Columbia River Project Water Use Plan

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

Reference: CLBMON-46 Implementation Year 2 (2020)

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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 2

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 2 (2020) related 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 this stage of the 5-year study period. In 2020 the flows were managed without 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:
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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. Historically, BC Hydro has monitored Rainbow Trout spawning in the LCR and Lower Kootenay River (LKR) below Brilliant Dam (BRD) 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 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 excavating redds at a range of intervals after redd dewatering to determine the percent mortality. The excavated redds are typically near the transects of temperature loggers established in March 2019 at Norn's Creek Fan in the LCR and the Kootenay River Oxbow in the LKR. Interstitial gravel temperatures as well as air temperature, solar radiation, and stage height are being recorded to refine our understanding of the mechanisms behind any egg and alevin mortality. This is in addition to continuing to track Rainbow Trout abundance, spawn timing and spatial distribution within the study area.

The current (2020) and previous (2019) study years represent the first two years without RTSPF enacted since 1992. However, 2020 was represented as a hybrid year starting with planned RTSPF subsequently transitioning away from stable or increasing flows over spring freshet. In the current year 192 redds were dewatered (representing about 1.1% of the annual total). In 2019, 101 redds were dewatered (representing about 0.7% of the annual total). Egg mortality 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.

Peak counts of redds showed the highest numbers at Genelle (1,022) and Norn's Creek Fan (845). These two areas have consistently provided the highest redd numbers through time. The analysis of the redd and spawner counts estimated that there were approximately 11,900 spawners in the mainstem of the LCR and LKR in 2020 (95% CIs from 9,000-16,500). Over the period of monitoring, there has been an 8.5-fold increase from an estimated abundance of 1,400 spawners in 1999 to the 11,900 spawners in 2020. Spawner abundance has been relatively stable since 2013 with overlapping CIs among years. The number of spawners in Norn's Creek has shown a similar trend through time.

Redd construction in 2020 was estimated to begin (exceed 2.5% of the total amount) between the 13th and 19th of March (depending on river segment), with the first redd detected recorded on March 2nd (during initial boat survey). Increases to early spawning detection may have implications to overall spawn period days which has been monitored since 1999. Peak spawning was estimated to occur on May 6th. Spawning was estimated to end (reach 97.5% of the total amount) between the 24th and

30th of June (depending on the river segment). This spawn timing is similar to the previous 20 years of monitoring under CLBMON 46.

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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 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

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 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 (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, 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. Due to environmental conditions, RTSPF were also not implemented in 2020 which resulted in 1.1% of the 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.

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 2020 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).

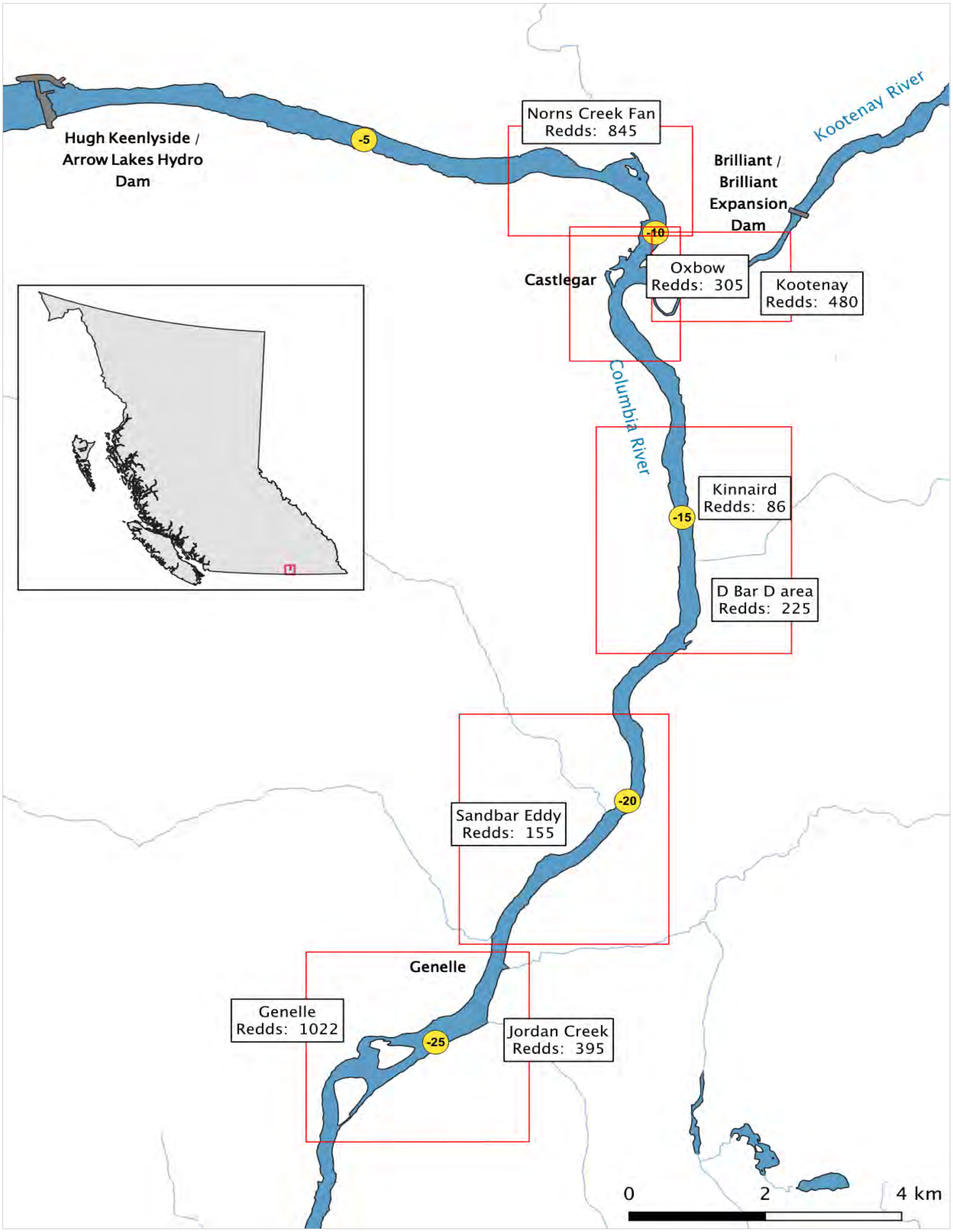

Figure 1. Overview map of the Lower Columbia River and Lower Kootenay River study area with peak count redd numbers by key areas. The red squares indicate the areas of the inset maps in Appendix A.

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 2020, 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.

A total of 5 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. In previous years, the crew members were situated on the same side of the helicopter. However, in 2020, due to COVID-19, the crew members were situated on different sides of the helicopter. To ensure both observers could view each spawning area a second pass in the opposite direction was conducted. Viewing conditions were classified as Good or Poor depending on whether fish could be clearly seen on the spawning gravels.

Table 1. Helicopter survey dates completed during active spawning including descending limb in 2020.

Survey Date	Survey Locations	Total Redd Count	Total Spawners
March 11, 2020	LCR above LKR, LKR, LCR below LKR	108	98
April 10, 2020	LCR above LKR, LKR, LCR below LKR	2103	1341
April 30, 2020	LCR above LKR, LKR, LCR below LKR, CR below Genelle to US border	4752	2853
May 29, 2020	LCR above LKR, LKR, LCR below LKR	1142	415
June 17, 2020	LCR above LKR, LKR, LCR below LKR	640	104

Notes:

[1.] *Helicopter surveys were limited in 2020 due to COVID restrictions.*

2.1.2 Boat Surveys

The helicopter surveys were supplemented by the use of boat surveys, which cover the main spawning areas from Norn's Creek Fan to Genelle (sections 2-6). Boat based shallow water surveys commenced February 27th and were completed June 11th resulting in 1,285 shallow redds being observed throughout the Rainbow Trout spawning season until increased turbidity levels associated with freshet flows rendered surveys ineffective. The 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).

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 five drone surveys were conducted between April 21st and June 15th, 2020 by Harrier Aerial Surveys. 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 inspected using mapping software (QGIS), so that each set of images could 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, providing an additional measure of confidence. A spatial layer of points was then created to represent the locations and distribution of all redds and redd clusters that were identified. This spatial layer was then 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 a elevation and depth for each redd. The elevations were then related to changes in LCR stage to detect dewatering events. Redds that were newly constructed and 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

The locations of shallow water redds (those in <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 (Table2). Depending on the river stage, fish exclusion fencing in past years has been 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). Due to COVID-19 safety concerns, exclusion fencing was not installed in 2020.

Table 2 Reduction dates, magnitude of reduction, number and general location of dewatered redds in 2020.

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
2020-02-29	1096	701	898	897	6	Norns Creek Fan
2020-03-07	661	424	679	682	0	Norns Creek Fan
2020-03-31	1024	547	349	349	10	Norns Creek Fan
2020-03-31	1024	547	349	349	55	Norns Creek Fan
2020-03-31	1024	547	349	349	0	Norns Creek Fan
2020-05-09	900	723	1152	1155	0	Norns Creek Fan
2020-06-12	780	438	2304	2255	117	Norns Creek Fan
2020-03-31	1024	547	349	349	2	RUB, Kinnaird
2020-03-31	1024	547	349	349	0	RUB, Kinnaird
2020-05-09	900	723	1152	1155	0	RUB, Kinnaird
2020-05-09	900	723	1152	1155	0	Oxbow (Total)
2020-03-07	661	424	679	682	0	Genelle (Total)
2020-03-31	1024	547	349	349	0	Genelle (Total)
2020-03-31	1024	547	349	349	2	Genelle (Total)
2020-03-31	1024	547	349	349	0	Genelle (Total)

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

2.2 Egg and Alevin Mortality Surveys

The 2020 study year was initially scheduled to be a RTSPF year with no egg mortality studies planned on dewatered redds, prior to June redds were not assessed for egg mortality. Due to environmental conditions (dry spring/delayed snow melt), a discharge decrease in June was required that dewatered additional redds beyond the redd dewatering threshold and deviated from RTSPF's of stable or increasing after April 1st. The June reductions made 2020 a non RTSPF year and provided an important opportunity to assess egg survival late in the spawning season. No redds were dewatered at the Kootenay Oxbow in 2019 or 2020, consequently the mortality of dewatered Rainbow Trout eggs and alevins was only monitored at Norn's Creek Fan. Individual dewatered redds were marked using a uniquely numbered tag. Egg and alevin 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 form previously dewatered redds in June. 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. Due to rapid increases in the discharge, there was not an opportunity to test the device.

During the limited redd excavations 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 #CB19-468675, issued by the Ministry of Forest, Lands and Natural Resource Operations, Kootenay – Boundary Region.

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 7 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. Between March 2019 and the main data download in September 2019 three gravel temperature monitoring stations were vandalized. Stations 19 and 21 were pulled from the gravel at Kootenay Oxbow and station 1 was removed completely at Norn's Creek Fan. Due to COVID-19 the loggers at the gravel temperature monitoring stations were not downloaded during the scheduled March 2020 event. When, the temperature loggers were downloaded after freshet in October 2020, it was discovered that the internal batteries had expired on all the units in January 2020. Our expectation was that the batteries would last three years. In addition, 10% of the recovered units had experienced water damage which meant their data was lost. Discussions with the manufacturers revealed that the battery life of less than 1 year was because Bluetooth was permanently on (to allow data downloads without having to excavate the temperature loggers). The water damage was attributed to freeze thaw events within the gravels. The MX2201 loggers will be replaced by Tidbit V2 loggers which will be re-deployed at established gravel temperature monitoring sites in March 2021. The Tidbit V2 loggers which are made from sealed epoxy will be further protected by a plastic housing. To prevent thermal conductance between the loggers it is recommended to join them together by 200 lb monofilament line. To reduce the chances of vandalism, the location of the stations should not be visible from the surface and should instead be marked by a metal nut which can be picked up by a metal detector.

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

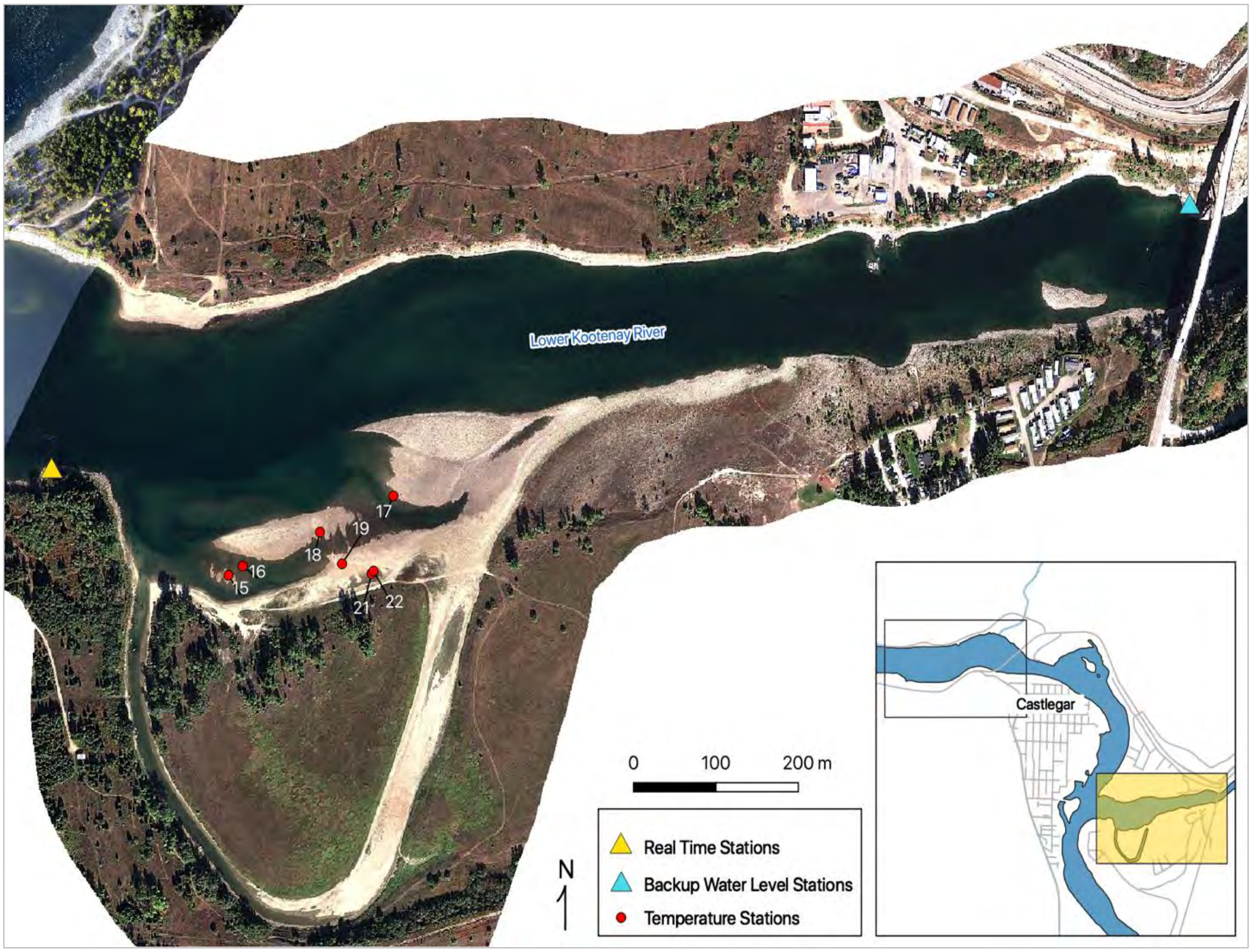

Figure 3. Monitoring stations on the Lower Kootenay River at the Oxbow.

