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Columbia River Project Water Use Plan

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

Reference: CLBMON-46 Implementation Year 4 (2022)

Prepared for:
BC Hydro
6911 Southpoint Drive, 11th Floor
Burnaby, BC V3N 4X8

Prepared by:

Poisson Consulting Ltd.
4216 Shasheen Road
Nelson, BC V1L 6X1
https://poissonconsulting.ca/

Mountain Water Research
107 Viola Crescent
Trail, BC V1R 1A1
https://fishtech.ca/

Nupqu Limited Partnership
7443 Mission Road
Cranbrook, BC V1C 7E5
https://nupqu.com/

January 4th, 2023

Nupqu Limited Partnership
7443 Mission Road
Cranbrook, BC V1C 7E5
T: 250.489.5762
F: 250.489.2091
www.nupqu.com

January 4th, 2023

BC Hydro
6911 Southpoint Drive, 11th Floor
Burnaby, BC V3N 4X8

Attention: Teri Neighbour – Natural Resource Specialist

Dear Teri,

Re: CLBMON-46 Lower Columbia River Rainbow Trout Spawning Assessment and Egg Mortality Study-Year 4

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 4 (2022) 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 4 of the 5-year study period. In 2022, 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:

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

Mark Fjeld
Aquatic Biologist/Project Manager
Nupqu Limited Partnership
250.919.6856
mfjeld@nupqu.com

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 the 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 Lower Kootenay River (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 the continued estimation of Rainbow Trout abundance and spawn timing, and the mapping of the spatial distribution within the study area.

RTSPF were not in place for 2022 resulting in the dewatering of 57 redds (representing ~ 0.3% of the estimated annual total).

Opportunistic egg mortality surveys took place at Norns Creek Fan with six out of a total of ten excavated redds containing eggs. The field crew observed 100% mortality in these six redds, four of which had been dewatered for ~ 46 days and experienced air temperatures as low as -9 ˚C. The remaining two had been dewatered for ~ 9 days and experienced air temperatures as low as -4 ˚C. 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 2022 were highest at Genelle (1000), Norn's Creek Fan (900), and left upstream bank at Norns Fan (750). 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 12,000 spawners in the mainstem of the LCR and LKR in 2022 (95% CIs from 8,700-18,000). Over the period of monitoring, there has been an eleven-fold increase from the estimated abundance of 950 spawners in 1999 to a peak of 12,000 spawners in 2022. 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 2022, the first redd was observed on February 7th during initial boat surveys. Based on the redd counts the model estimated that 2.5% of the total number of redds had been constructed by the 11th, 18th, or 21st of March (depending on river segment). The model also estimated that peak spawning occurred on May 14th and that 97.5% of the total number of redds had been constructed by the 8th, 11th, or 18th of July (depending on river segment). This spawn timing is similar to the previous 20 years of monitoring under CLBMON 46.

In 2022, no exclusion fencing was installed in Channel E at Genelle and spawning was allowed to occur at the site, resulting in 16 of 57 redds being dewatered.

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2.0	2023/01/04	Mark Fjeld	Final Report

TABLE OF CONTENTS

LIST OF TABLES (WITHIN TEXT)

LIST OF FIGURES (WITHIN TEXT)

LIST OF APPENDICES

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
CNN	Columbia River Below Norns Creek Water Level Station
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.
RTSPF	Rainbow Trout Spawning Protection Flows
UAV	Unmanned aerial vehicle (drone)
WUP	Water Use Plan

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
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

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 Lower Columbia River (LCR) and Lower Kootenay River (LKR) and the resulting impact of the egg mortality on Rainbow Trout population abundance (BC Hydro 2018). 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 eggs and alevins, and the effect of environmental conditions on inter-gravel temperatures in exposed redds.

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 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 (eleven-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 originally scheduled for 2020, exceptional environmental conditions required minor flow reductions within the spawning period. This mixture of stable or increasing flows and minor reductions resulted in ~ 1% redd dewatering. As RTSPF were not officially in place for 2020, the yearly alternation of flow protocols was shifted. In accordance with this shift, 2021 was designated as an RTSPF ‘on’ year and 2022 was designated as an RTSPF ‘off’ year.

In September 2021, a review of the RTSPF protocols was conducted to estimate the extent of potential redd dewatering in off-years, and to assess the feasibility of implementing targeted redd dewatering flows on the LCR. 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). Rainbow trout redd dewatering was estimated to increase to 3.5% with no RTSPF in place, a proportion highly unlikely to affect recruitment (Casselman and Thorley 2021).

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 all 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 analysis 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).

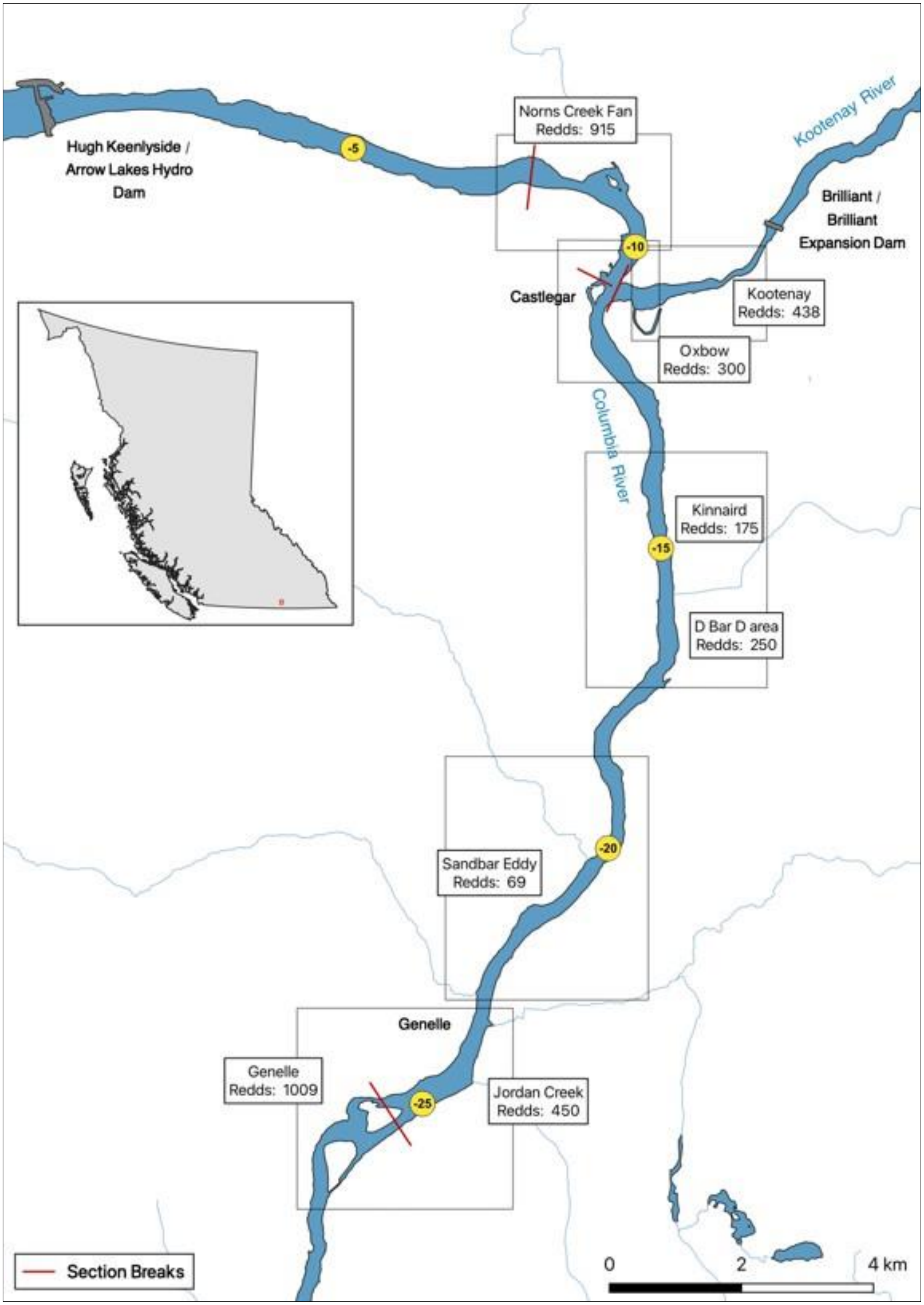

Figure 1. Overview map of the Lower Columbia River and Lower Kootenay River study area with 2022 peak count redd numbers by key area. The red lines indicate river section breaks. See Appendix A for detailed spawning maps of the outlined areas.

