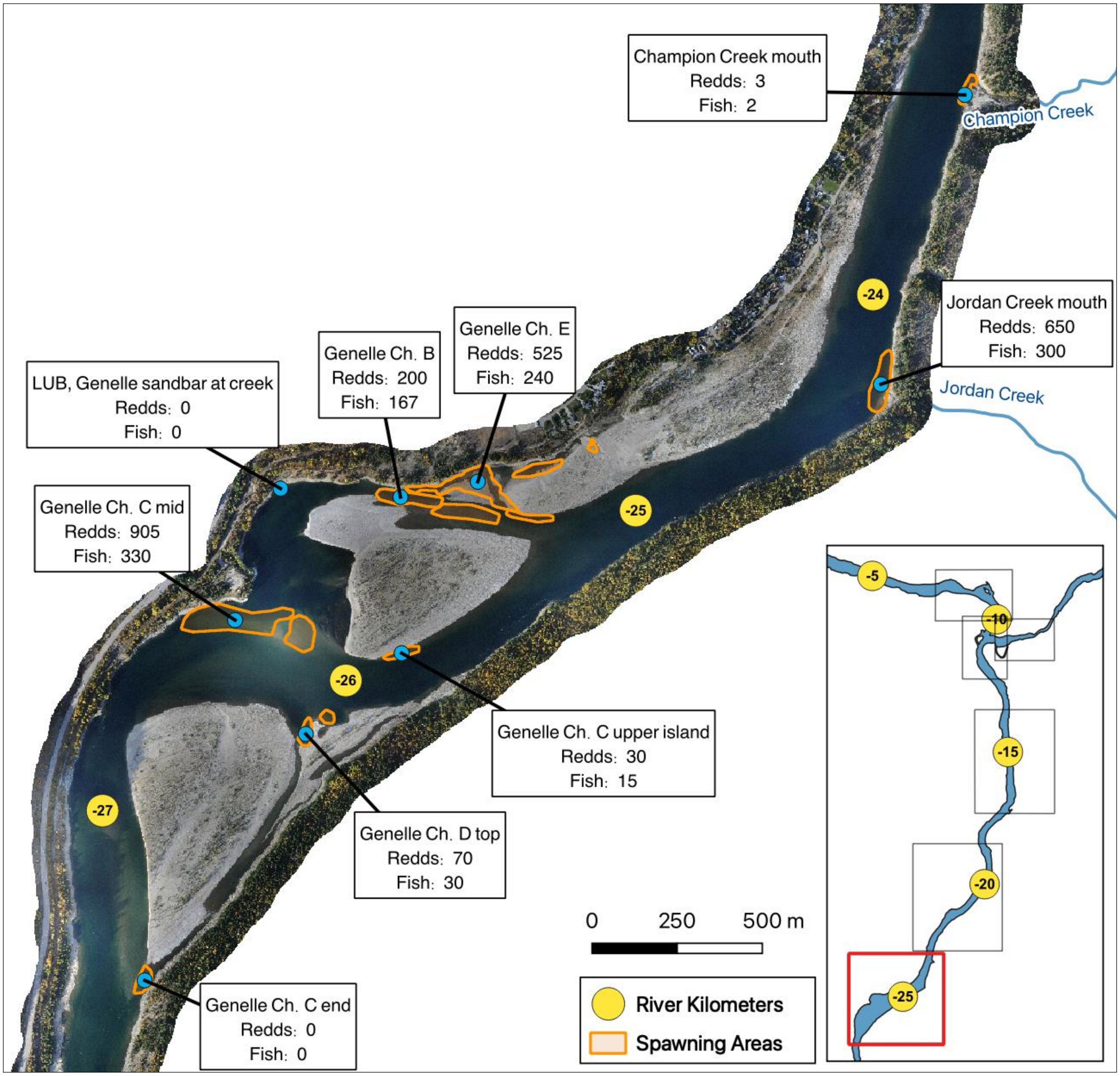

Figure A6. Fish and redd peak counts in the Genelle area.