2.4 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 LCR water level. 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 will be used to ensure the accuracy of all elevational data for Norn's Creek Fan.

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 discharge 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 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 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 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 values are based on professional judgment. 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 recruits per spawner at low density (α) is normally distributed 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. The values are based on professional judgment.

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/626789785.

3.1 Redd and Spawner Abundance

As in previous years, the areas with the most spawning in 2020 were Genelle (1,022 redds; Figure 1) and Norn's Creek Fan (845 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 11,900 fish spawned in the LCR and LKR mainstem in 2020 (95% CIs from 9,000-16,500). Over the period of monitoring, there has been an 8.5-fold increase from an estimated abundance of 1,400 spawners in 1999 to the 11,900 spawners in 2020. The abundance has been relatively stable since 2013 with overlapping CIs among years. (Figure 4).

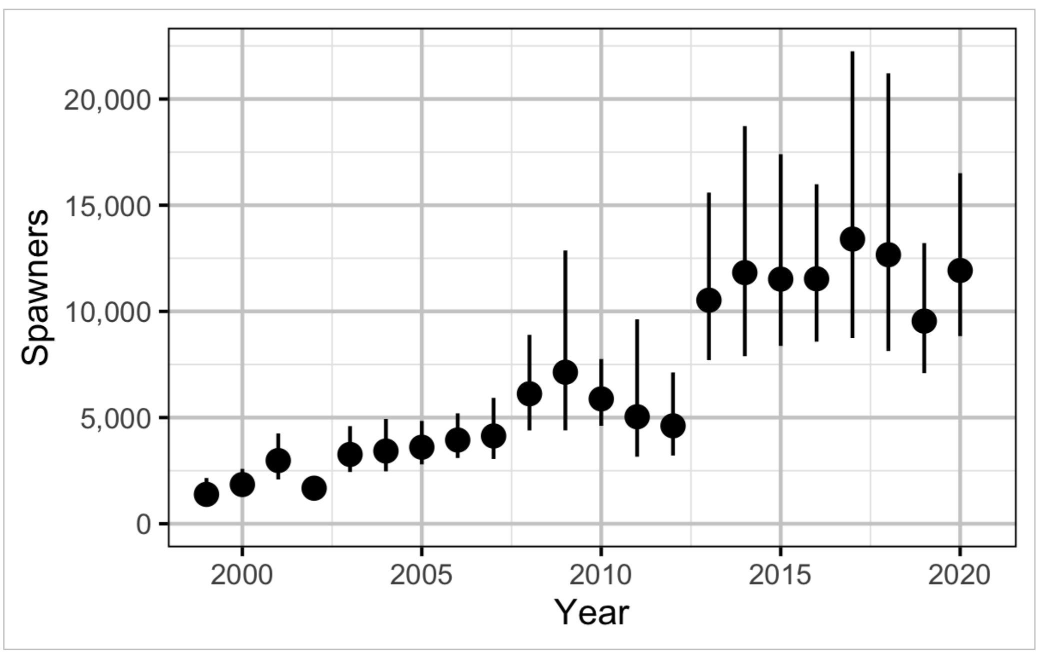

Figure 4. Estimated total spawner abundance by year with 95% CIs.

3.2 Redd Dewatering

There was no dewatering of the 785 redds recorded on the LKR in 2020. The discharge from HLK dam in 2020 underwent reductions that caused redd dewatering in March, early April and mid-June 2020(

Figure 5). A total of 192 redds (Figure 6) were dewatered by these reductions corresponding to 1.1% of the estimated total number of redds (95% CI 0.7-1.8 %; Figure 6 and Figure 7). The current and historical discharge time series for HLK dam are available in Appendix C.

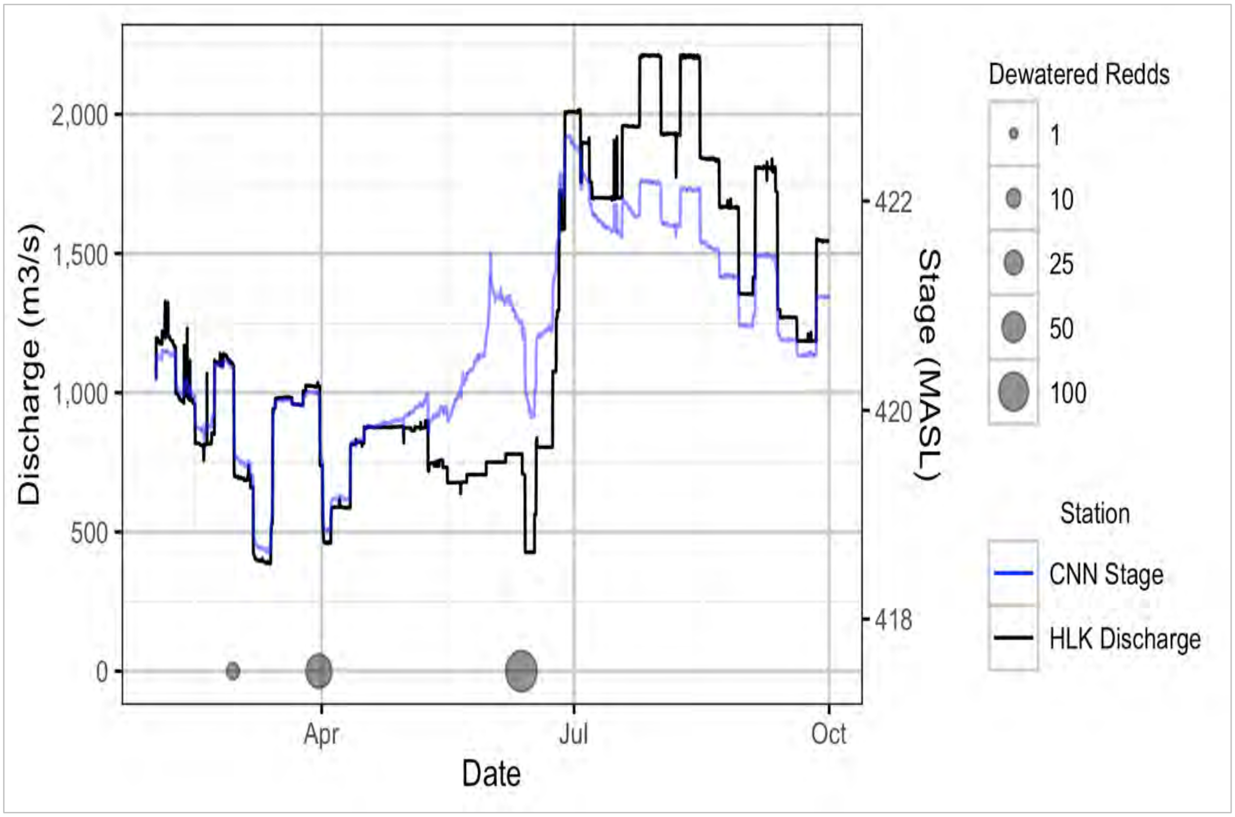

Figure 5. Discharge at HLK and stage at CNN and number of dewatered redds by date for 2020.

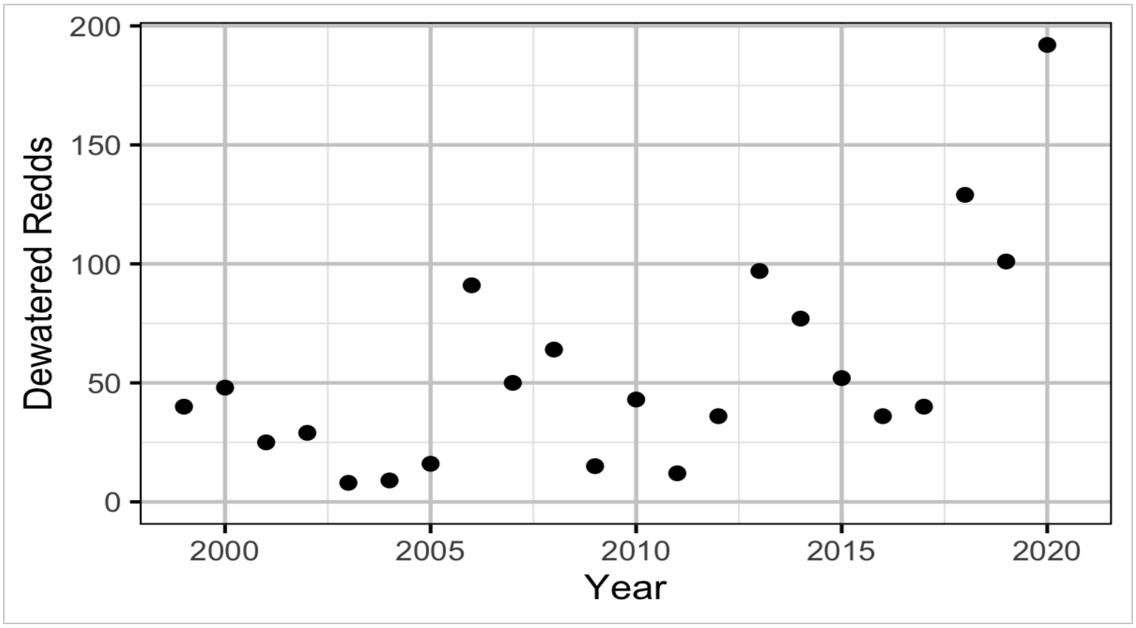

Figure 6. Actual number of enumerated dewatered redds by year.

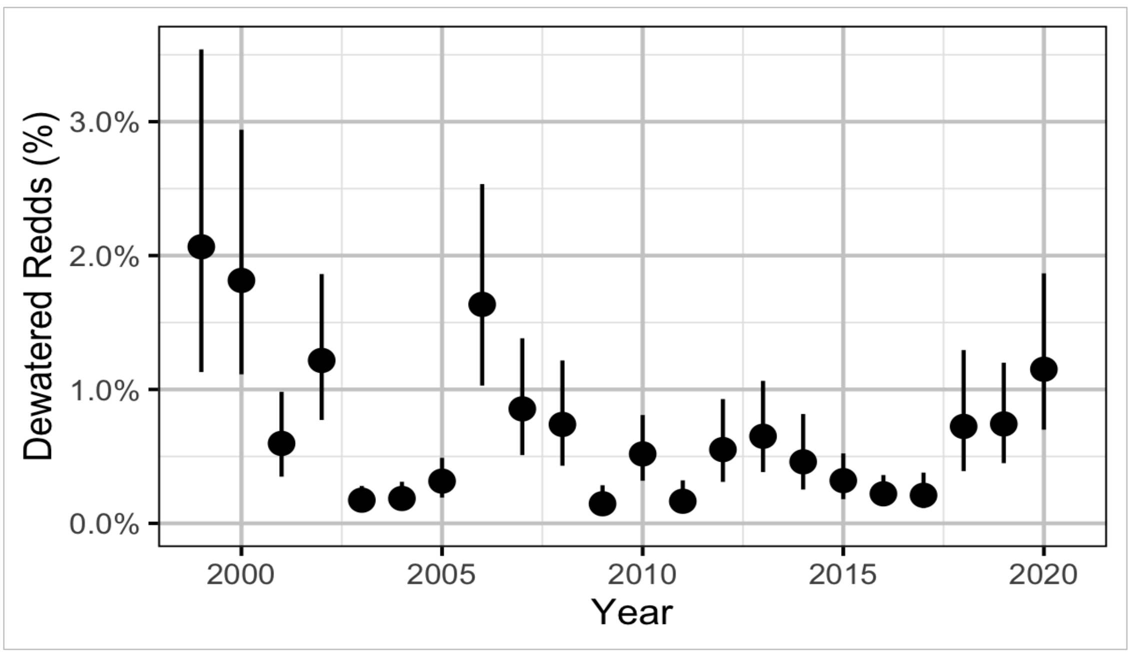

Figure 7. Estimated percentage of redds dewatered by year with 95% CIs.

3.3 Drone Based Monitoring

Drone identified redds were mapped against water depth to begin exploring additional measures for assessing dewatering, and to provide a succinct overview of redd distribution within the habitat over a duration of 5 surveys in 2020 (Figure 8). Drone surveys completed by Harrier Aerial Surveys at Norn`s Creek Fan occurred on April 21st, April 29th, May 12th, May 28th, and June 15th.