2.0 METHODS

2.1 Rainbow Trout Redd and Spawner Surveys

Rainbow Trout redds and spawners were monitored in the Lower Columbia River with ground, boat, drone, and helicopter surveys. Prior to the first helicopter and drone surveys in 2022, boat surveys were conducted 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 2022, 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 the spawning gravels.

Table 1 Helicopter survey dates completed during active spawning including descending limb in 2022.

Survey Date (YY/MM/DD)	Survey Locations	Total Redd Count	Total Spawners
2022-03-07	LCR above LKR, LKR, LCR below LKR	81	132
2022-03-23	LCR above LKR, LKR, LCR below LKR	464	394
2022-03-30	LCR above LKR, LKR, LCR below LKR	943	465
2022-04-05	LCR above LKR, LKR, LCR below LKR	955	571
2022-04-13	LCR above LKR, LKR, LCR below LKR	2151	627
2022-04-22	LCR above LKR, LKR, LCR below LKR	3150	1264
2022-04-29	LCR above LKR, LKR, LCR below LKR	3634	2016
2022-05-06	LCR above LKR, LKR, LCR below LKR	2147	820
2022-05-20	LCR above LKR, LKR, LCR below LKR	1324	565
2022-05-27	LCR above LKR, LKR, LCR below LKR	1535	672
2022-06-04	LCR above LKR, LKR, LCR below LKR	556	230

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 7th and were completed April 30th. A total of 133 redds were identified as having the potential to dewater from subsequent flow reductions. Shallow redd surveys ended in early April as stable or increasing flows were anticipated 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 and mapping redds at the Norn’s Creek Fan area. A total of 14 drone surveys were conducted between March 18th and June 16th, 2022, 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, geolocated, and stitched together using image analysis software 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 per pixel) 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, then a spatial layer of points was then created to represent the locations of all redds and redd clusters identified within the habitat. Unanticipated turbidity and surface disturbance prevented the digitization of redds for 1 of the 12 drone surveys performed at Norns Creek Fan. As of 2022, redds within the Columbia River thalweg adjacent to Norns Creek fan are no longer digitized, as turbidity and depth issues do not allow for consistent visibility. 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, except for 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.

Drone surveys were also intended as a supplementary method of assessing dewatering at Norns Creek Fan. However, due to changes in the topography at the site since the time the Digital Elevation Model was developed, small inaccuracies in elevation resulted in errors when dewatering was calculated, especially in areas of low slope gradient. As a result, no estimation of dewatering for drone counted redds is included in 2022. An updated digital elevation model is required to correctly calculate dewatering at Norns Creek Fan. A simple approach would be to conduct a drone-based LiDAR or photogrammetric survey during one of the scheduled weekly drone surveys to capture elevations for all substrate above the water's edge. If timed appropriately for low water in the spring, this would allow for the development of an updated Digital Elevation Model capturing the majority of the available habitat at Norns Creek Fan.

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 2022 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).

Table 2 Reduction dates, magnitude of reduction, number, and general location of dewatered redds in 2022.

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
2022-02-26	1436	974	728	719	10	Norns Creek Fan
2022-03-12	962	591	715	713	5	Norns Creek Fan
2022-04-08	616	285	592	581	26	Norns Creek Fan
2022-04-08	616	285	592	581	16	Genelle Ch. E

**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. Due to poor visibility and high discharge the Norn's Creek survey was not completed in 2022. The results of previous snorkel survey estimates can be found in the 2021 report (Amies-Galonski et al. 2022).

2.2 Egg and Alevin Mortality Surveys

Egg and alevin mortality surveys were initiated in 2019 and took place opportunistically in 2019, 2020 and 2022 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. In 2022, the egg mortality survey methods were updated. Each redd was only excavated a single time due to the possibility that exposure and mechanical force caused by the excavation process could impact egg survival in subsequent surveys. A total of ten Rainbow trout redds were excavated at Norns Creek Fan in 2022. 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 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.

On March 28th, 2022, an Onset Hobo MX2001 level logger was installed at the bottom end of Channel E at Genelle to improve the understanding of how various discharges from the LCR and LKR influence river stage at Channel E and how Rainbow Trout spawners respond to various flows at this site. A Tidbit V2 logger gravel temperature station was also installed in Channel E (Figure 4). The level logger is not yet tied into any elevation benchmarks and is currently recording raw elevation in meters. The Channel E level logger station will be upgraded to an RX3000 monitoring station prior to the 2023 spawning season. On April 4th, 2022 an elevation survey was conducted in Channel E at Genelle to provide a preliminary understanding of the topography in the channel. Additional elevational data of Channel E may be collected in 2023 to aid field crews in predicting stranding and dewatering events.

2.5 Genelle Channel E

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 'on' years. Observations from historical surveys estimate that approximately 100 additional redds may dewater without the installation of the exclusion fence (Thorley et al. 2017). At various times of the year, the forebay at BRD is used for shaping power generation. Load shaping at BRD matches peak generation with peak load needs, such as in the evening. This results in daily fluctuations in flow that affect river stage downstream. Historically, the load shaping from the BRD after RTSPF's are implemented at HLK in April, is the primary reason the Channel E fence is installed. If Channel E is at vulnerable elevations (between 35 kcfs and 38 kcfs at BIR) spawners can enter the channel and construct redds as flows increase from load shaping at BRD. These spawners can become stranded and newly constructed redds can dewater daily as the water levels are reduced during load shaping from BRD. The study team, BC Hydro environmental staff, and Columbia Power Corporation staff collectively decided not to install the Channel E fence in 2022 and allow redds to be constructed. Subsequent redd dewatering in Channel E would be valuable in reducing uncertainties associated with egg mortality from dewatered redds as part of the CLMBON-46 study. Any stranded spawners observed in Channel E because of load shaping from BRD were to be salvaged and placed back into the mainstem Columbia River with monitoring to occur daily as required. In 2022 a total of 16 redds were dewatered at Channel E and no spawner salvage was necessary.