APPENDIX B

AREA-UNDER-THE-CURVE PLOTS

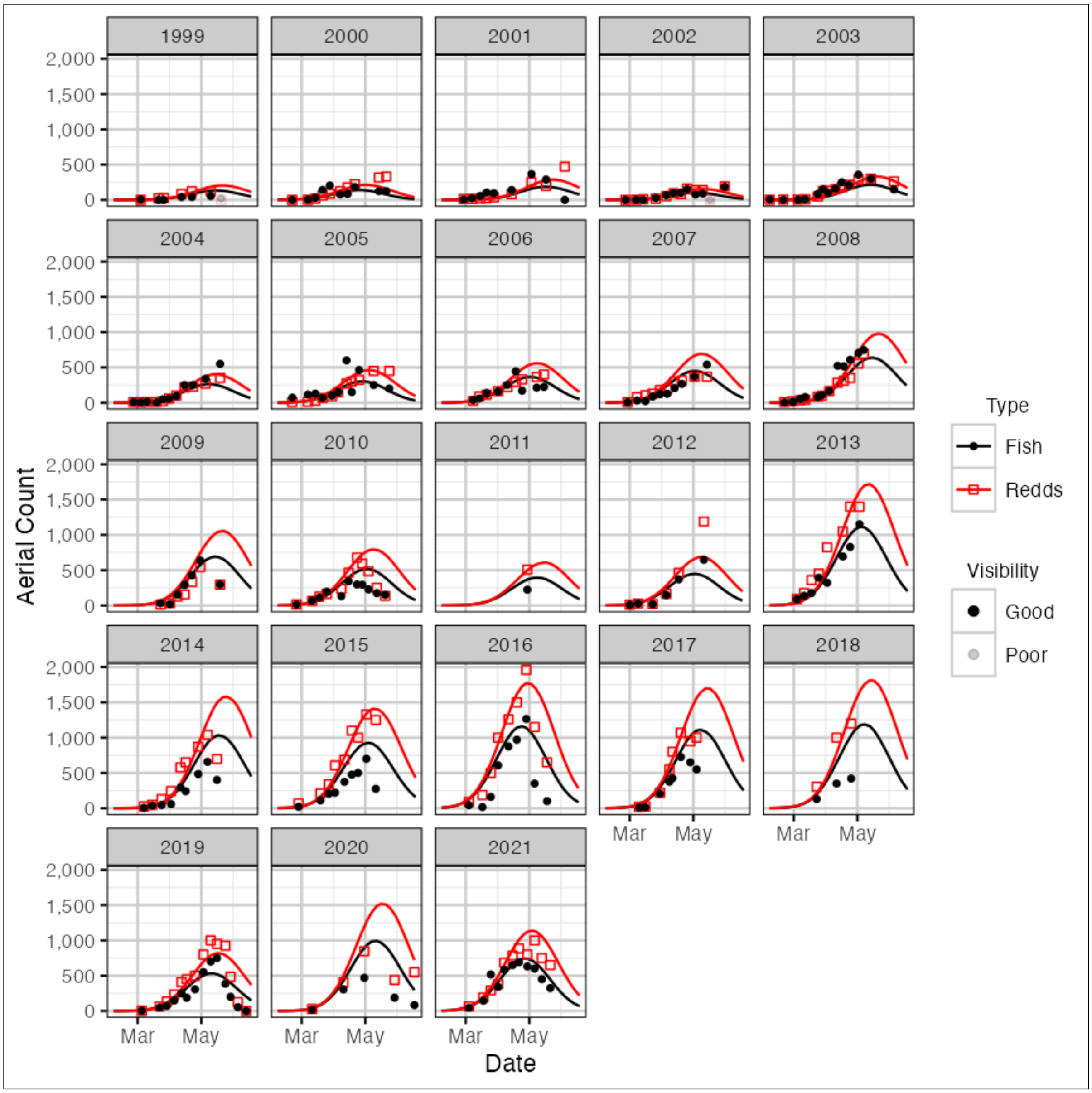

Figure B1. Predicted and actual aerial fish and redd counts at Norn's Creek Fan by date and year.