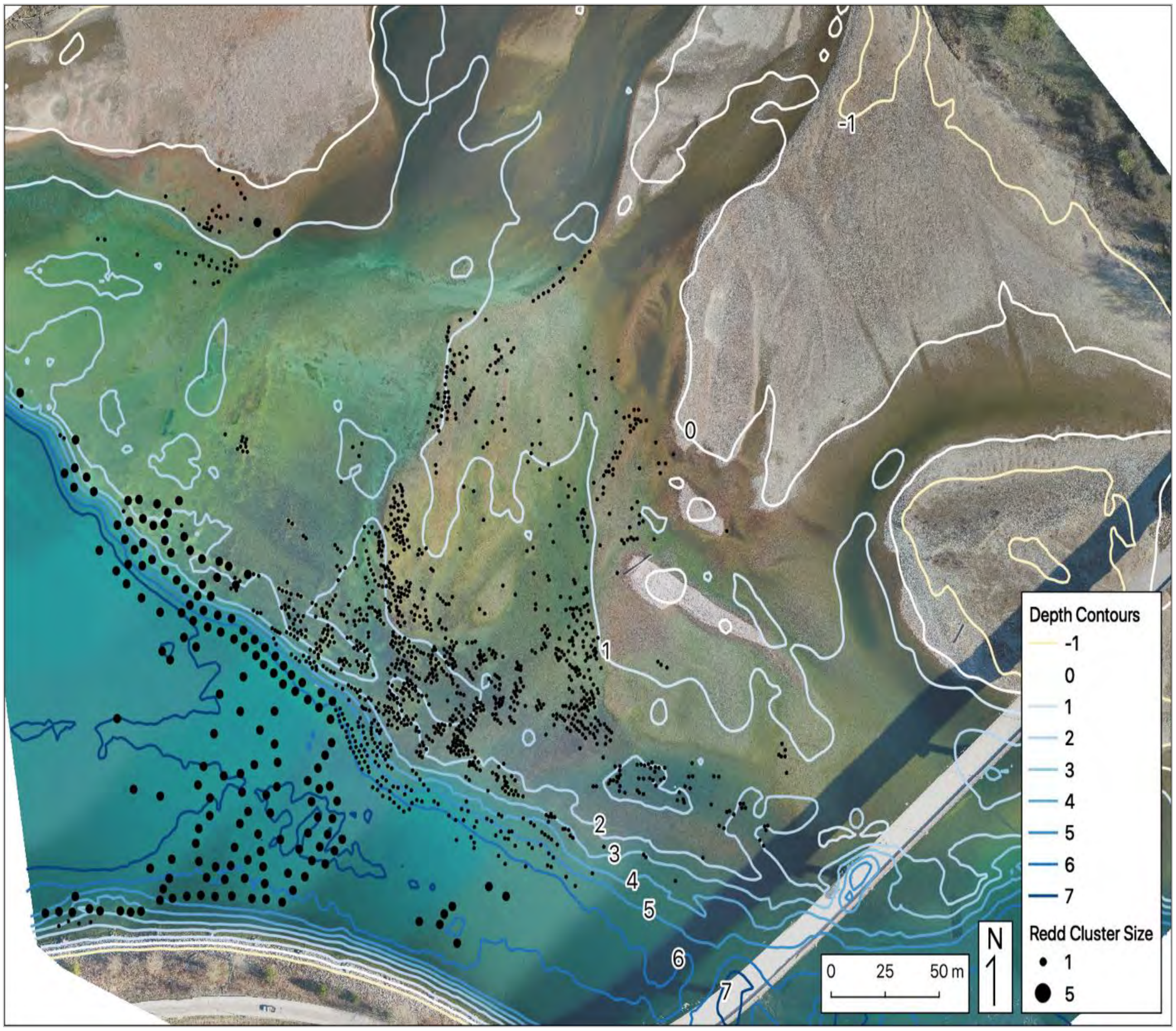

Figure 8. Cumulative redds identified over five drone surveys at Norn's Creek Fan, and adjacent main channel in 2020.

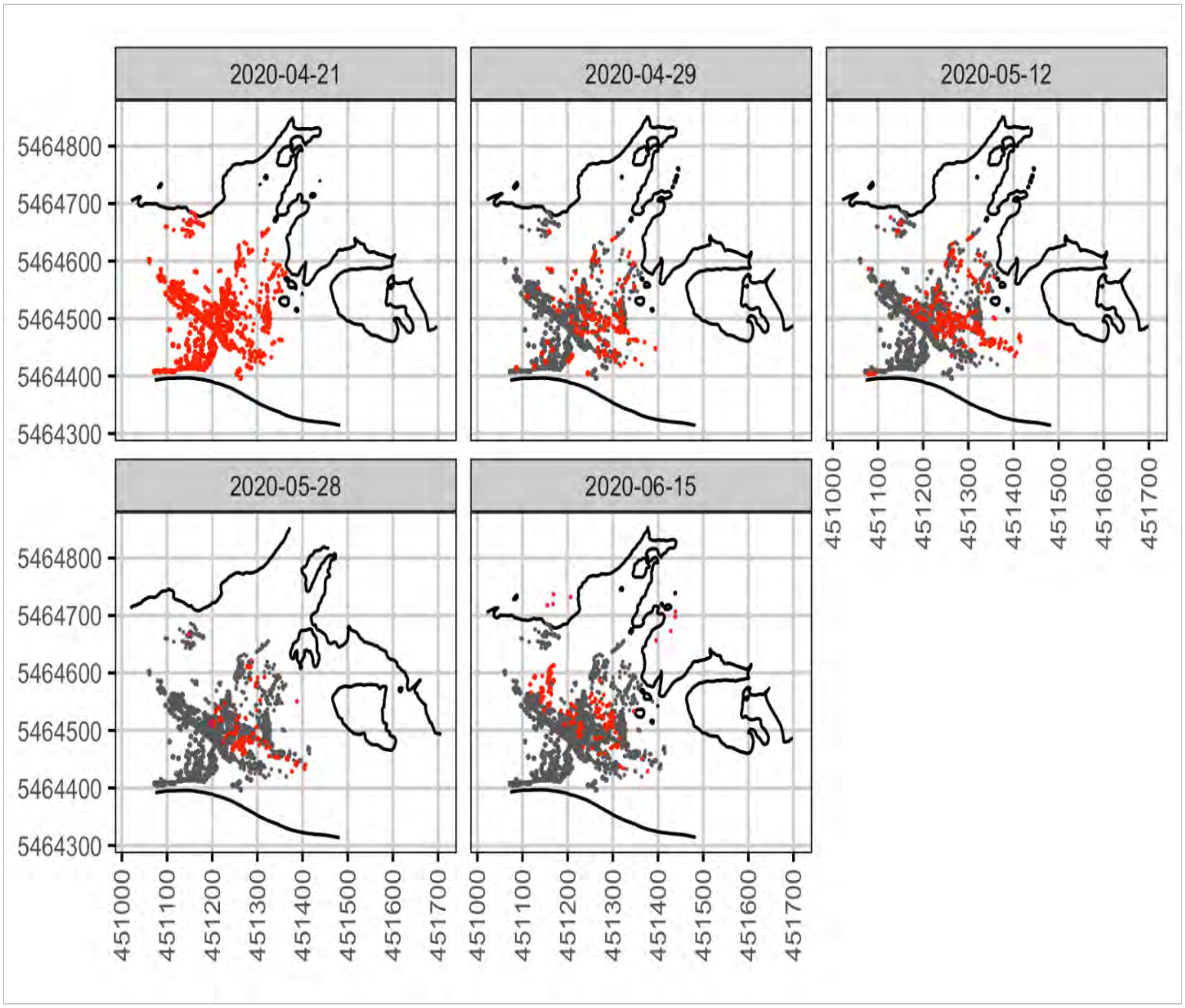

Figure 9. Accumulation of drone counted redds by date, with new redds highlighted in red. The wetted edge contour is shown for each survey date.

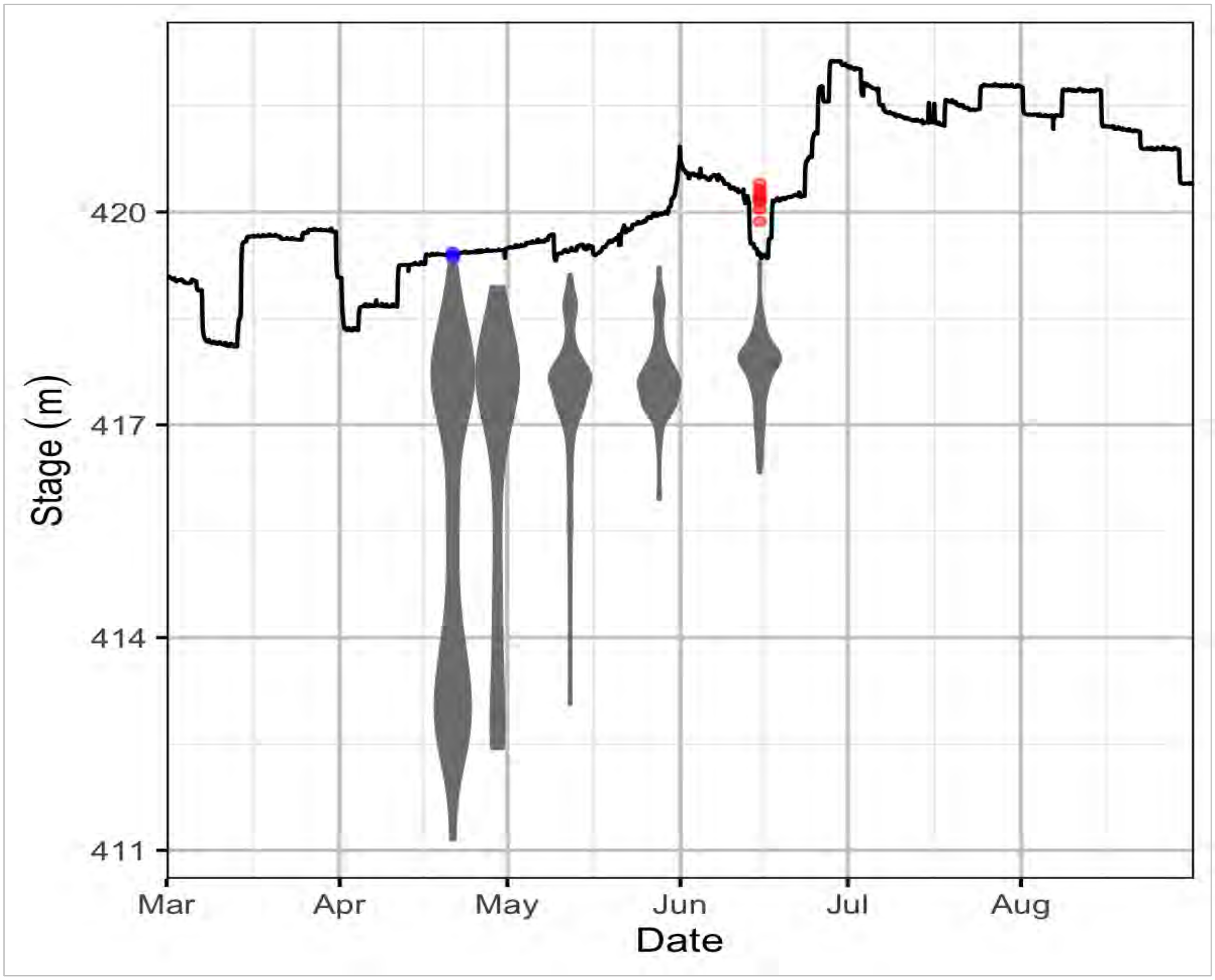

Figure 10. Elevational distribution of newly detected drone surveyed redds at Norn's Creek Fan in 2020 by survey date. Drone surveyed redds that were subsequently dewatered based on the stage elevation are indicated by blue points. Dewatered redds that were identified and excavated during ground surveys are indicated by red points.

3.4 *Egg Mortality*

Due to COVID-19 and the short duration of the reductions only two days of redd excavations were carried out in 2020 - on June 14th and June 16th. Although the June decrease provided an important opportunity to assess egg survival, flows were increased within three days. Of the 10 dewatered redds that were assessed, 8 had a 0% mortality rate after three days while the remaining two had a 13% and 2.7% mortality rate (Figure 11).

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.

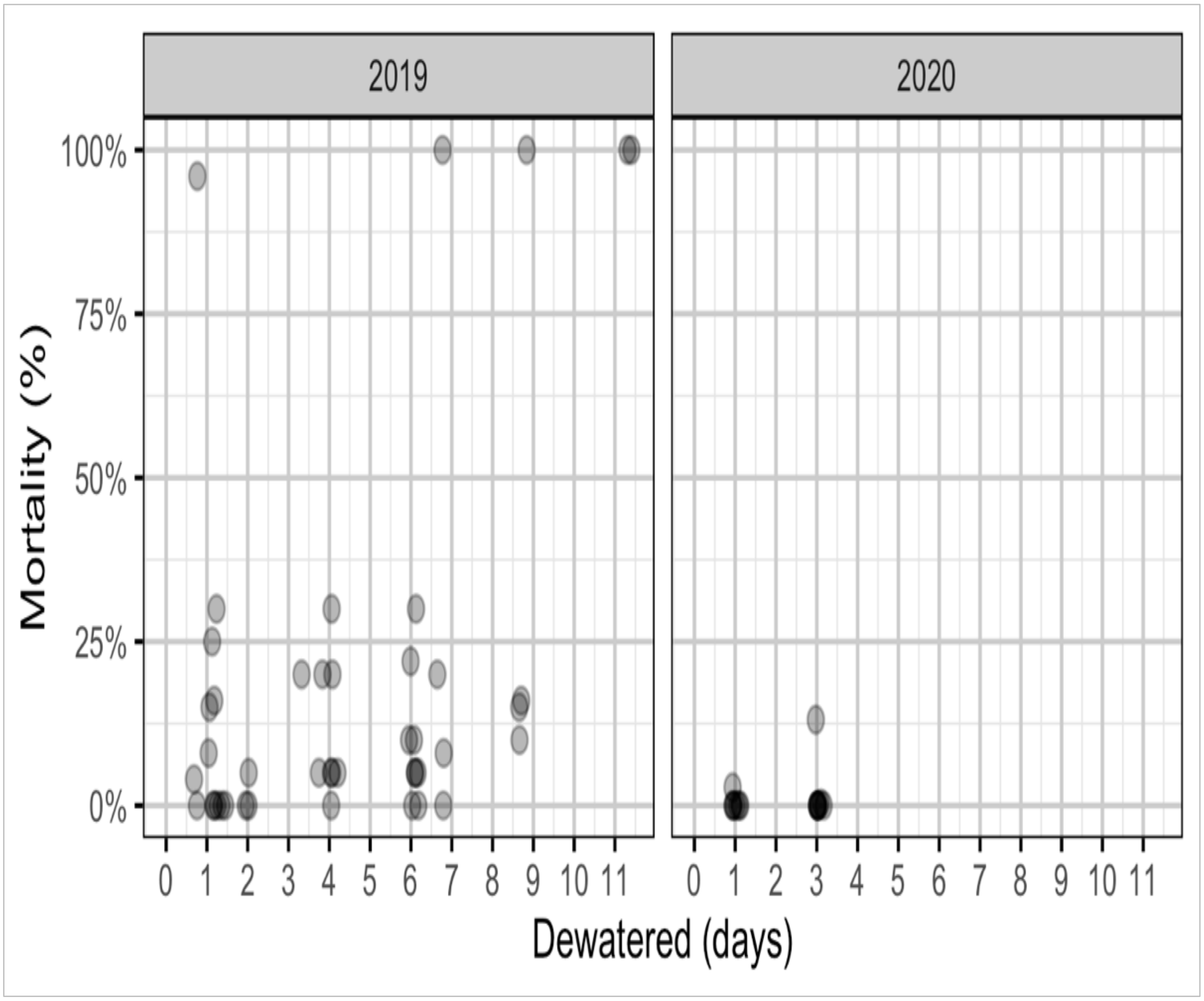

Figure 11. Observed egg mortality in natural redds by days dewatered in 2019 & 2020.