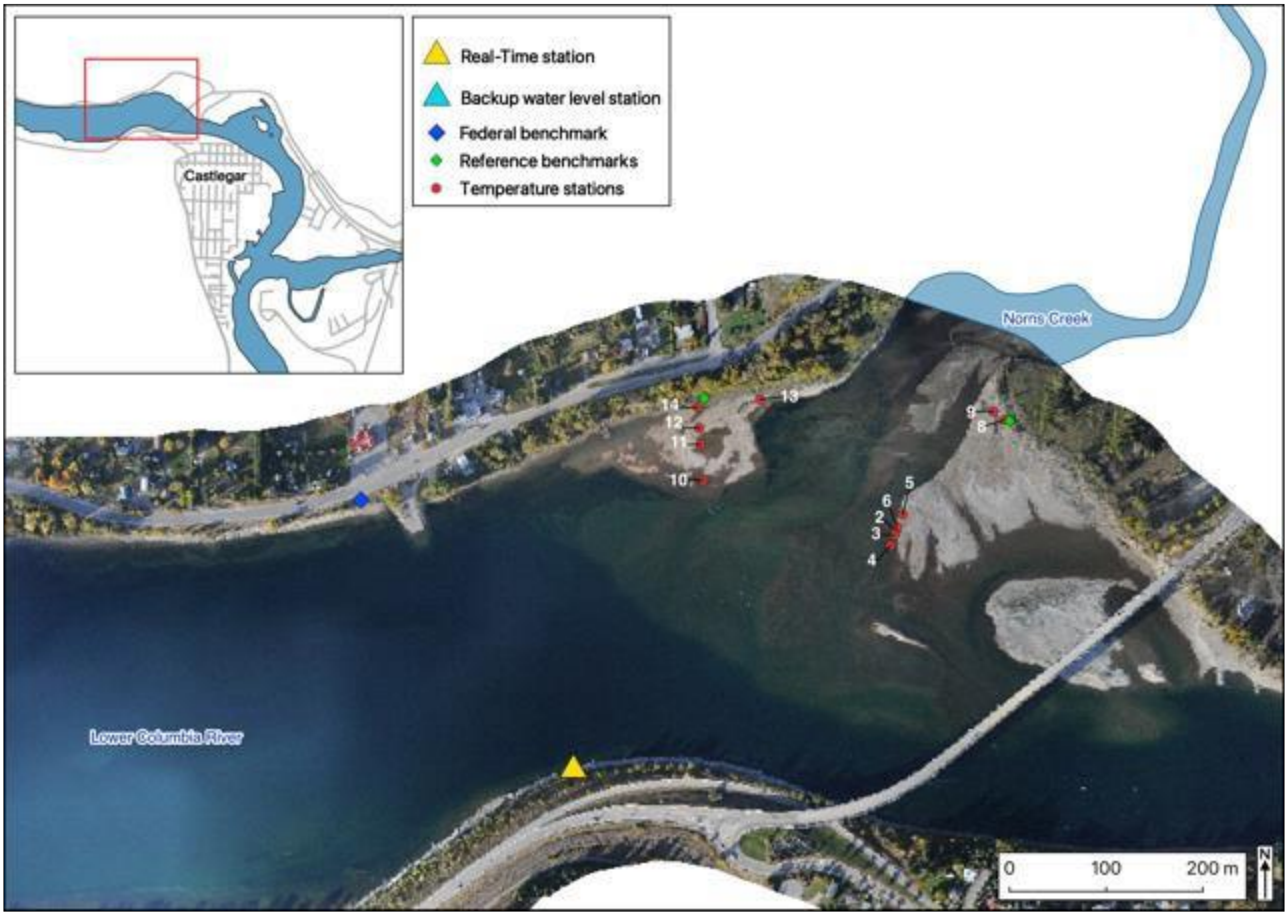

Figure 2. Monitoring stations on the Lower Columbia River at Norn's Creek Fan.

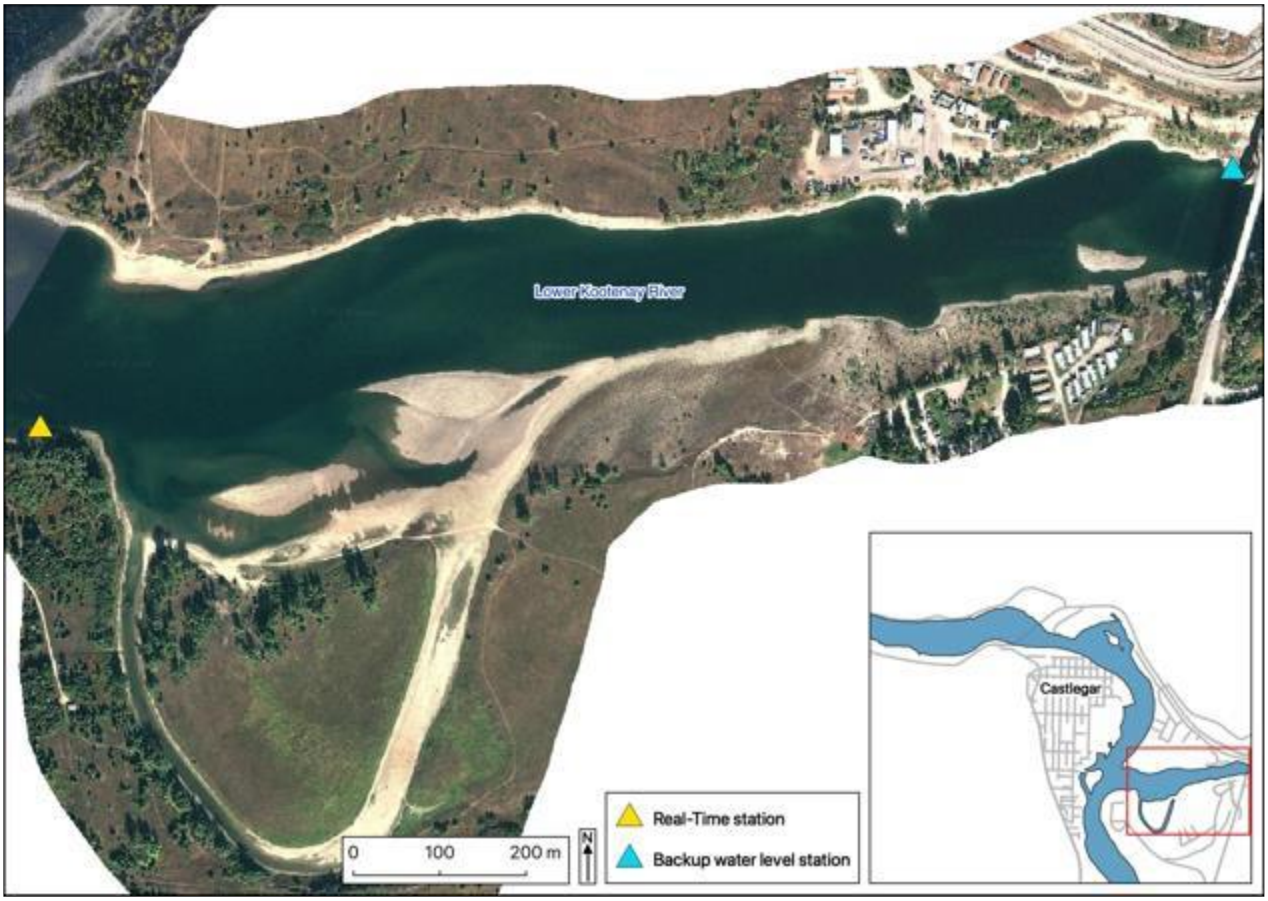

Figure 3. Monitoring stations on the Lower Kootenay River at the Oxbow.