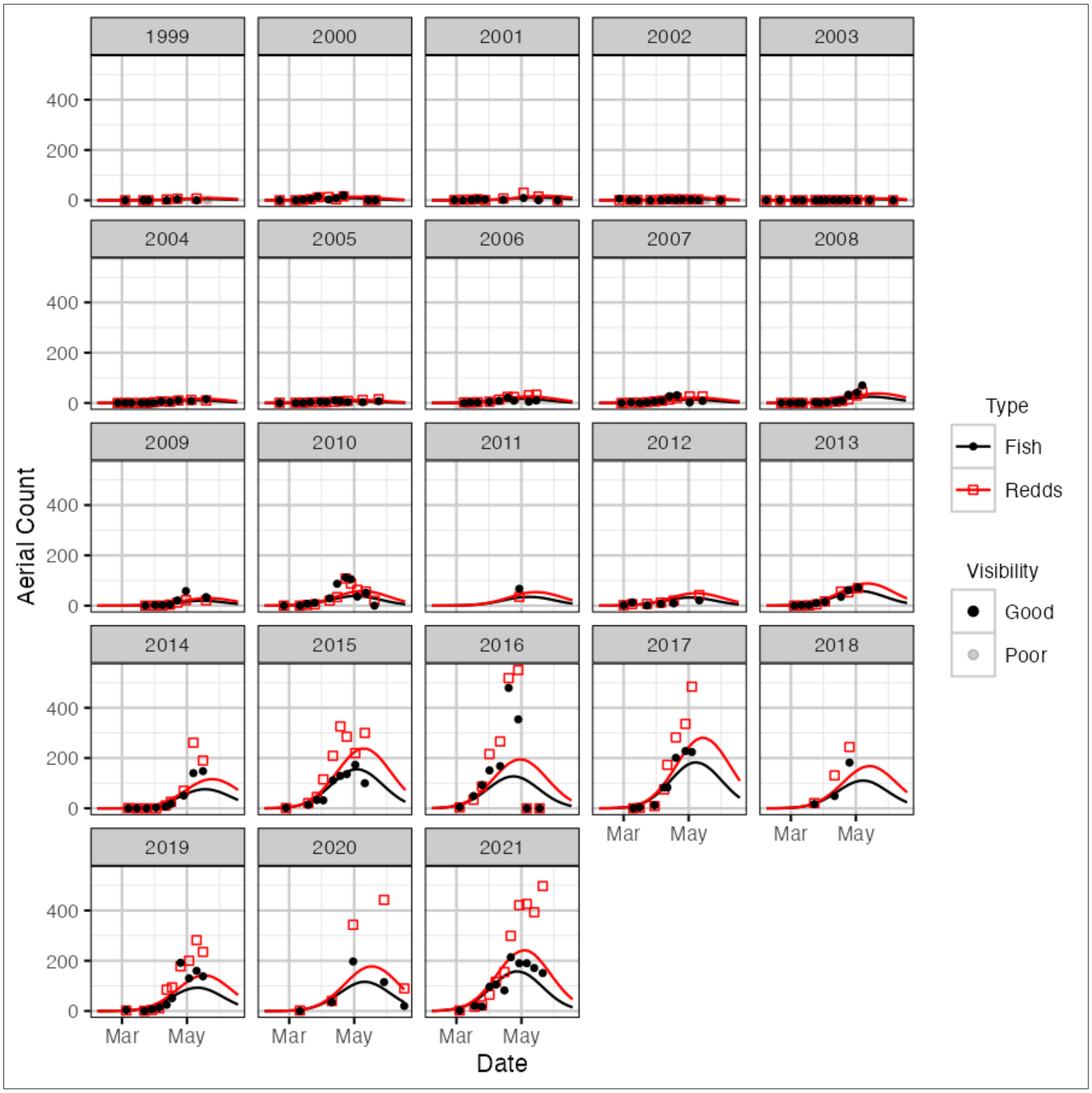

Figure B2. Predicted and actual aerial fish and redd counts in the section from Norn's Creek Fan to the Lower Kootenay River by date and year.