3.5 Spawn Timing

Generally, the spawn timing has been quite stable through the period of monitoring (Figure 12). similar to 2019, 2020 spawn timing in the LKR to Genelle section was compressed compared to the previous years. When comparing the total number of days in the estimated spawn period, this section has changed from 157 days in 1999 to 97 days in 2020. In the 2020 spawning year, peak spawning was estimated to occur on May 6th (95% CIs ranged from the 2nd of May to the 12th of May), the start (2.5% of spawning) was on the 13rd, 14th, or 19th of March depending on river segment), and the end (97.5% of spawning) was estimated to be on the 24th, 29th, or 30th of June depending on the river segment (Figure 12).

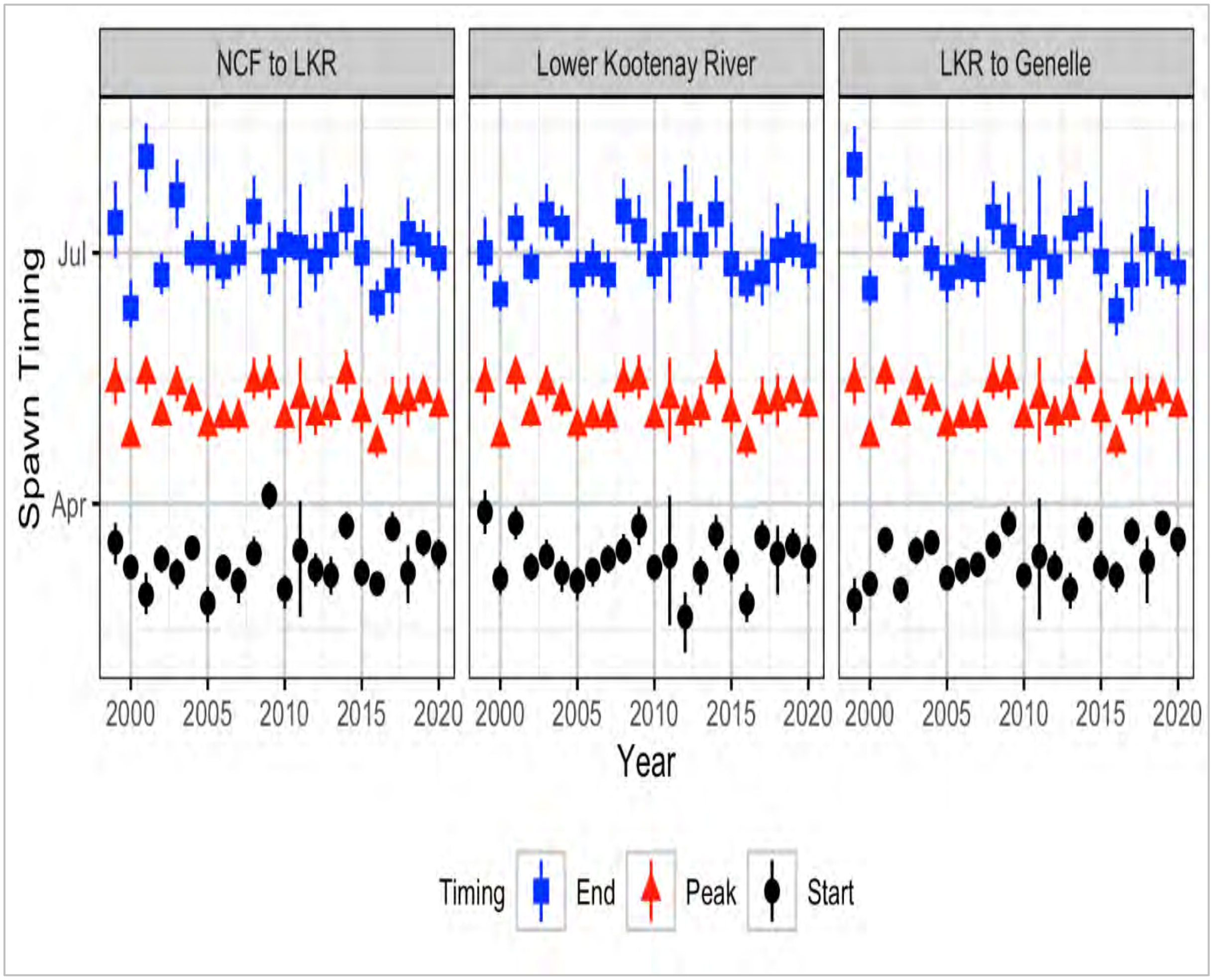

Figure 12. Estimated start (2.5% of spawners arrived), peak and end (2.5% of spawners remaining) spawn timing by year and segment with 95% CIs.

3.6 Stock Recruitment

The Beverton-Holt stock recruitment models fitted to age-1 Rainbow Trout abundance suggest density-dependent survival (Figures 13 and 14). 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 in the 2000, 2001, 2006 and 2010 spawn years. The number of recruits showed no increase associated with the higher stock years.

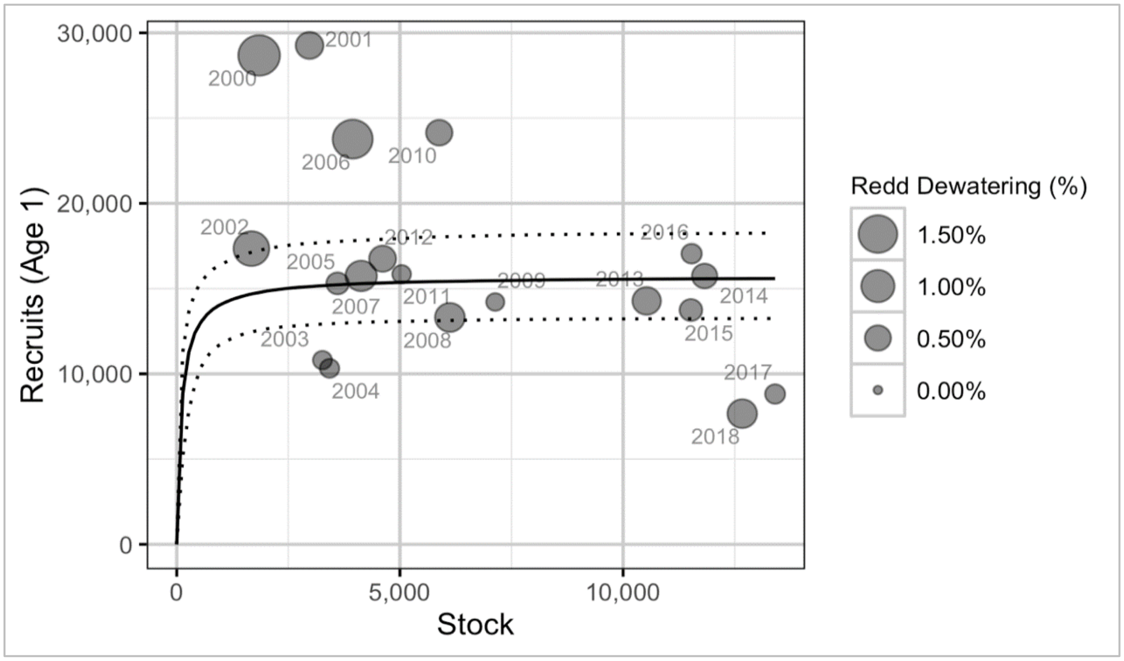

Figure 13. Predicted stock-recruitment relationship from spawners to subsequent age-1 recruits by spawn year with 95% CIs.

The number of age-1 recruits was positively correlated with number of dewatered redds (Figure 14) which taken at face value suggests that higher redd dewatering is associated with increased recruitment success. In reality the correlation is due to fact that the highest densities and lowest relative redd dewatering rates have both tended to occur from 2013 onwards.

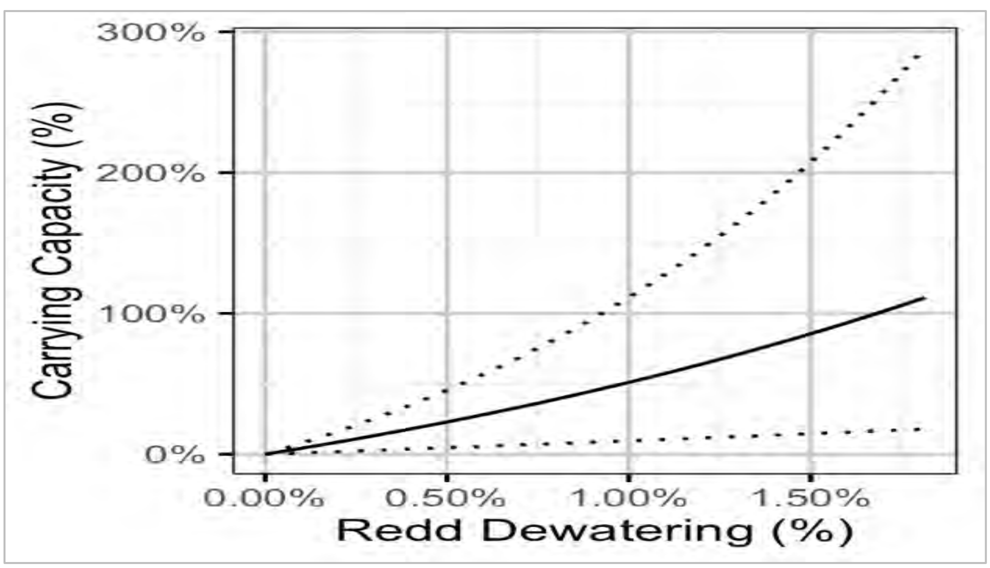

Figure 14. Predicted age-1 recruits carrying capacity vs. percentage egg dewatering with 95% CRIs.

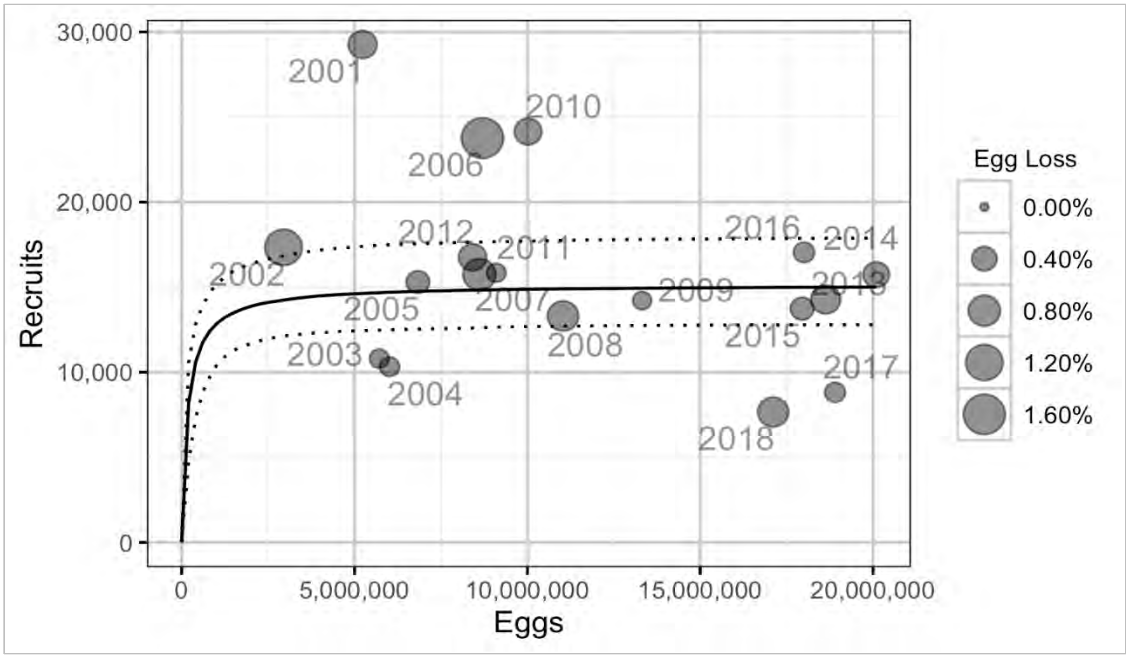

Figure 15. Predicted stock-recruitment relationship by spawn year (with 95% CRIs)

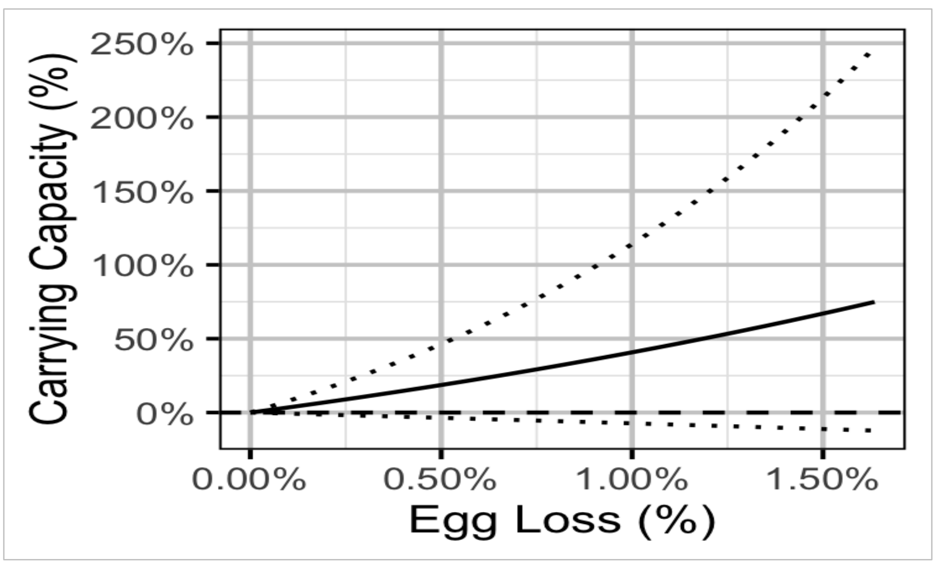

Figure 16. Predicted effect of egg loss on the age-1 carrying capacity (with 95% CRIs)

4.0 DISCUSSION

In 2020, considering the nature of the flow regime with a mixture of stable and increasing flows and reductions defined as a hybrid year de, only 192 redds (1.1% of the estimated redd total) were dewatered. The average number of redds dewatered per year with RTSPF in place is 46 (data from 1999-2018) therefore the dewatering was higher than average in 2020 when considering abundance of redds dewatered but was marginally above the average value when considering the proportion of redds dewatered with only 1.1% 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 are 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 *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 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 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.