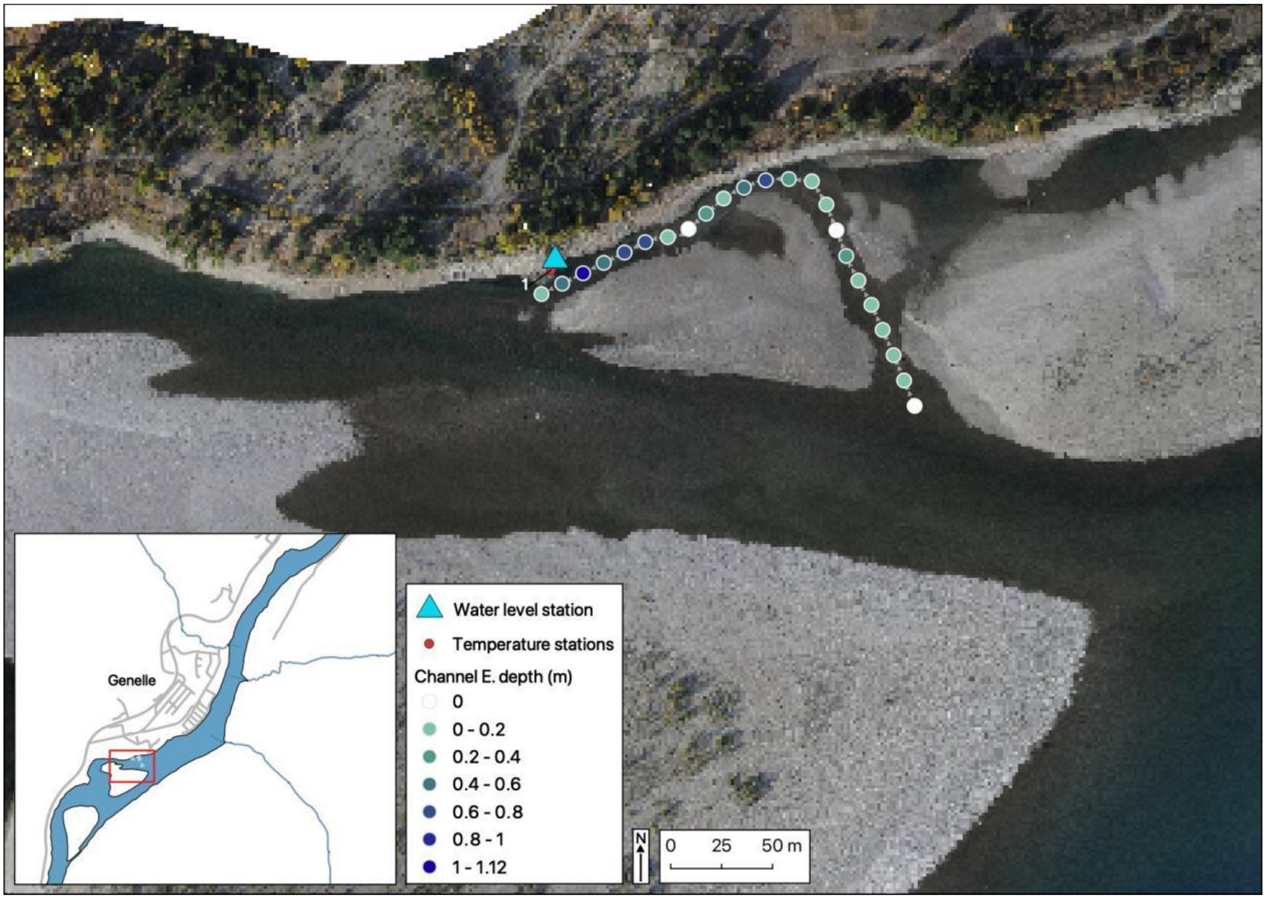

Figure 4. Monitoring stations on the Lower Columbia River at Genelle with depth transect at Channel E. The depths displayed are relative to the level at which the head end of the channel is dewatered.

2.6 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, Poisson Consulting and Nupqu.

The real-time stations continuously transmitted all sensor data to a project specific HOBOlink account where it was securely stored online. 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 4.2.1 (R Core Team 2022) and entered into a customized SQLite database.

2.7 Statistical Analysis

Model parameters were estimated using Bayesian methods. The estimates were produced using JAGS (Plummer 2017) 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, lower and upper 95% compatibility limits (CLs) (Rafi and Greenland 2020) and the surprisal s-value (Greenland 2019). The estimate is the median (50th percentile) of the MCMC samples while the 95% CLs are the 2.5th and 97.5th percentiles. The s-value indicates how surprising it would be to discover that the true value of the parameter is in the opposite direction to the estimate (Greenland 2019). An s-value of > 4.3 bits, which is equivalent to a significant p-value < 0.05 (Kery and Schaub 2011; Greenland and Poole 2013), indicates that the surprise would be equivalent to throwing at least 4.3 heads in a row.

The condition that parameters describing the effects of secondary (nuisance) explanatory variable(s) have significant p-values was used as a model selection heuristic (Kery and Schaub 2011). Based on a similar argument, the condition that random effects have a standard deviation with a lower 95% compatibility interval (CL) > 5% of the estimate was used as an additional model selection heuristic.

Model adequacy was assessed via posterior predictive checks (Kery and Schaub 2011). More specifically, the first four central moments (mean, variance, skewness and kurtosis) and where relevant the number of zeros for the deviance residuals were compared to the expected values by simulating new residuals. In this context the s-value indicates how surprising each observed metric is given the estimated posterior probability distribution for the residual variation.

Where computationally practical, the sensitivity of the parameters to the choice of prior distributions was evaluated by increasing the standard deviations of all normal, half-normal and log-normal priors by an order of magnitude and then using r-hat to evaluate whether the samples were drawn from the same posterior distribution (Thorley and Andrusak 2017).

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% compatibility intervals (CIs) (Bradford et al. 2005).

The analyses were implemented using R version 4.2.1 (R Core Team 2022) and the mbr family of packages.

2.7.1 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 randomly 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 river segment within year.
- Peak spawner arrival timing varies randomly by section and 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.

In 2017 when the AUC model code was converted from JAGS to STAN an indexing error was introduced into the estimates of spawner abundance and spawner arrival duration by section. The error, which had relatively minor consequences for the AUC and resulting redd dewatering estimates, was corrected in 2022. In 2022, a correction was also made to the visibilities for an aerial survey from 2021. The visibilities on 2021-05-21 for the survey sections downstream from the LKR were corrected from 'Good' to 'Poor'.

2.7.2 Stock-recruitment Relationship

2.7.2.1 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.

2.7.2.2 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/1901991895*.

3.1 Redd and Spawner Abundance

As in previous years, the areas with the most spawning in 2022 were Genelle (1,009 redds; Figure 1) and Norn's Creek Fan (915 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 12,100 fish spawned in the LCR and LKR mainstem in 2022 (95% CIs from 8,700 - 18,100). Over the period of monitoring, there has been an eleven-fold increase from an estimated abundance of 950 (95% CIs from 700 - 1,450) spawners in 1999 to the 12,100 spawners in 2022. The abundance has been relatively stable since 2013 with broadly overlapping CIs among years. (Figure 5).

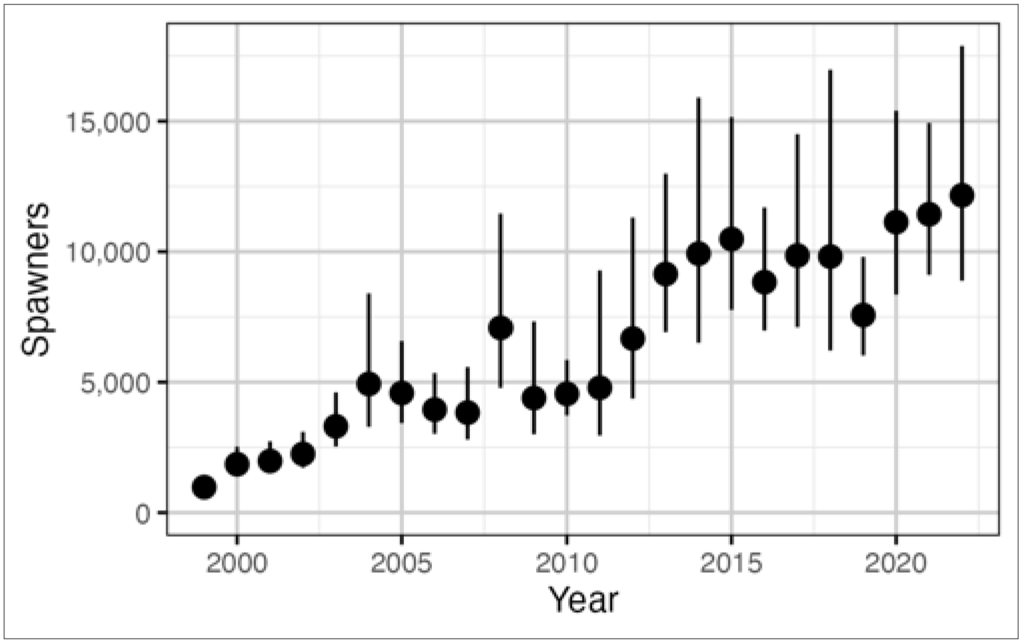

Figure 5. Estimated total spawner abundance by year with 95% CIs.

3.3 Redd Dewatering

The discharge from HLK dam in 2022 underwent reductions that caused redd dewatering on the LCR in late February, mid-March, and early April (Figure 6). A total of 57 redds (Figure 7) were dewatered by these reductions corresponding to 0.3% of the estimated total number of redds (95% CI 0.2-0.5%; Figure 7 and Figure 8). In 2022, all redd dewatering occurred at Norns Creek Fan except for a single dewatering event at Genelle in Channel E on April 9th when 16 redds dewatered from an HLK reduction (Table 2). Current and historical discharge time series for HLK dam are available in Appendix C.