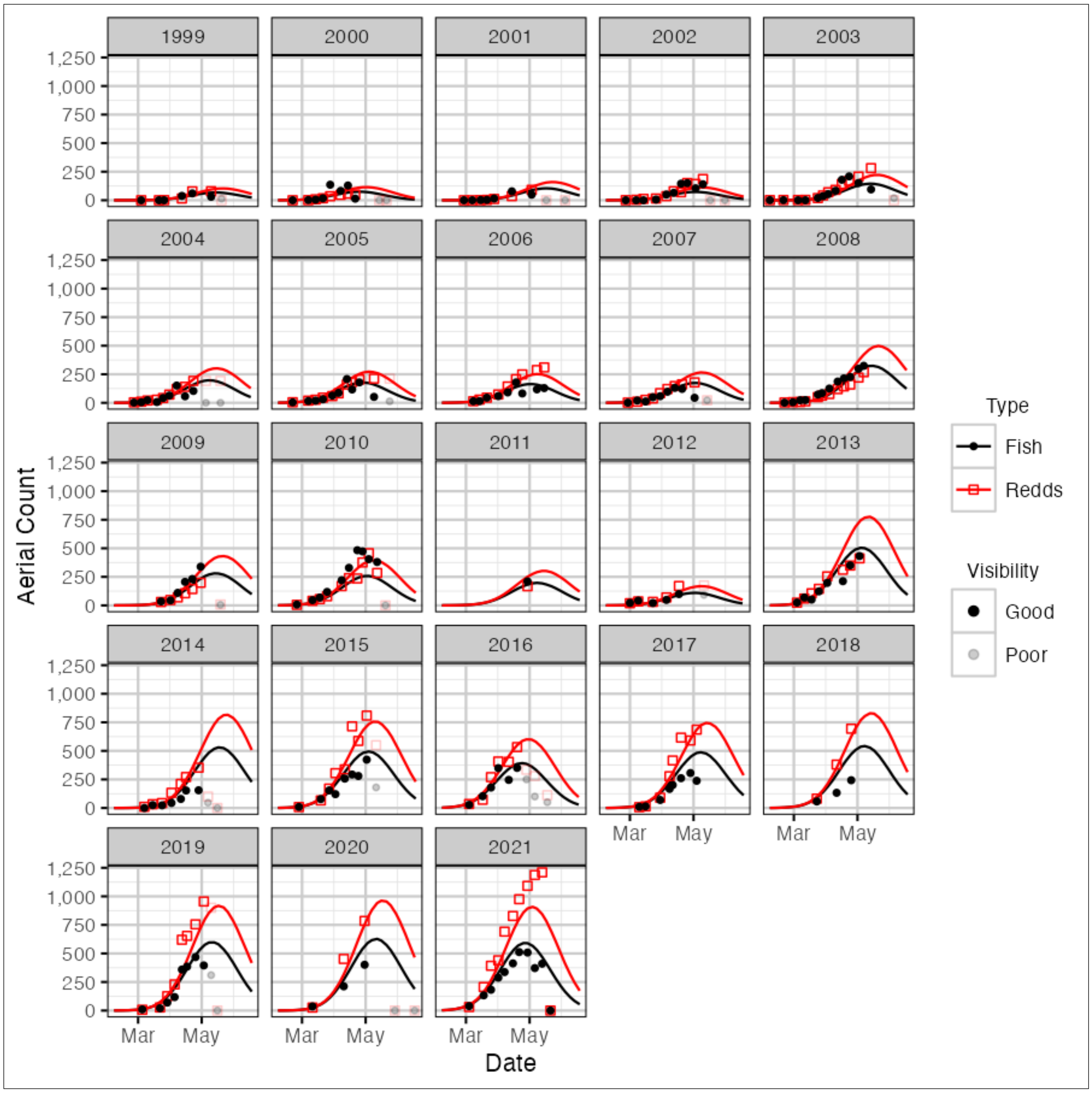

Figure B3. Predicted and actual aerial fish and redd counts at Lower Kootenay River by date and year.