The redd excavations completed for the period of 2019-2020, albeit minor in overall effort, did not result in 100% mortality immediately after dewatering as had previously been assumed. Egg mortality in 2019 was less than 25% in 79% of the samples and was greater than 25% in 21%, 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 on the dependent variable of egg mortality. The weather in the spring and summer of 2020 was quite dry with delayed freshet flows compared to most years. 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).

Since 1999 redd counts have been conducted throughout the same study area in the LCR and LKR. In 2020, peak counts of redds were highest at Genelle (1,022) and Norn's Creek Fan (845). 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 8.5-fold since monitoring began in 1999 and peak abundance was recorded in 2018 with an estimate of 13,756 spawners. The estimated abundance in 2020 was 11,900 spawners (95% CIs from 9,000-16,500).

Spawn timing estimates in 2020 had a start date between March 13th to 19th (depending on location within the river), spawning peaked on May 6th and was completed between June 24th to June 30th.

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

- Conduct first drone survey in March when spawning has just begun and conduct surveys every two weeks and just prior to large flow reductions until conditions become turbid. Surveys to confirm and map newly constructed redds or those that dewater during scheduled flow reduction events using imagery and elevational data.
- Trial drone survey at the Kootenay Oxbow (Figure 3) to see if it can collect useful imagery in areas with more turbulent flow.
- Redeploy gravel temperature stations using Tidbit V2 loggers in protective boots joined together by 200 lb mono-filament line. The location of the stations should not be visible from the surface and marked by a metal nut which can be picked up by a metal detector. The redeployments will allow for continued monitoring of interstitial temperatures at varying gravel depths providing data on the influence of temperature on alevin and egg mortality.
- Continue to refine the accuracy of elevations at monitoring stations using the federal geodetic benchmark and hypsometer. As modeling relies on accurate elevational data, ensuring the use of precise elevations will further reduce discrepancies and ensure repeatability.
- Conduct opportunistic redd excavations to collect additional information on the dewatering mortality of eggs and alevins in the LCR.

6.0 CLOSING

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

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Computational Biologist	Fisheries Biologist	Fisheries Research Tech

7.0 REFERENCES

7.1 Literature Cited

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

BC Hydro. 2018. CLBMON-46 Lower Columbia River Rainbow Trout Spawning Assessment Terms of Reference. Addendum 1. BC Hydro.

Becker, C.D., and Neitzel, D.A. 1983. Salmonid Redd Dewatering: What Do We Know. PNNL Technical Library.

Bjornn, T.C., and Reiser, D.W. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 83–138.

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

Brooks, S., Gelman, A., Jones, G.L., and Meng, X.-L. (Editors). 2011. Handbook for Markov Chain Monte Carlo. Taylor & Francis, Boca Raton.

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

Carter, K. 2005. The Effects of Temperature on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage. : 27.

Casas-Mulet, R., Saltveit, S.J., and Alfredsen, K.T. 2016. Hydrological and thermal effects of hydropeaking on early life stages of salmonids: A modelling approach for implementing mitigation strategies. Science of The Total Environment 573: 1660–1672. http://doi.org/10.1016/j.scitotenv.2016.09.208.

Dahlberg, M.D. 1979. A Review of Survival Rates of Fish Eggs and Larvae in Relation to Impact Assessments. Marine Fisheries Review: 12.

Dalla Santa, G., Peron, F., Galgaro, A., Cultrera, M., Bertermann, D., Mueller, J., and Bernardi, A. 2017. Laboratory Measurements of Gravel Thermal Conductivity: An Update Methodological Approach. Energy Procedia (125): 671–677.

Gelman, A., Simpson, D., and Betancourt, M. 2017. The Prior Can Often Only Be Understood in the Context of the Likelihood. Entropy 19(10): 555. http://doi.org/10.3390/e19100555.

Gibbins, C., Shellberg, J., Moir, H., and Soulsby, C. 2008. Hydrological Influences on Adult Salmonid Migration, Spawning, and Embryo Survival. American Fisheries Society. pp. 195–223.

Golder Associates Ltd., Poisson Consulting Ltd., and Okanagan Nation Alliance. 2017. Middle Columbia River Fish Population Indexing Program: Year 10 (2016 Study Period). An Okanagan Nation Alliance, Golder Associates and Poisson Consulting Report, BC Hydro, Castlegar, BC.

Golder, Poisson Consulting, and Okanagan Nation Alliance. 2019. Lower Columbia River Fish Population Indexing Surveys: Year 12 (2018 Study Period). A Golder Associates, Poisson Consulting and Okanagan Nation Alliance Report, BC Hydro, Castlegar, BC.

Irvine, R.L., Baxter, J.T.A., and Thorley, J.L. 2018. Lower Columbia River Rainbow Trout Spawning Assessment: Year 10 (2017 Study Period). A Mountain Water and Poisson Consulting Ltd. Research Report, Prepared for BC Hydro, Kootenay Generation Area, Castlegar, B.C.

Jensen, J.O.T., and Groot, E.P. 1991. The effect of moist air incubation conditions and temperature on chinook salmon egg survival. In American Fisheries Society Symposium. American Fisheries Society, Bethesda, Maryland. pp. 529–538.

Kery, M., and Schaub, M. 2011. Bayesian population analysis using WinBUGS : a hierarchical perspective. Academic Press, Boston. Available from http://www.vogelwarte.ch/bpa.html.

Korman, J., Kaplinski, M., and Melis, T.S. 2011. Effects of Fluctuating Flows and a Controlled Flood on Incubation Success and Early Survival Rates and Growth of Age-0 Rainbow Trout in a Large Regulated River. Transactions of the American Fisheries Society 140(2): 487–505. http://doi.org/10.1080/00028487.2011.572015.

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

McElreath, R. 2016. Statistical rethinking: a Bayesian course with examples in R and Stan. CRC Press/Taylor & Francis Group, Boca Raton.

Myrick, C.A., and Cech, J.J. 2001. Temperature Effects on Chinook Salmon and Steelhead: A Review Focusing on California's Central Valley Populations. Bay-Delta Modeling Forum.

Neitzel, D.A., and Becker, C.D. 1985. Tolerance of Eggs, Embryos, and Alevins of Chinook Salmon to Temperature Changes and Reduced Humidity in Dewatered Redds. Transactions of the American Fisheries Society 114(2): 267–273. http://doi.org/10.1577/1548-8659(1985)114<267: TOEEAA>2.0.CO;2.

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

R Core Team. 2019. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available from https://www.R-project.org/.

R Core Team. 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available from https://www.R-project.org/.

Reiser, D.W., and White, R.G. 1983. Effects of Complete Redd Dewatering on Salmonid Egg-Hatching Success and Development of Juveniles. Transactions of the American Fisheries Society 112(4): 532–540. http://doi.org/10.1577/1548-8659(1983)112<532: EOCRDO>2.0.CO;2.

Rombough, P.J. 1988. Growth, aerobic metabolism, and dissolved oxygen requirements of embryos and alevins of steelhead. Canadian Journal of Zoology (66): 651–660.

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

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

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

APPENDIX A

MAPS OF PEAK FISH AND REDD COUNTS 2020

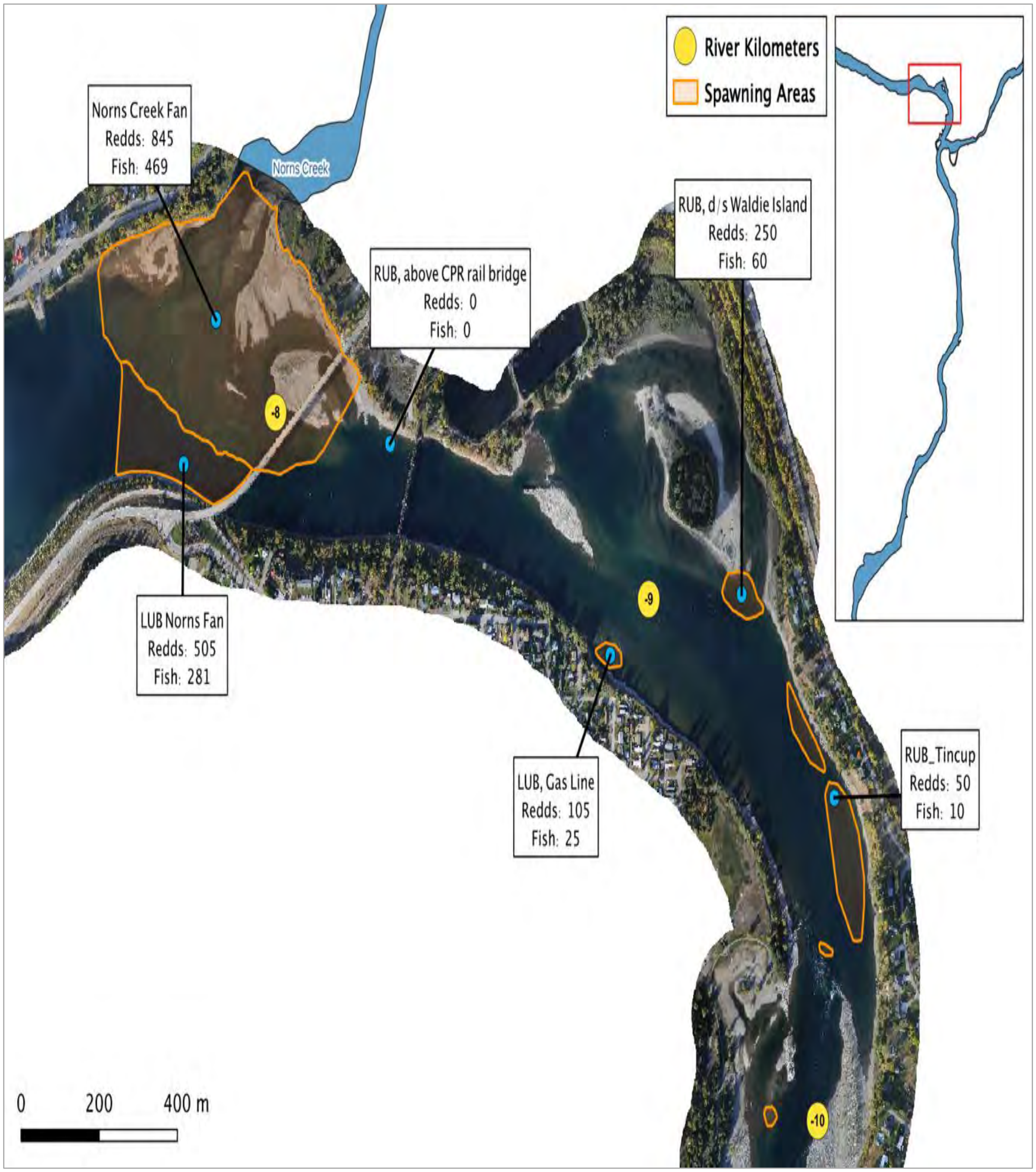

Figure A1. Fish and redd peak counts in the Norn's Creek Fan and Robson Bridge area.

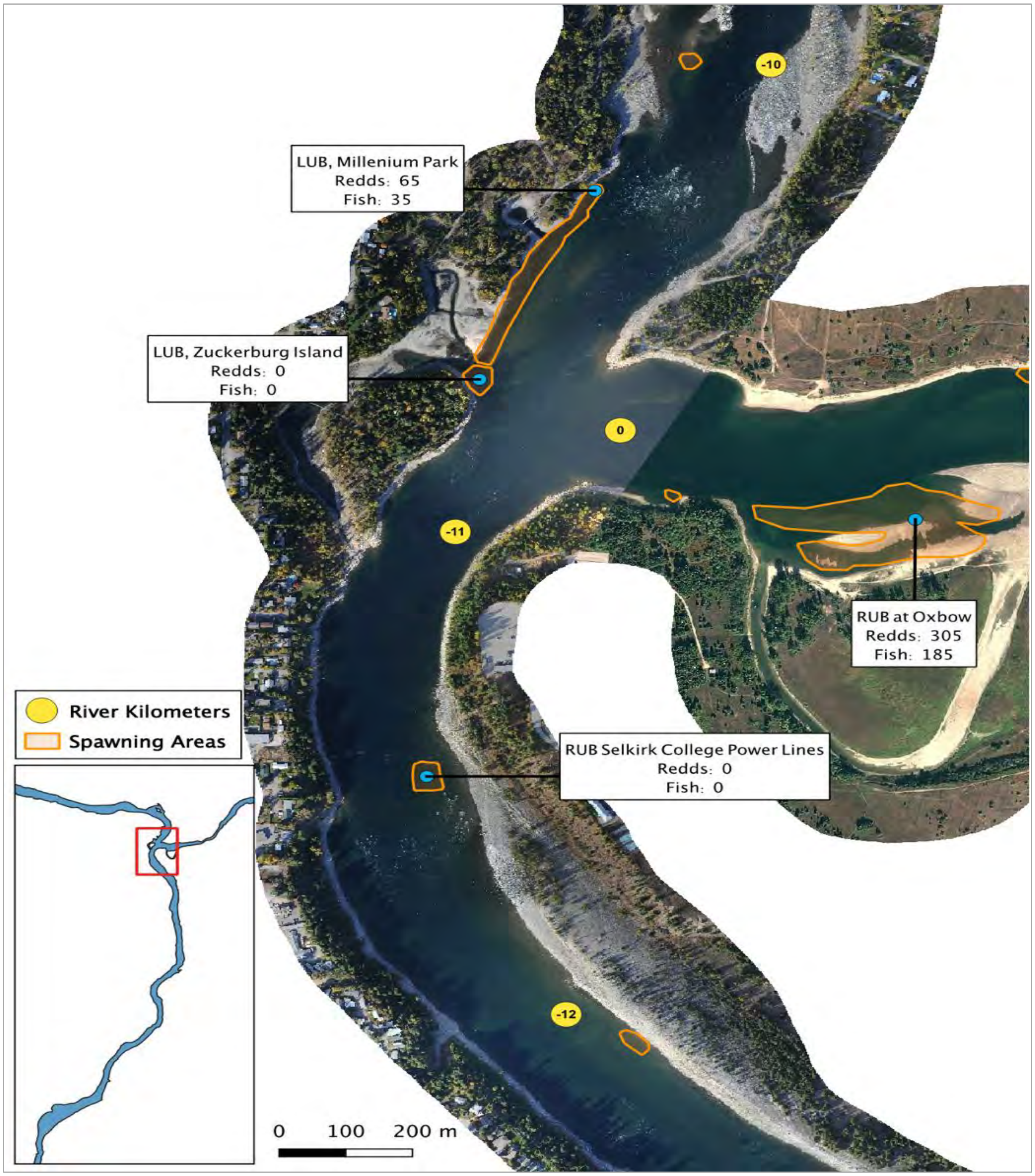

Figure A2. Fish and redd peak counts in the Zuckerberg and Millennium Park area.