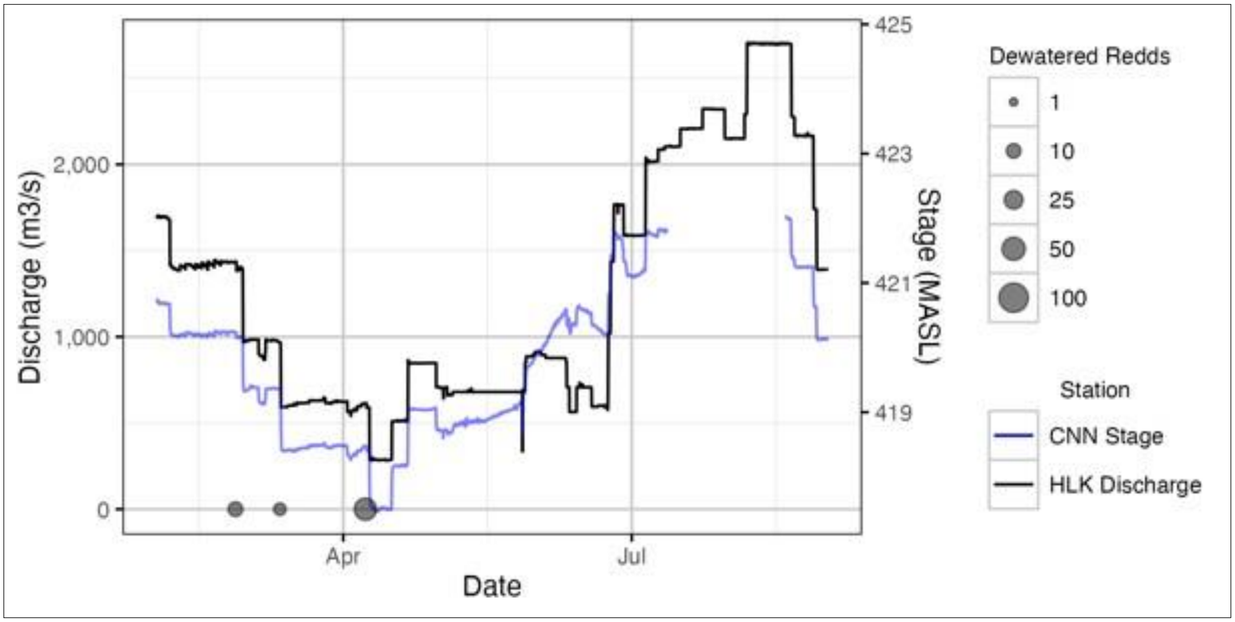

Figure 6. Discharge at HLK and stage at CNN and number of dewatered redds by date of dewatering in 2022.

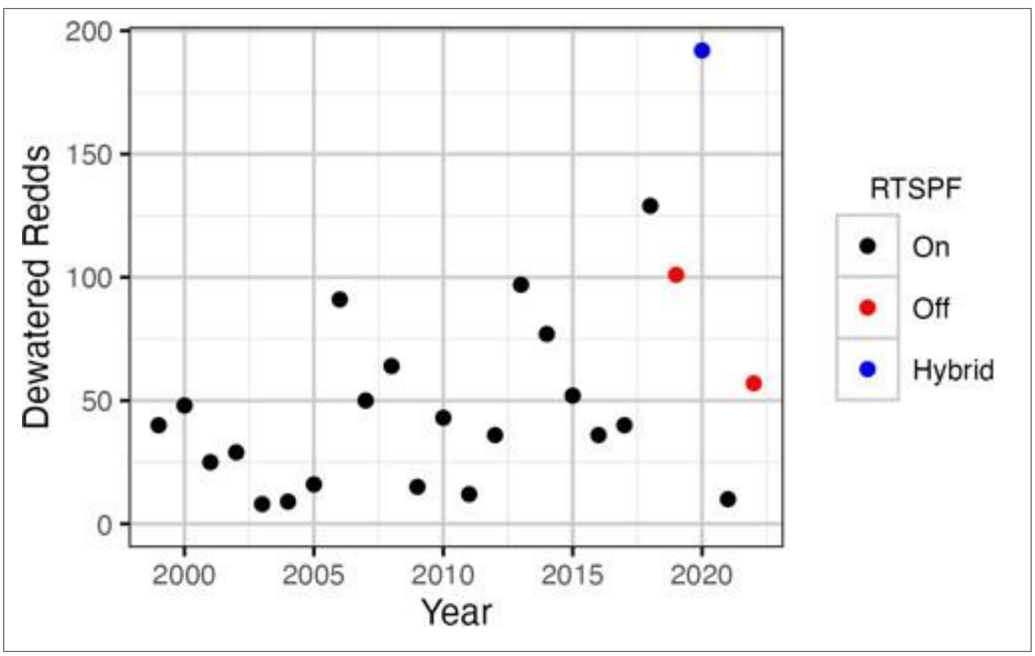

Figure 7. Actual number of enumerated dewatered redds by year and RTSPF protocol.

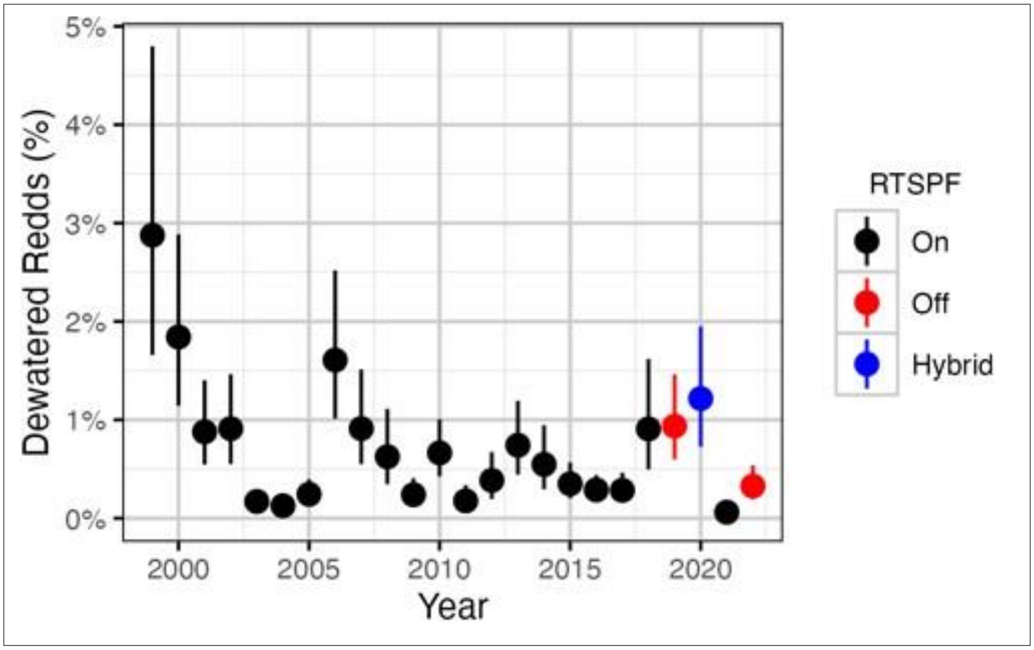

Figure 8. Estimated percentage of redds dewatered with 95% Cis by year and RTSPF protocol.

3.4 Genelle Channel E.

The depth profile at Channel E following the direction of flow is plotted at the time of survey in Figure 9. Due to the varying topography, isolated pools form when river stage drops below the elevation of the channel's head end.

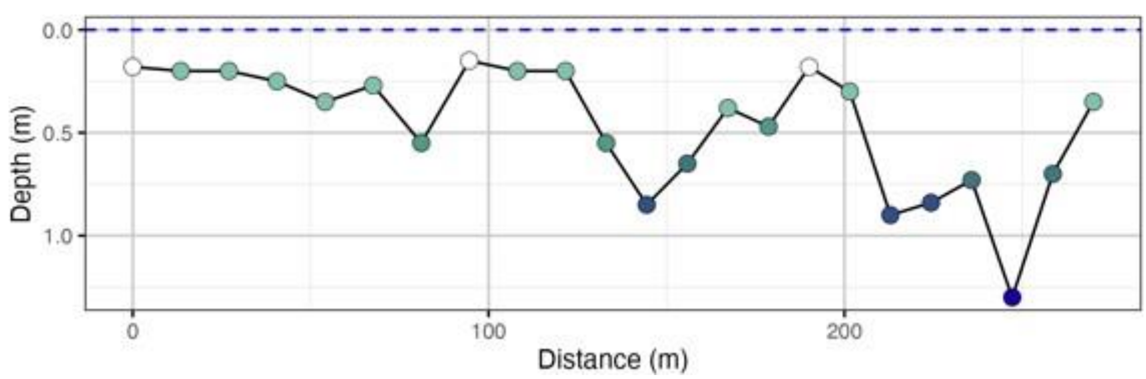

Figure 9. Depth profile of Channel E at Genelle at the time of the survey. Transect points follow the direction of flow starting at the head end and are colored to match the map of Channel E (Figure 4).