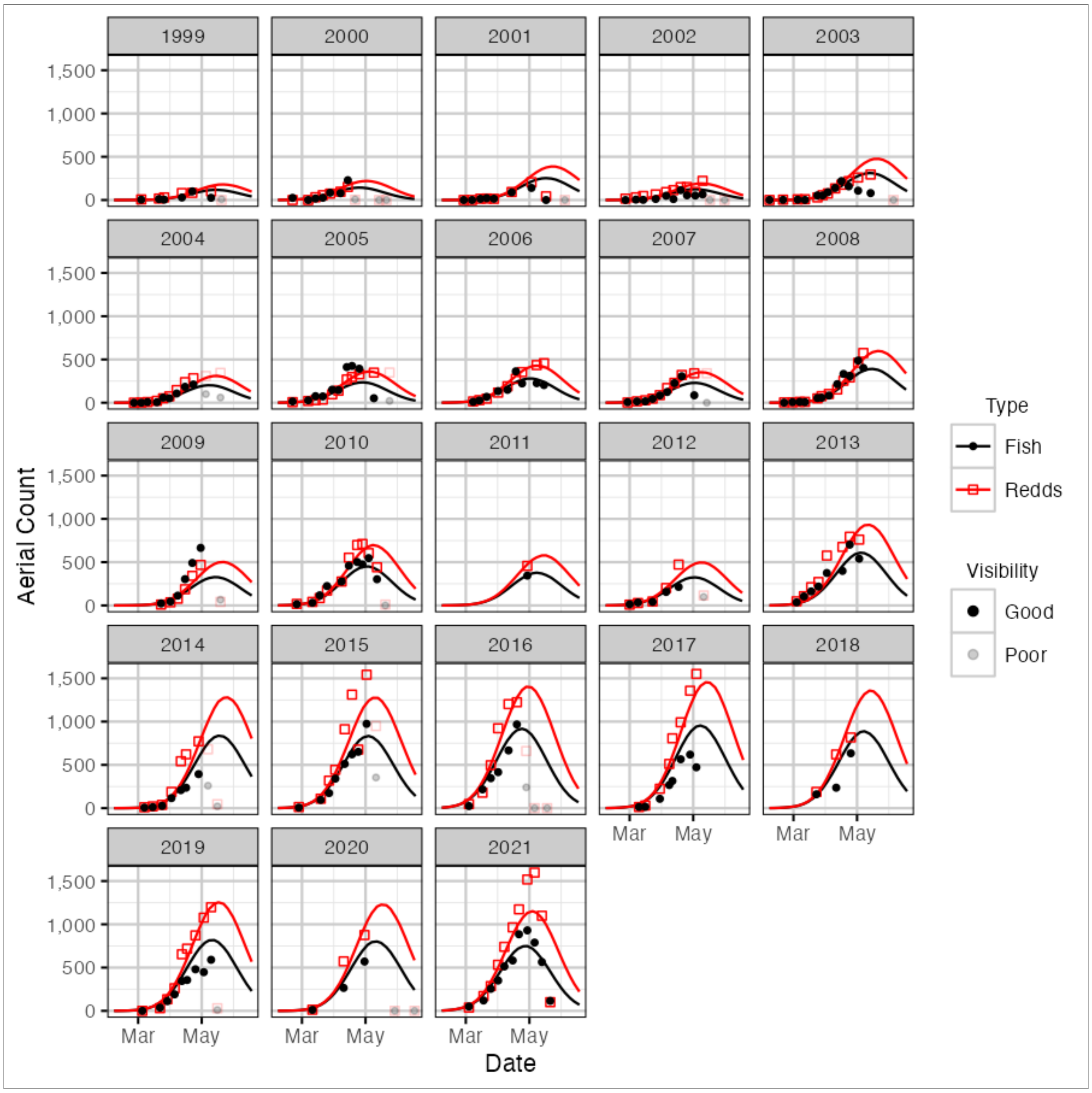

Figure B4. Predicted and actual aerial fish and redd counts in the section from Lower Kootenay River to Genelle by date and year.