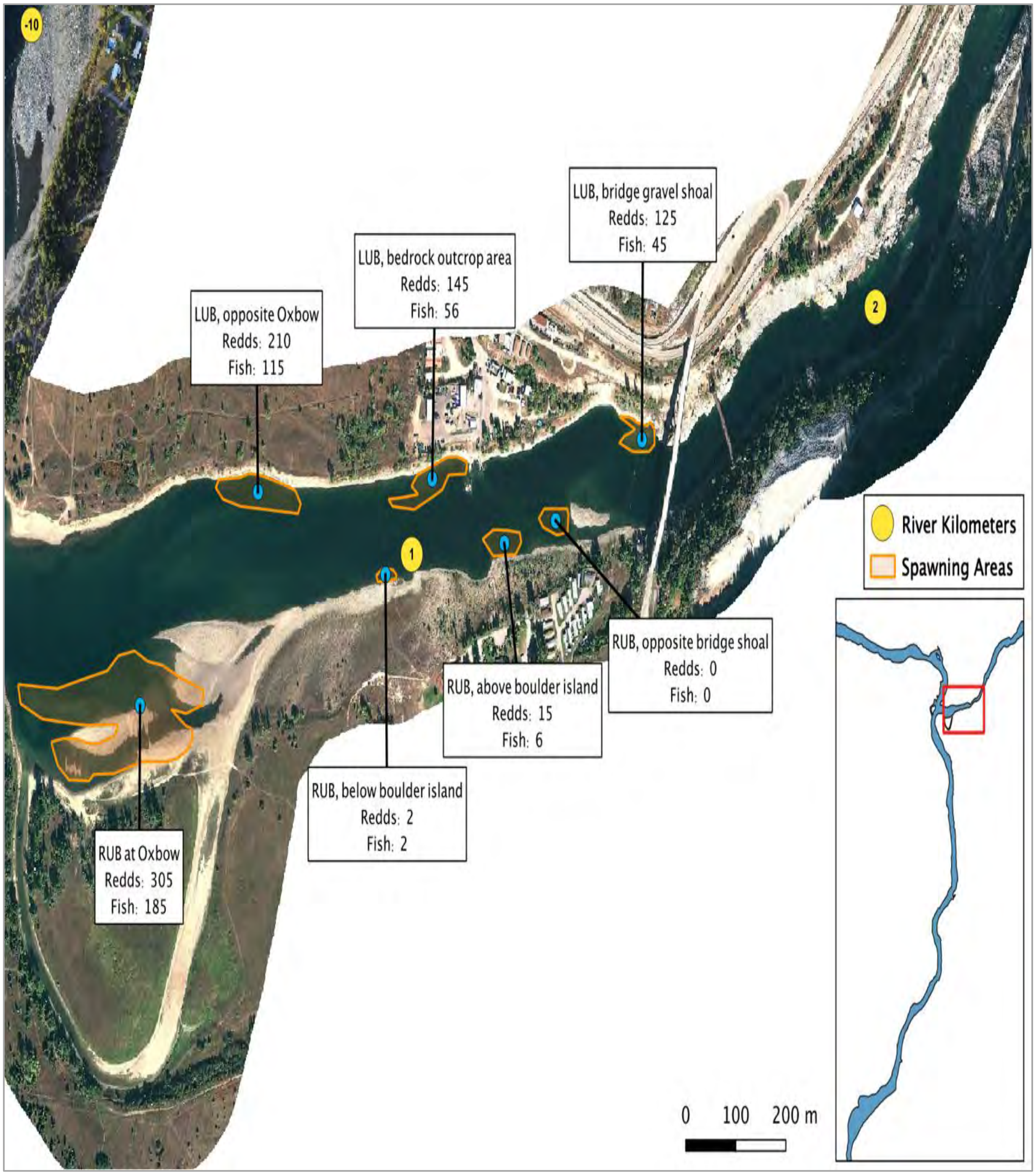

Figure A3. Fish and redd peak counts in the Lower Kootenay river area.

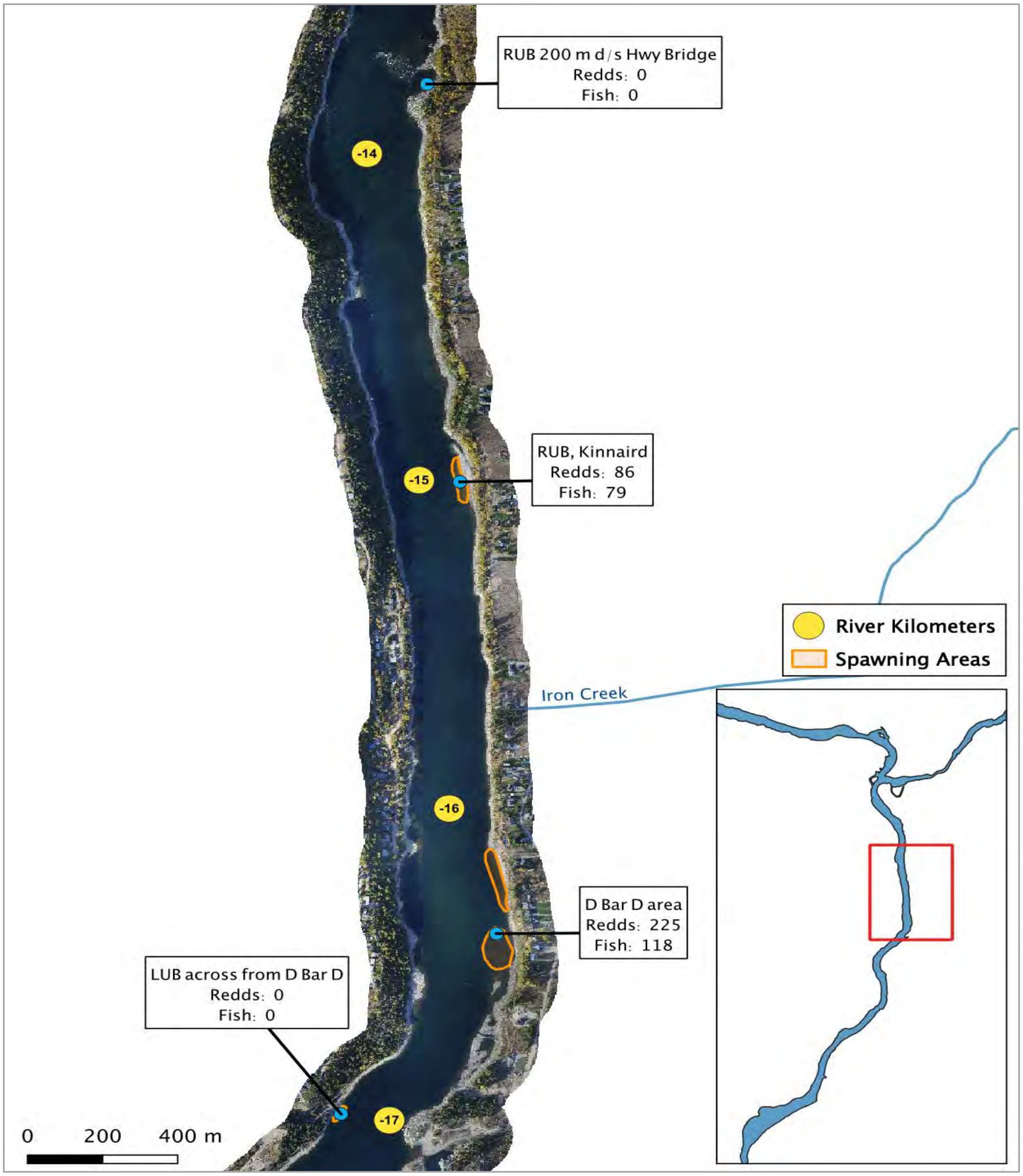

Figure A4. Fish and redd peak counts in the Kinnaird area.

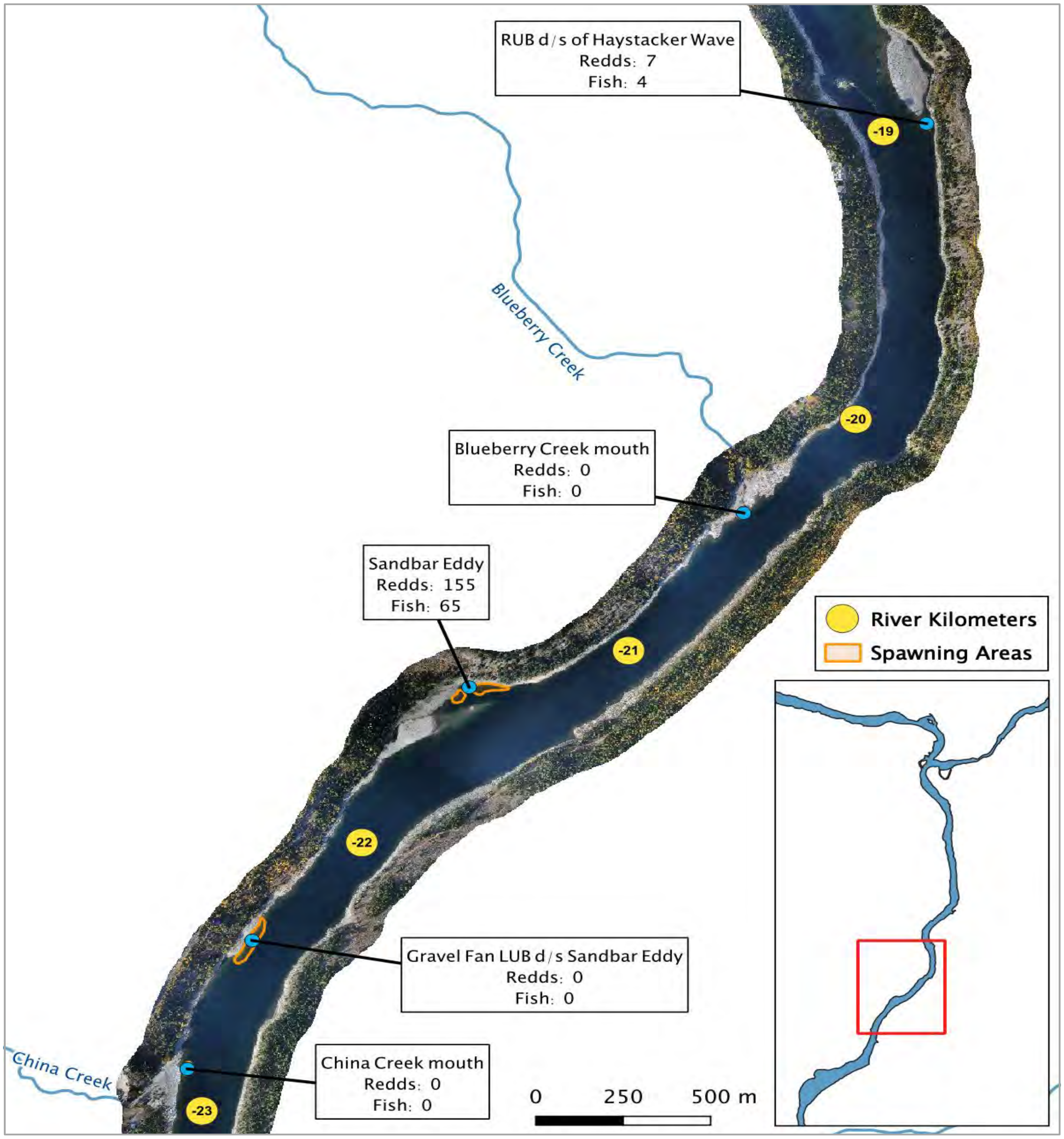

Figure A5. Fish and redd peak counts in the Blueberry and China Creek area.

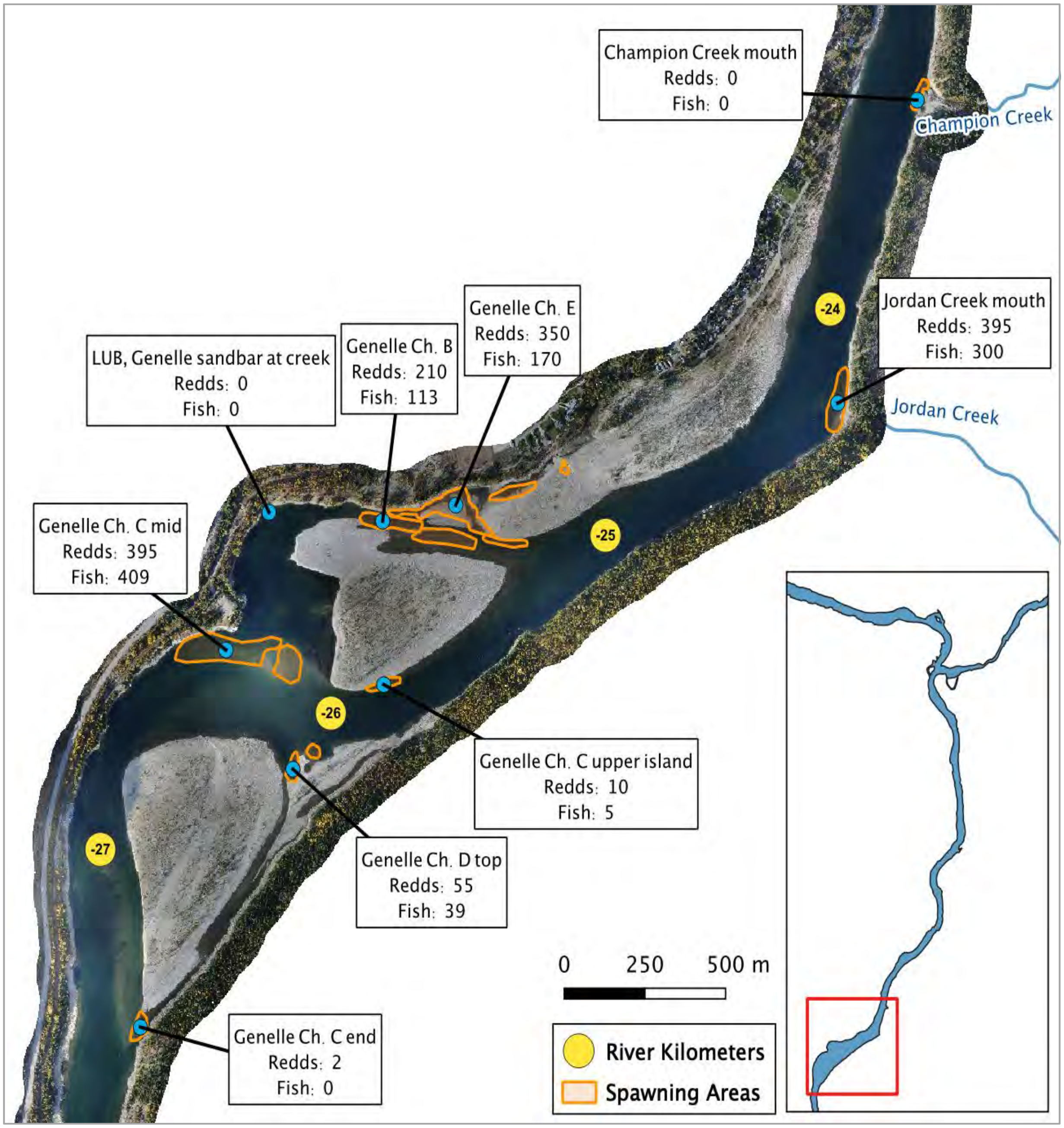

Figure A6. Fish and redd peak counts in the Genelle area.