Columbia River stage at Birchbank and at the Genelle level logger station are plotted in Figure 10. The elevation cut-off for the Channel E head end is also displayed as a red dashed line. A disparity can be observed between the two stations when elevations drop below the cut-off at the head end of channel E (Figure 10). The pool at the base of channel E where the level logger is located retains water while the elevation in the main river channel continues to drop.

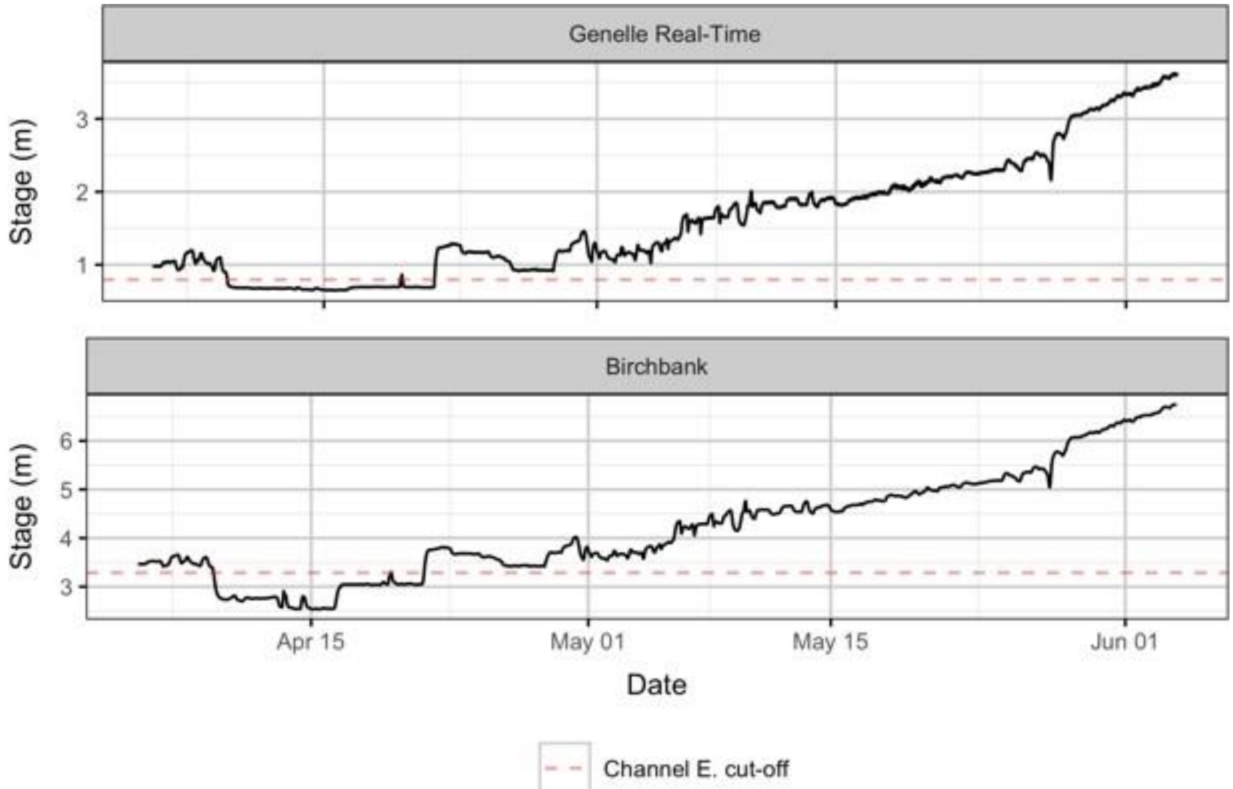

Figure 10. Columbia River stage at the Genelle real-time station and at Birchbank.The redd dashed line indicates the elevation for the zero-depth cut-off at the head end of Channel E.

BRD load shaping did not have an impact on Rainbow trout spawning in Channel E. Dewatering did occur at the site, but the LCR remained primarily above or below the vulnerable discharges at which BRD load shaping causes daily dewatering and re-wetting of the channel. Channel E remained dry for most of the BRD load shaping period in April and well below the discharge that allows spawners to enter the channel. Inflows increased substantially on April 21st, keeping Channel E wetted and above the cut-off at the channel head end (Figure 10). Peak counts of 248 redds and 77 spawners were observed at Channel E on May 6th, 2022.

3.5 Drone Based Monitoring

Redds mapped from drone imagery were related to river stage to provide a measure of the spatial and elevational distribution of redds within the habitat. Weekly drone surveys were carried out at Norn`s Creek Fan throughout the spawning period. All redds above the drop-off to the deeper LCR thalweg (414 MASL) were spatially digitized and are plotted in Figure 11 and Figure 12. The elevational distribution of redds is plotted in Figure 13. Due to inaccuracies in the DEM, the relationship between the redd elevations and river stage plotted in Figure 13 is not representative of the actual redd dewatering observed in the field.

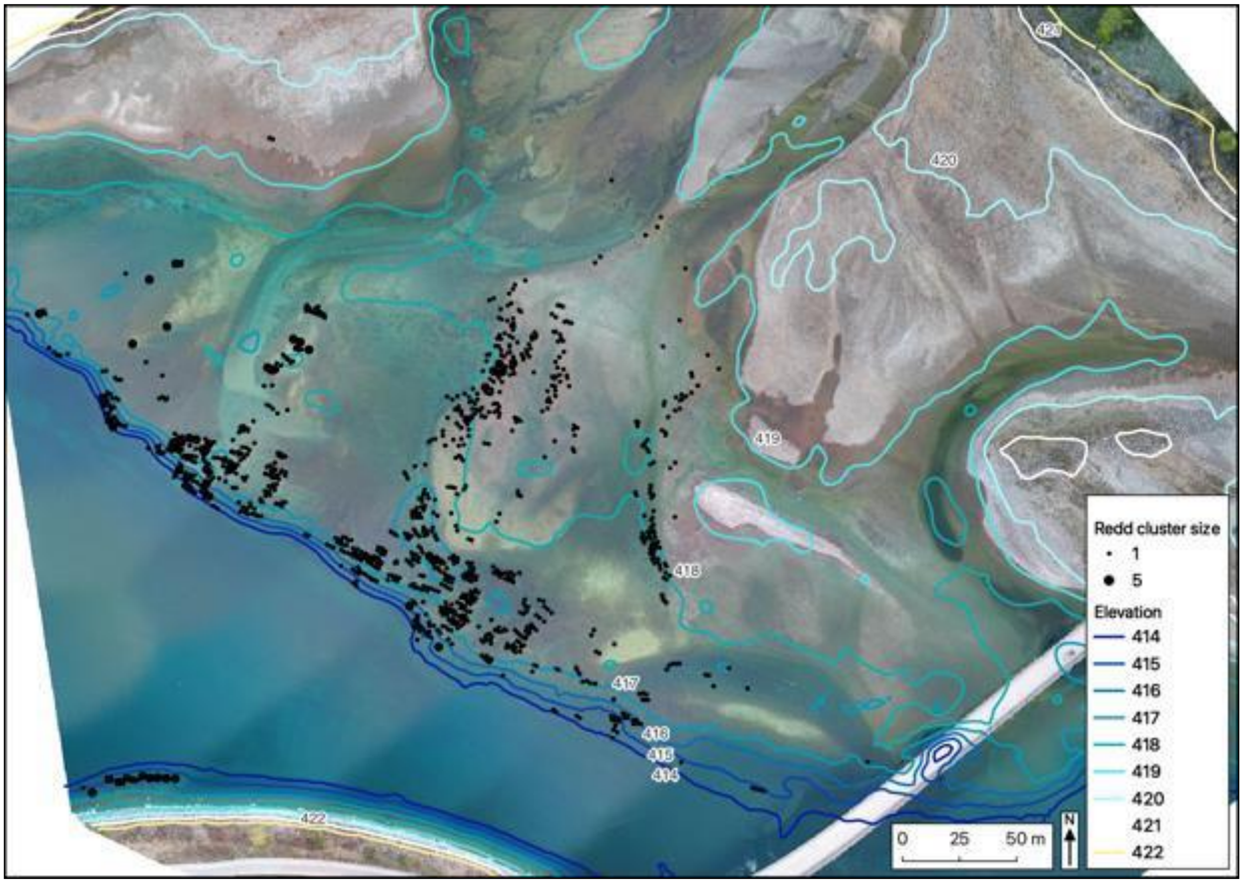

Figure 11. Cumulative redds identified at Norn's Creek Fan above the LCR thalweg drop-off (414 MASL) over 13 drone surveys in 2022.