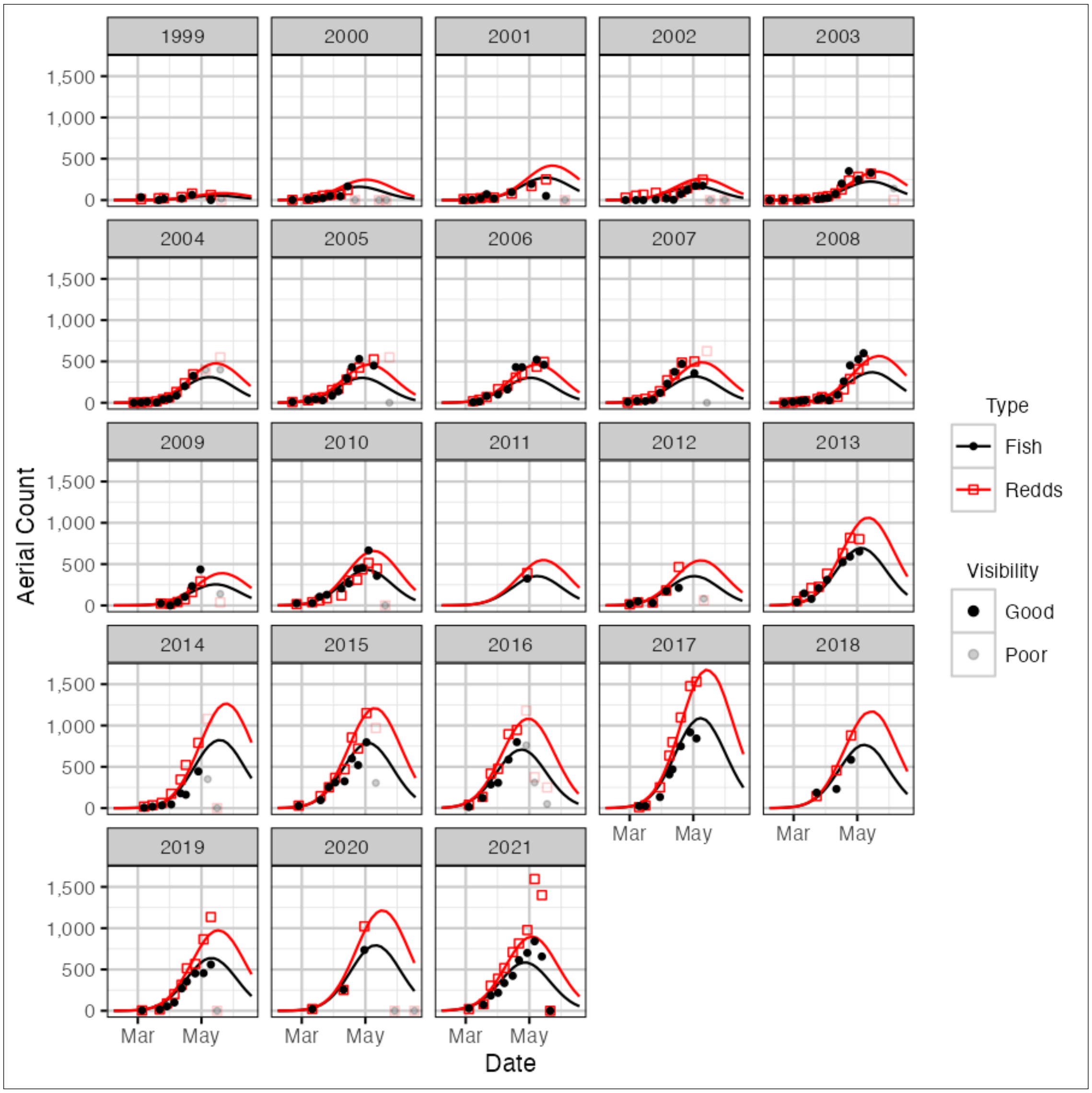

Figure B5. Predicted and actual aerial fish and redd counts at Genelle by date and year.