APPENDIX B
AREA-UNDER-THE-CURVE PLOTS

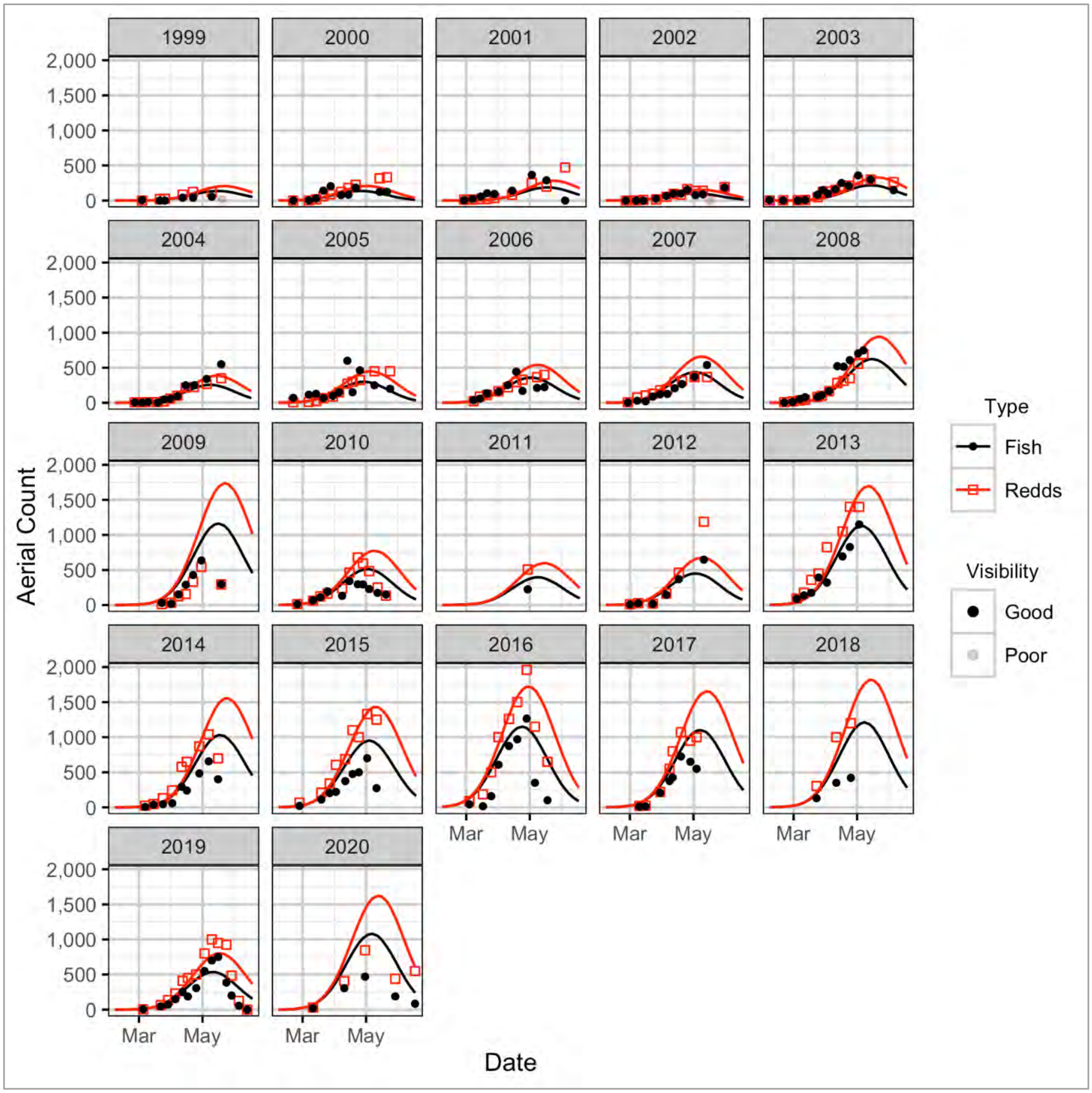

Figure B1. Predicted and actual aerial fish and redd counts at Norn's Creek Fan by date and year.

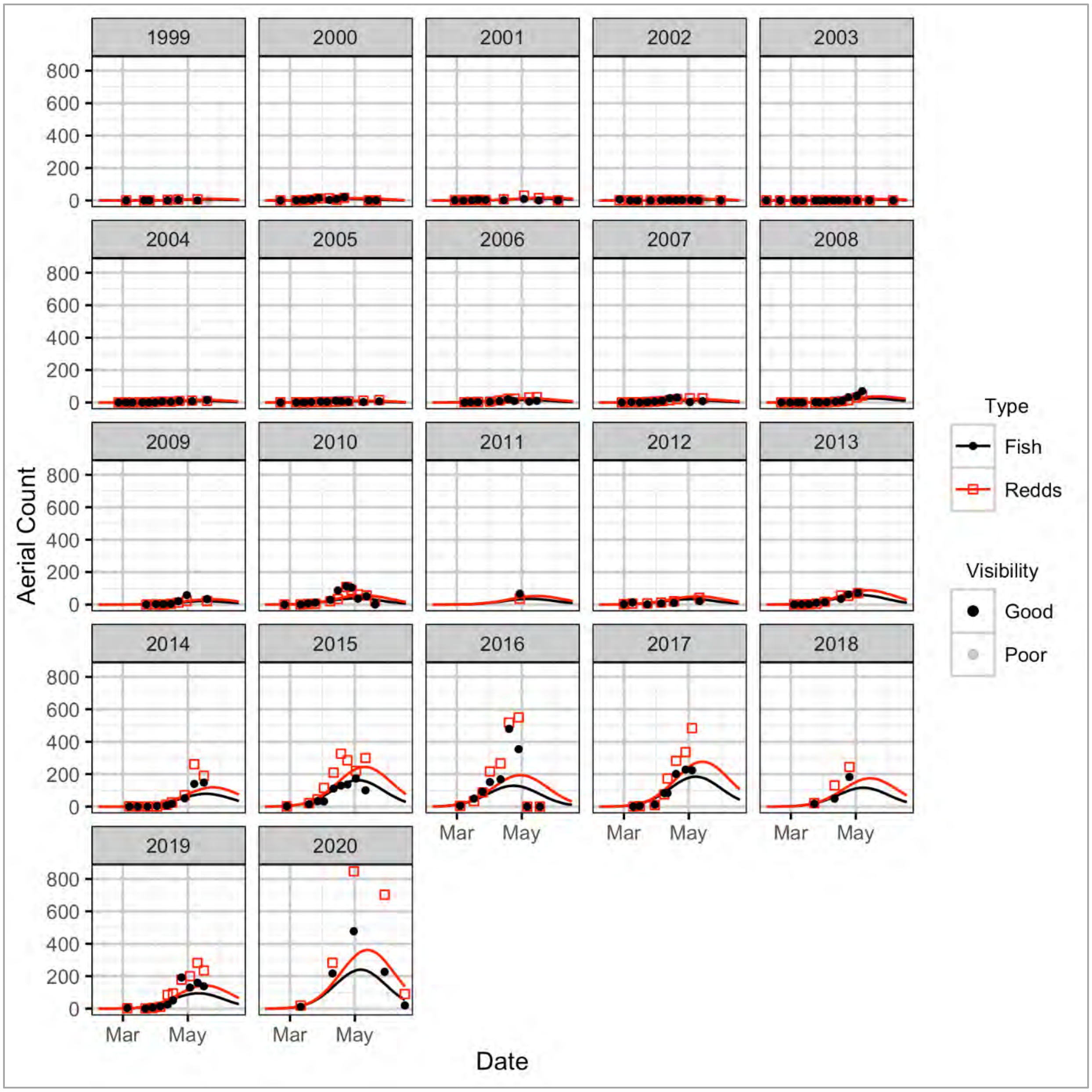

Figure B2. Predicted and actual aerial fish and redd counts in the section from Norn's Creek Fan to the Lower Kootenay River by date and year.

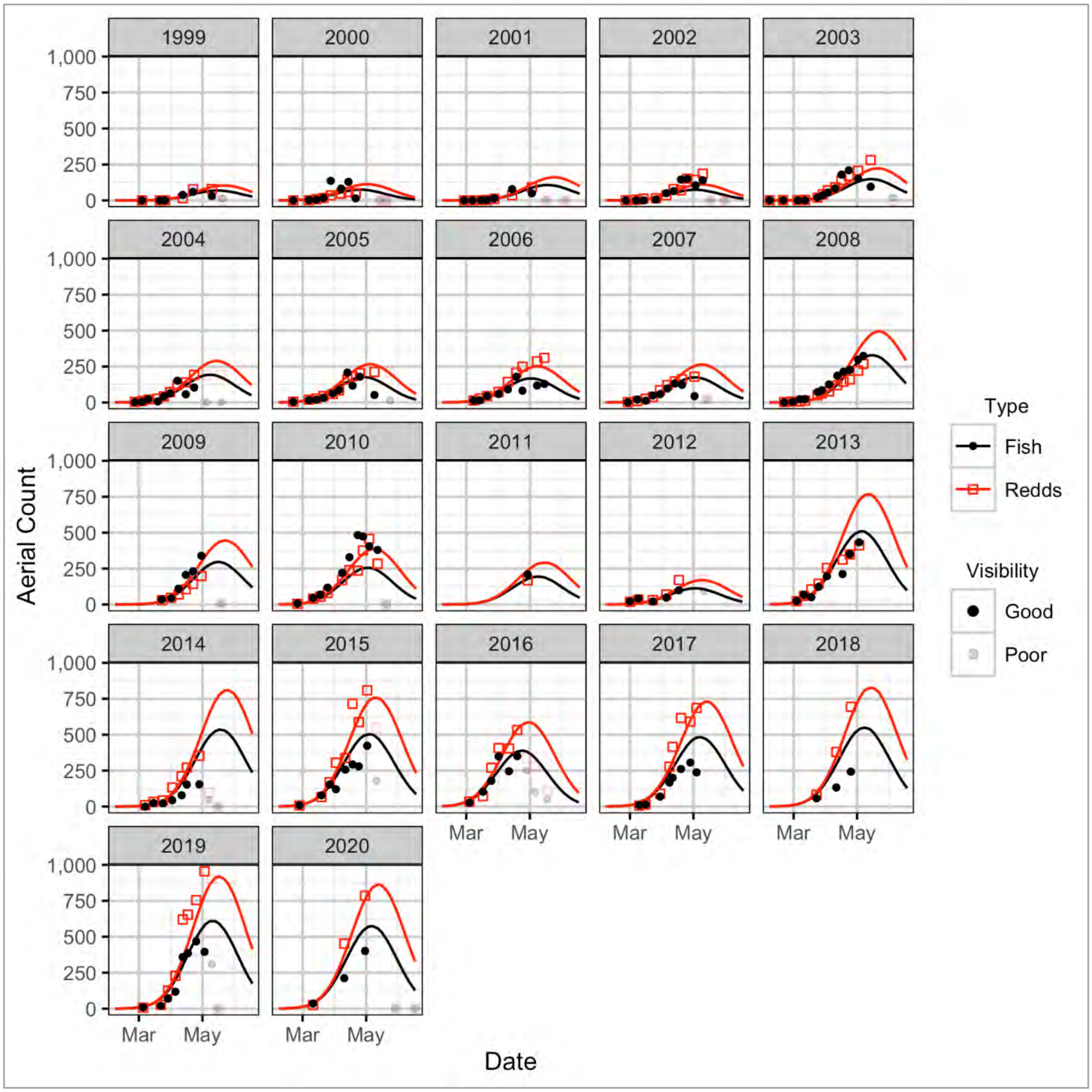

Figure B3. Predicted and actual aerial fish and redd counts at Lower Kootenay River by date and year.