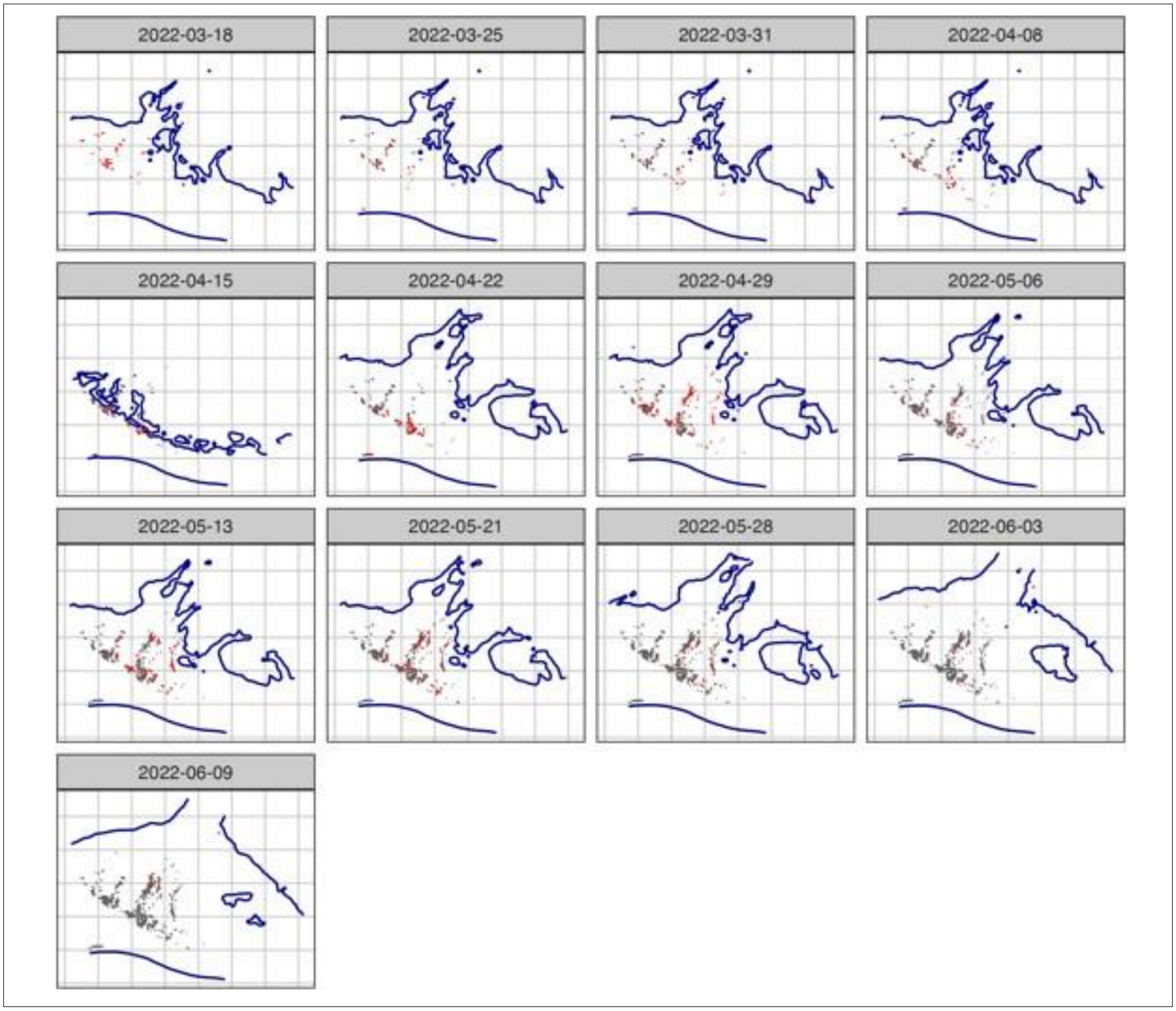

Figure 12. Accumulation of drone counted redds by date in 2022, with new redds highlighted in red. The wetted edge elevation contour is shown for each survey date.

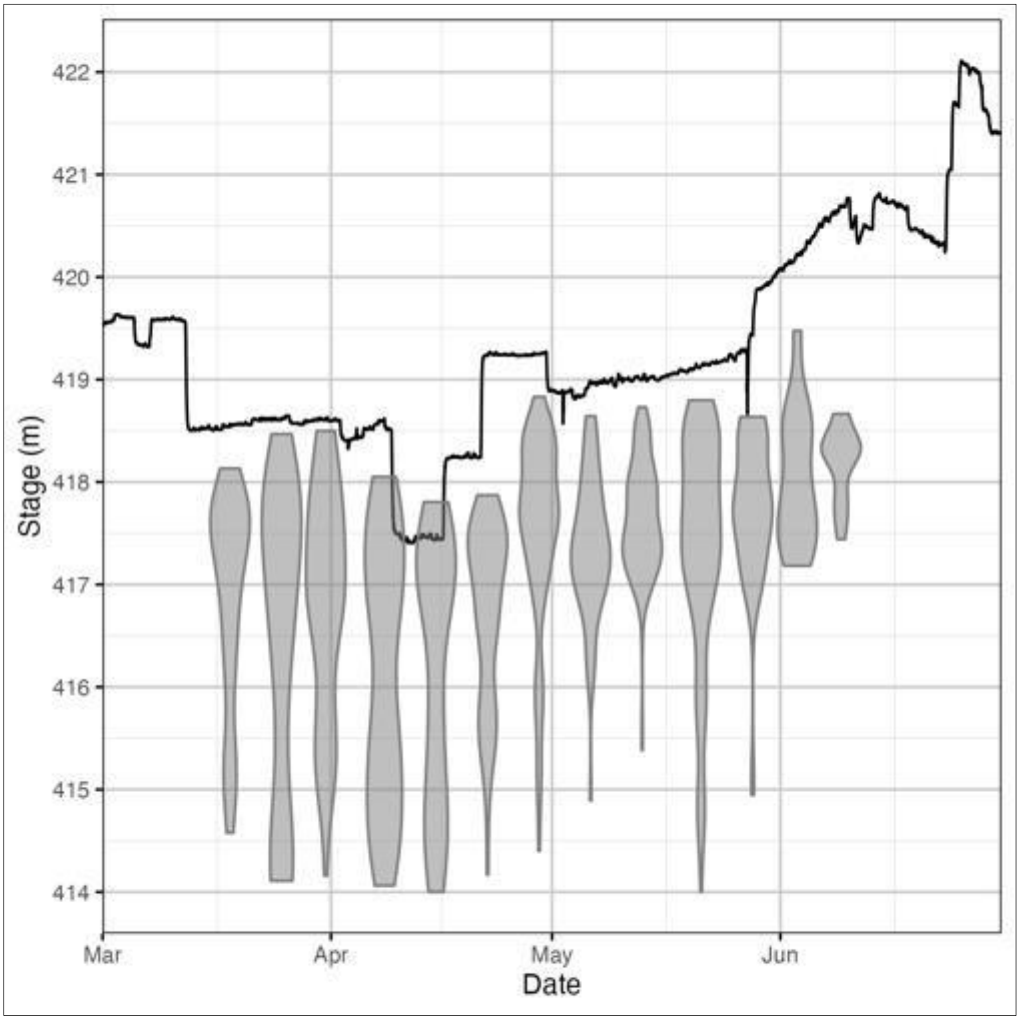

Figure 13. Elevational distribution of newly detected drone surveyed redds at Norn's Creek Fan above the drop-off to the Columbia River thalweg by survey date in 2022.