APPENDIX C
HISTORICAL DISCHARGE PLOT

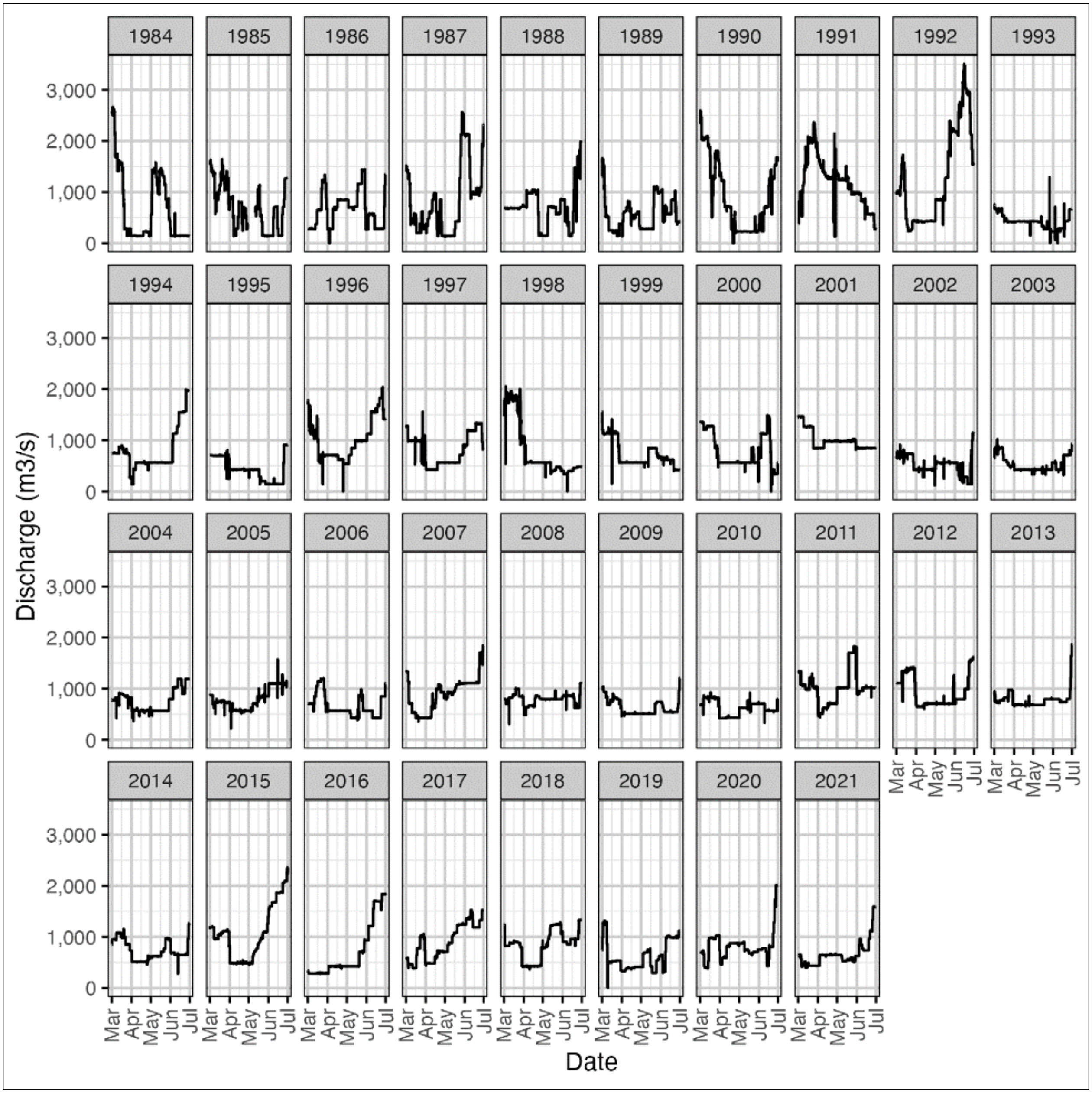

Figure C1. Hourly discharge at HLK Dam by date and year.

APPENDIX D

EGG AND ALEVIN MORTALITY SURVEYS AND STAGING GUIDE

Egg and Alevin mortality surveys took place opportunistically in 2019 and 2020 when significant dewatering events occurred. Individual dewatered redds were marked using a uniquely numbered tag. Mortality percentages were monitored through consecutive redd excavations to better understand the relationship between duration of dewatering and mortality. Due to the limited opportunities to excavate dewatered redds the study team developed a redd capping device to monitor fry emergence from previously dewatered redds in June 2020. The device was constructed from fine mesh and angular steel tubing materials with dimensions of 4' x 2' and included a fry emergence trap. The redd capping device was designed to facilitate the collection of all fry emerging from a single redd or tightly grouped redd cluster in shallow water. This device prototype is ready to be trialed during future opportunistic mortality surveys.