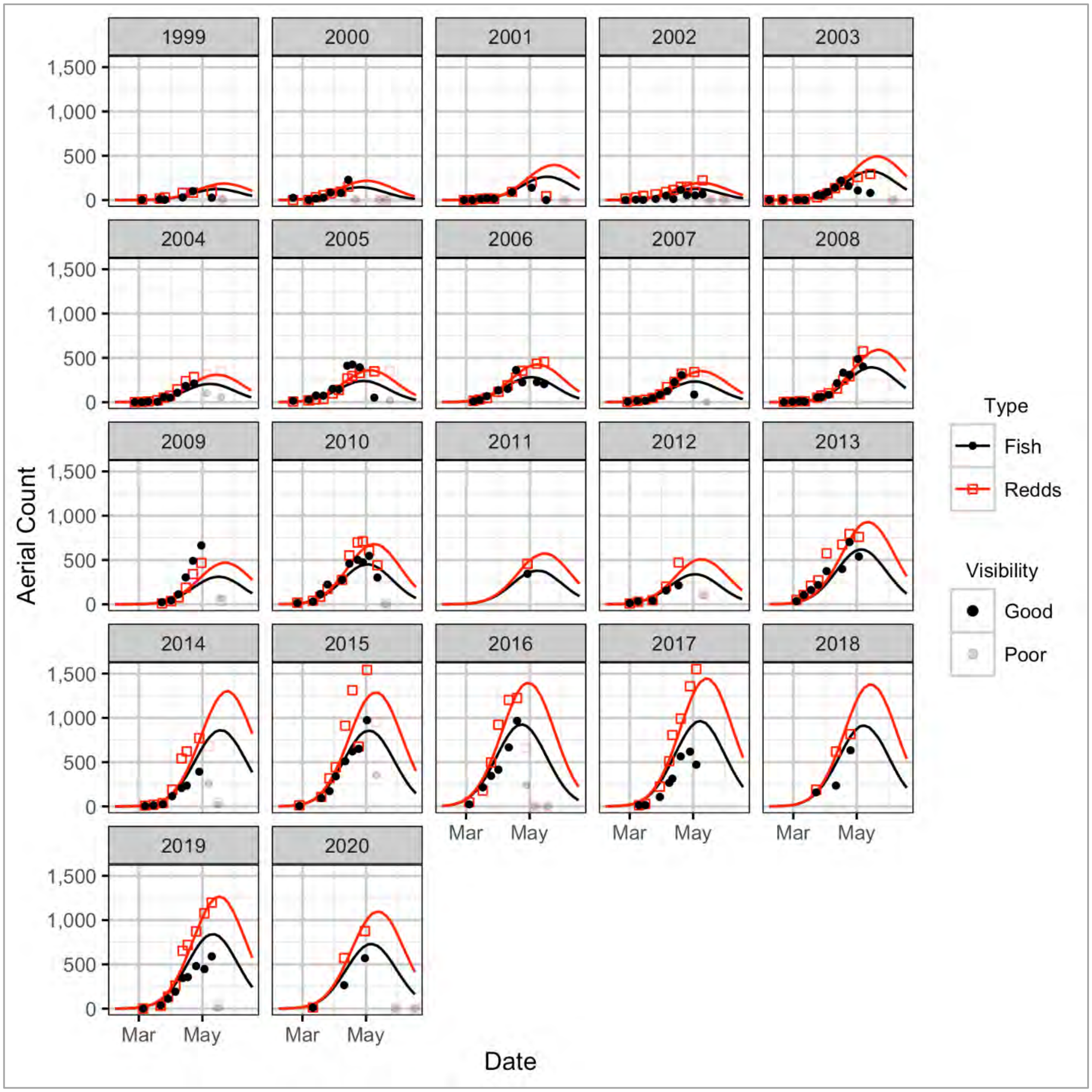

Figure B4. Predicted and actual aerial fish and redd counts in the section from Lower Kootenay River to Genelle by date and year.

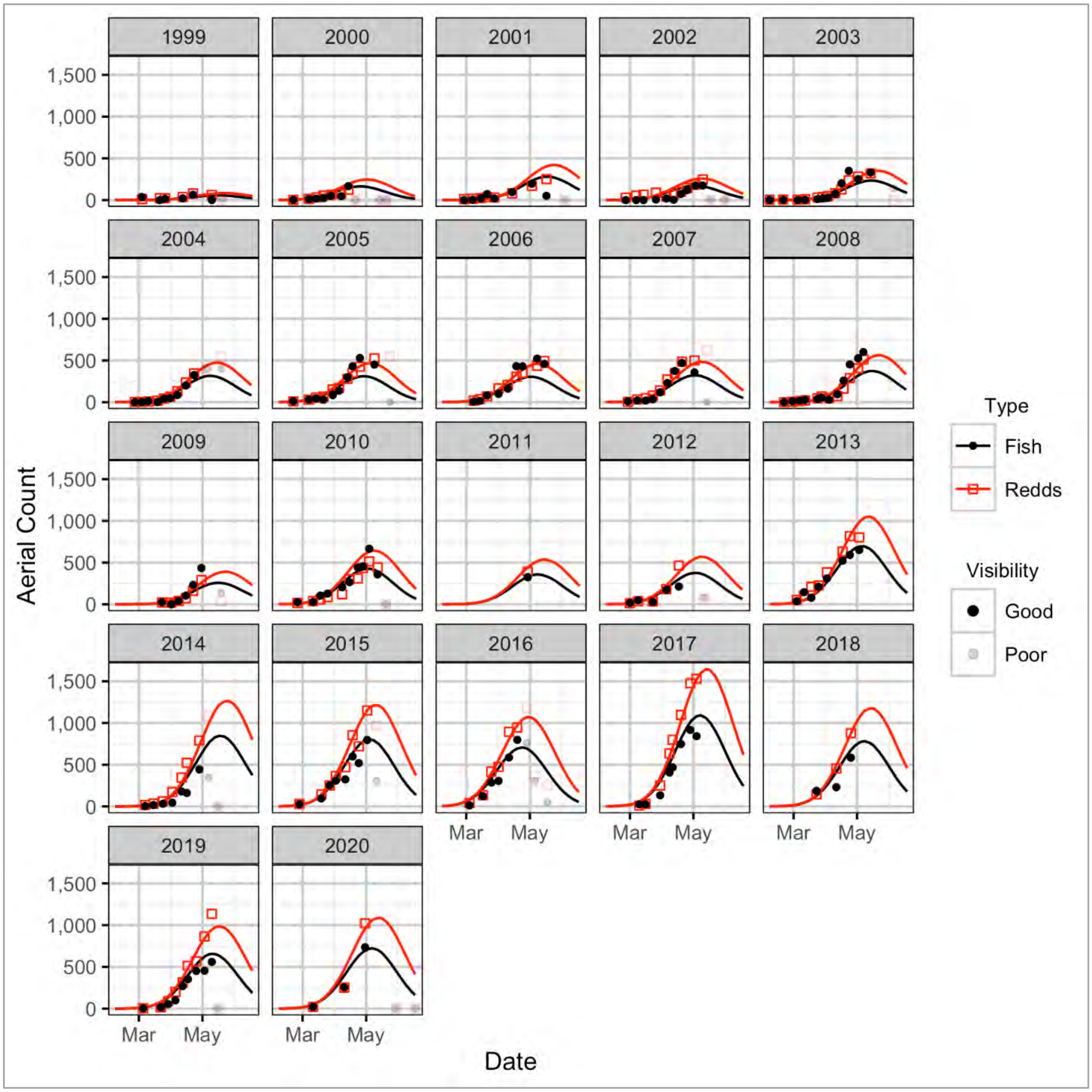

Figure B5. Predicted and actual aerial fish and redd counts at Genelle by date and year.

APPENDIX C

HISTORICAL DISCHARGE PLOT

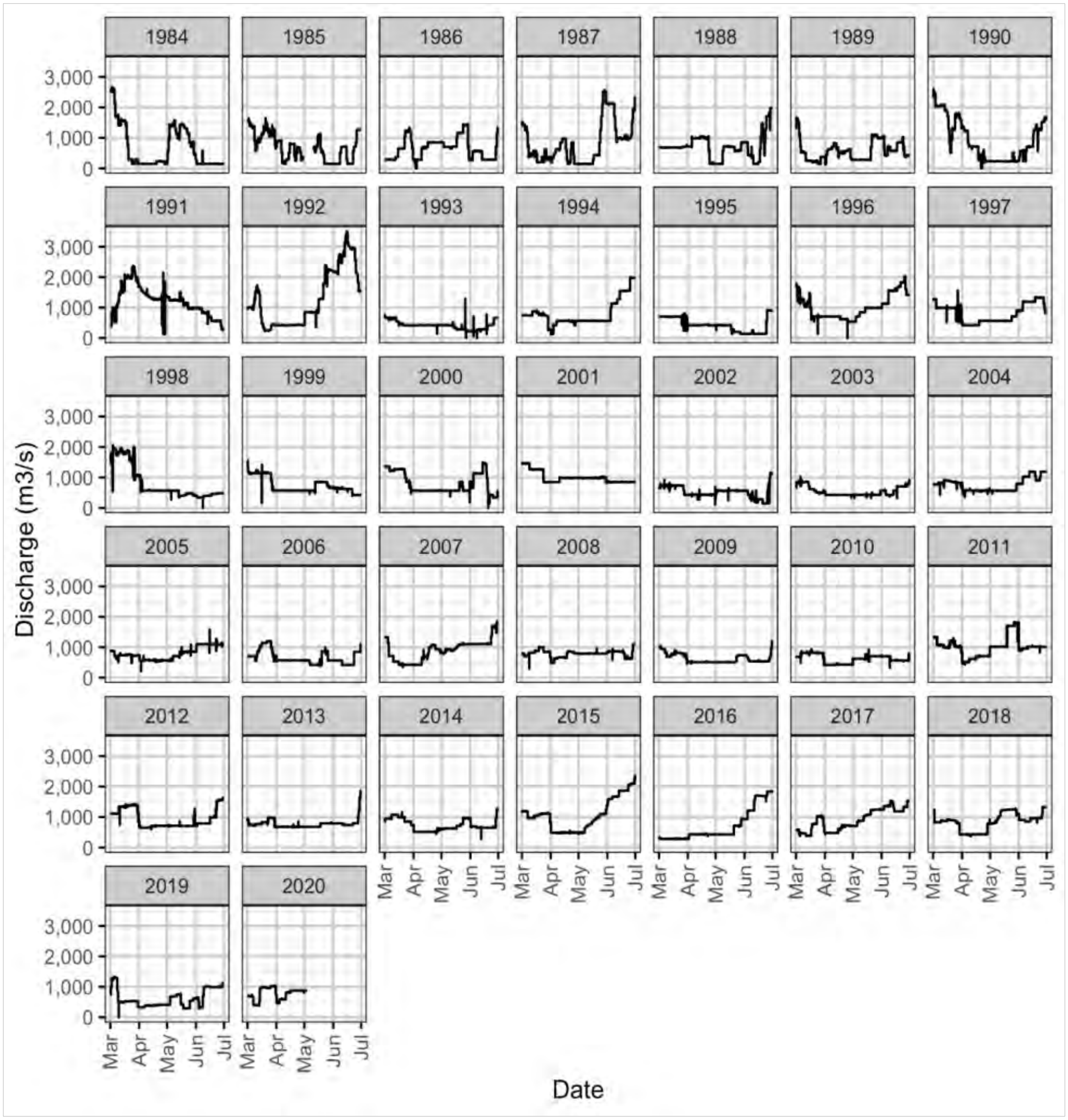

Figure C1. Hourly discharge at HLK Dam by date and year.

APPENDIX D

RAINBOW TROUT EGG STAGING GUIDE

Rainbow Trout Egg and Alevin Development Field Guide

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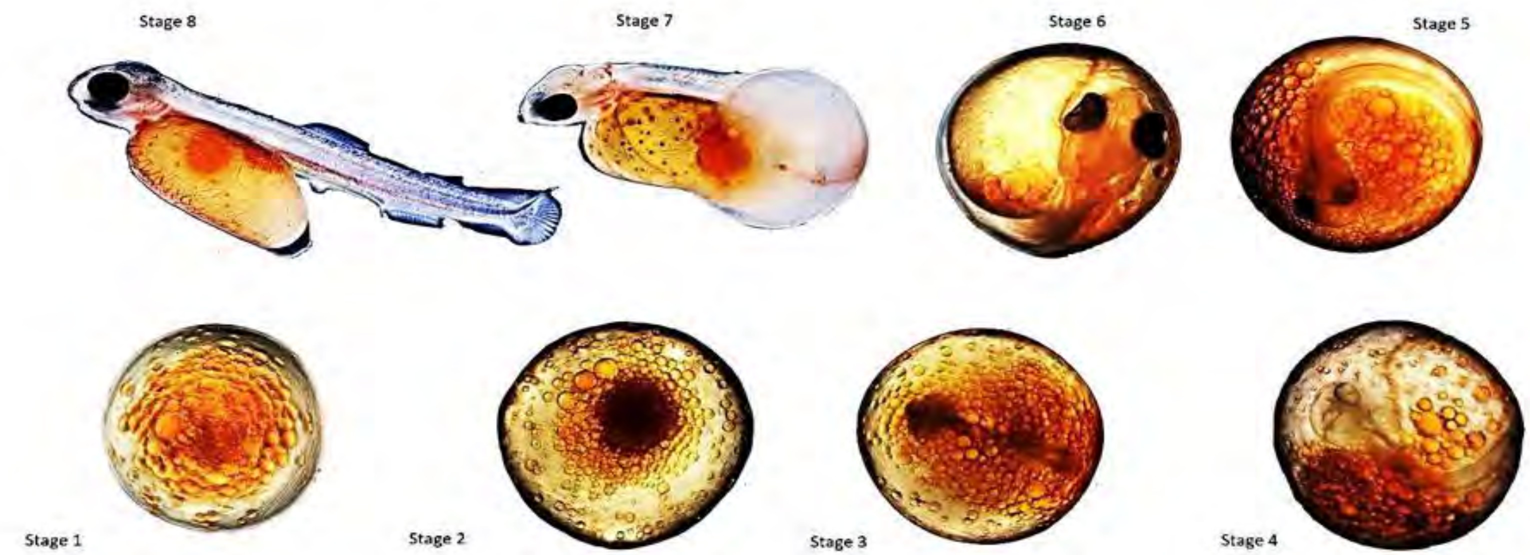
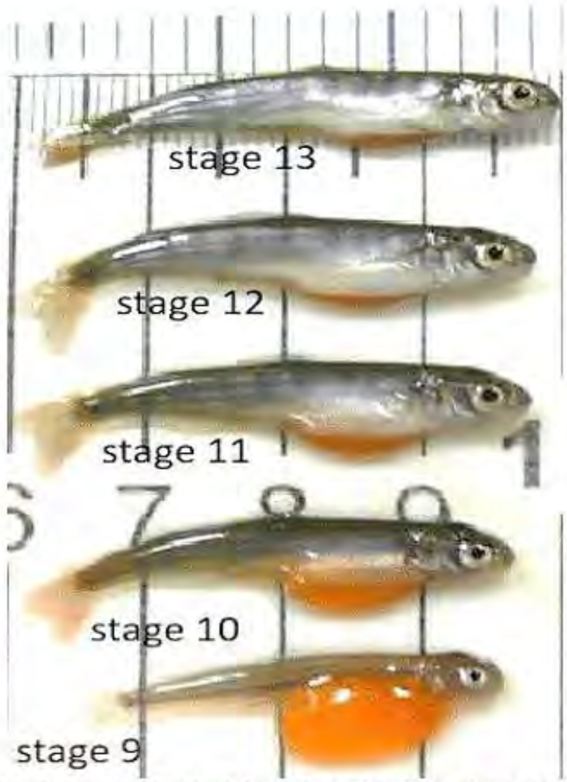


Stage	Description & development time based on 10°C (Days since fertilization)
1	Fertilization-Early Blastula (hours)
2	Blastula-Gastrula (12 hours to 6 days)
3	Embryo with ocular development (7 days)
4	Embryo with faint pigmentation of eyes (12 days)
5	Eyed - Full pigmentation of eyes (20 days)
6	Ready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