During the limited redd excavations in 2019 and 2020 the embryos were inspected using a 10x hand lens and staged using a photographic guide (see Appendix D). The excavation depth and number of alive vs dead embryos were also recorded using field data sheets. All excavated embryos were subsequently reburied within their original redd. In 2020, previously undisturbed redds were excavated on each site visit to avoid handling effects inflating embryo mortality. Elevation above water surface for each inspected redd was measured using a level rod and a laser clinometer.

Sampling of Rainbow Trout eggs and associated redd excavations occurred in accordance with the Department of Fisheries and Oceans Canada Species at Risk Permit #18-PPAC-00009 and Scientific Fish Collection Permit #CB21-649219, issued by the Ministry of Forest, Lands and Natural Resource Operations, Kootenay – Boundary Region.

Rainbow Trout Egg and Alevin Development Field Guide

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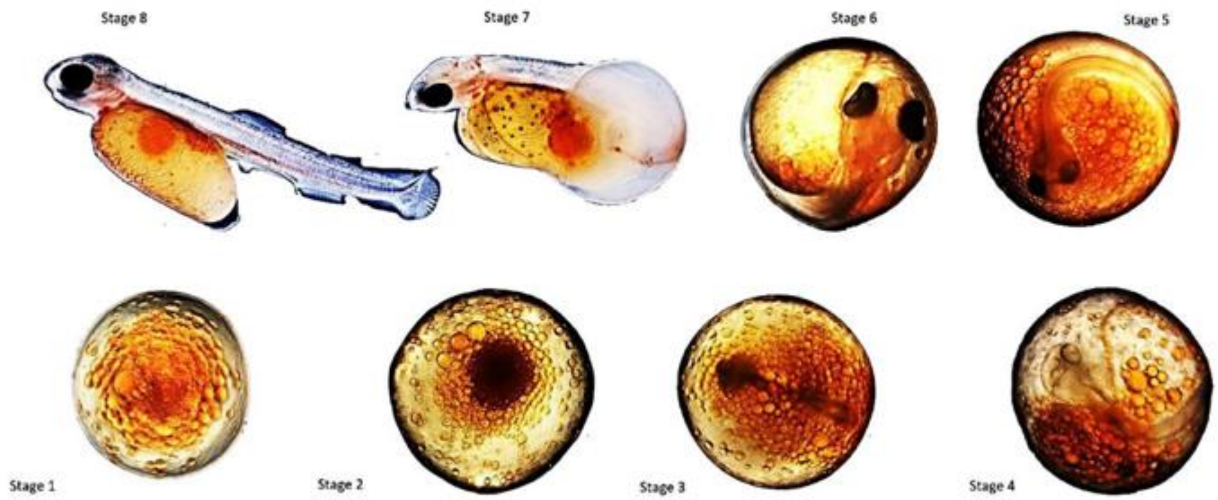
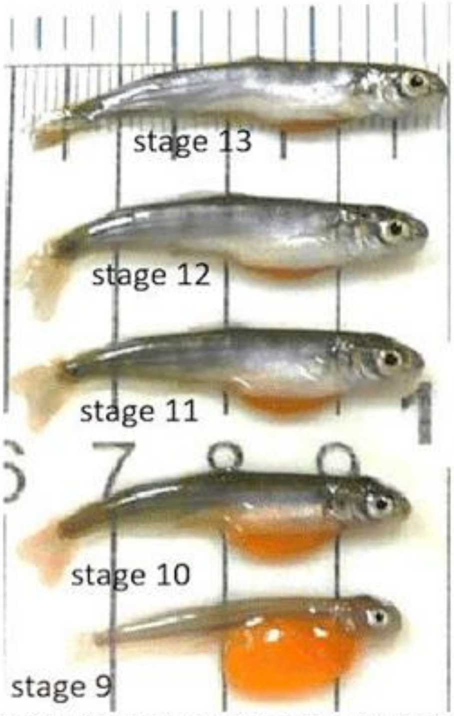


Stage	Description & development time based on 10°C (Days since fertilization)
1	Fertilization-Early Blastula (hours)
2	Blastula-Gastrula (12 hours to 6 days)
3	Embryo with ocular development (7 days)
4	Embryo with faint pigmentation of eyes (12 days)
5	Eyed - Full pigmentation of eyes (20 days)
6	Ready 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 Eggs

Healthy Eggs (one or two dead)

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