3.6 Egg Mortality

Mortality surveys took place opportunistically on April 18th, 2022, at Norns Creek Fan. The field crew observed 100% mortality in six of the ten redds excavated with the other four redds containing no eggs. Four out of six of the redds that contained eggs had been dewatered for ~ 46 days and experienced air temperatures as low as -9 ˚C. The remaining two redds had been dewatered for ~ 9 days and experienced air temperatures as low as -4 ˚C (Figure 14). In accordance with the change in methods for mortality surveys in 2022, only the data from the first excavation of each redd is displayed in Figure 14. No redd excavations took place at Genelle Channel E due to the relatively short duration of dewatering. 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 mortality.

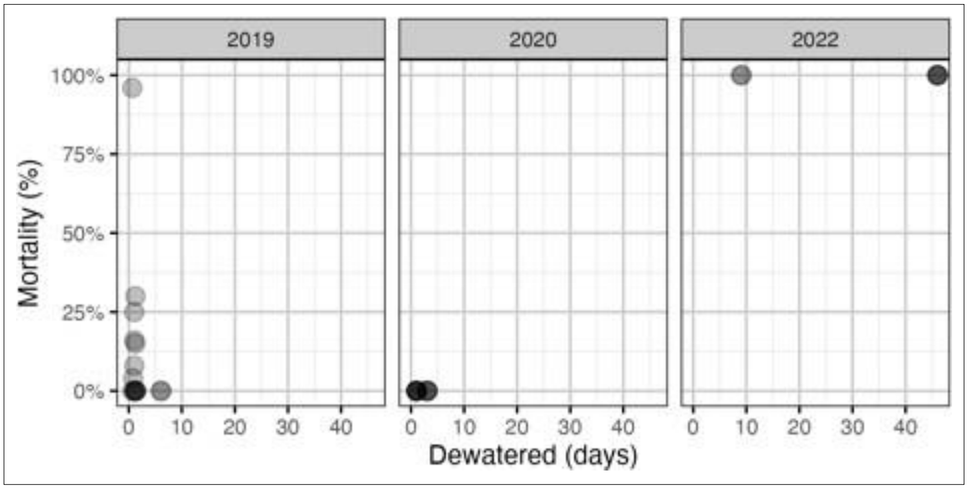

Figure 14. Observed egg mortality in natural redds by days dewatered in 2019, 2020, and 2022.

3.7 Spawn Timing

Spawn timing has been generally stable through the period of monitoring with minor fluctuations among years (Figure 15). The 2022 spawn timing window was comparable to recent years with an estimated duration of 115, 129, or 109 days at NCF to LKR, LKR and LKR to Genelle, respectively. Spawning was estimated to 'start' (2.5% of spawning) on the 18th, 11th, or 21st of March depending on river segment, peak on May 14th (95% CIs ranged from the 6th of May to the 24th of May), and 'end' (97.5% of spawning) on the 11th, 18st, or 8th of July depending on the river segment (Figure 15).

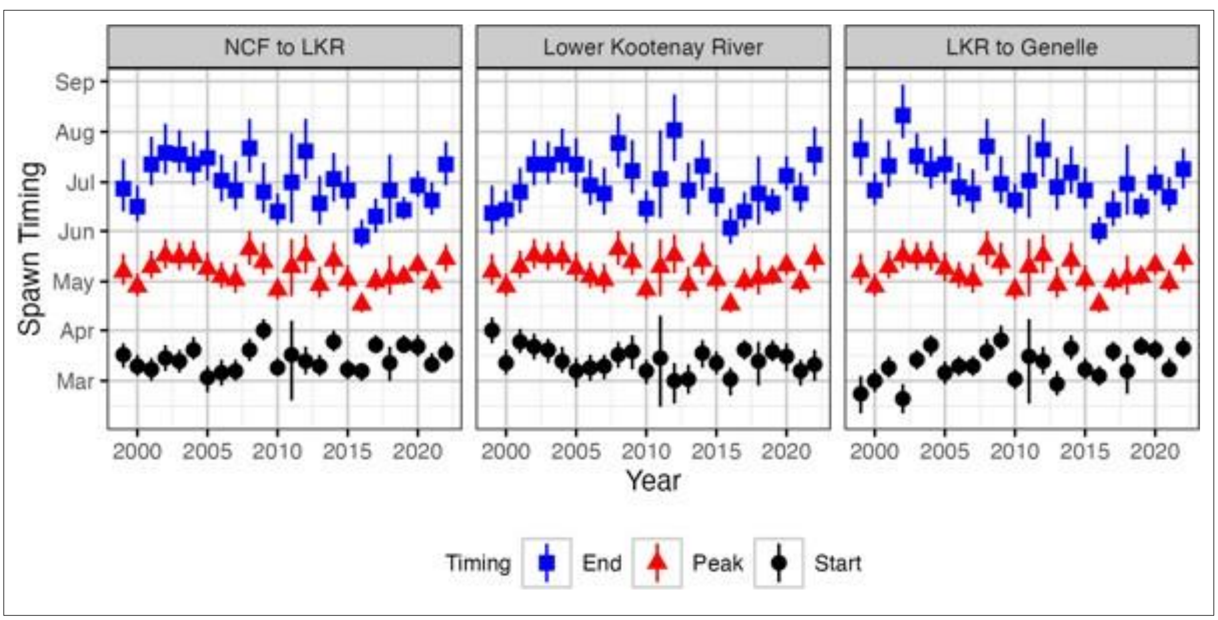

Figure 15. Estimated start (2.5% of spawners arrived), peak and end (2.5% of spawners remaining) spawn timing by year and segment with 95% CIs.

3.8 Stock Recruitment

The Beverton-Holt stock recruitment models fitted to age-1 Rainbow Trout abundance suggest density-dependent survival (Figure 16 and Figure 17). 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 has tended to decrease with higher stock abundance.

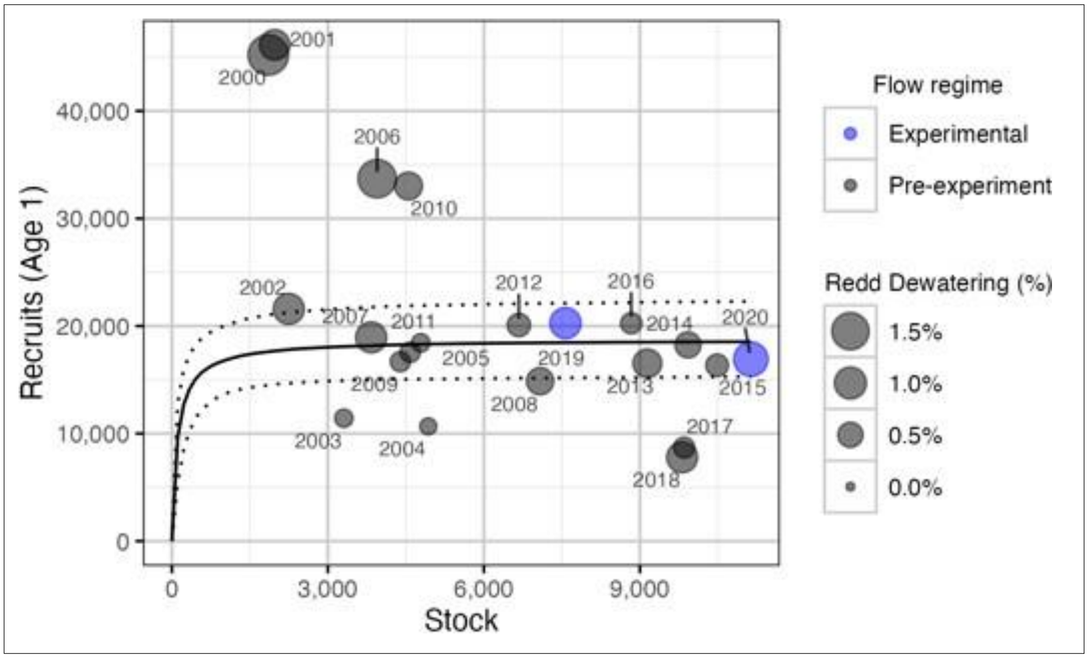

Figure 16. Predicted stock-recruitment relationship from spawners to subsequent age-1 recruits by spawn year with 95% CIs.

The number of age-1 recruits was positively correlated with the proportion of dewatered redds (Figure 16) 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 the proportion of redds dewatered and the number of recruits declined overtime.

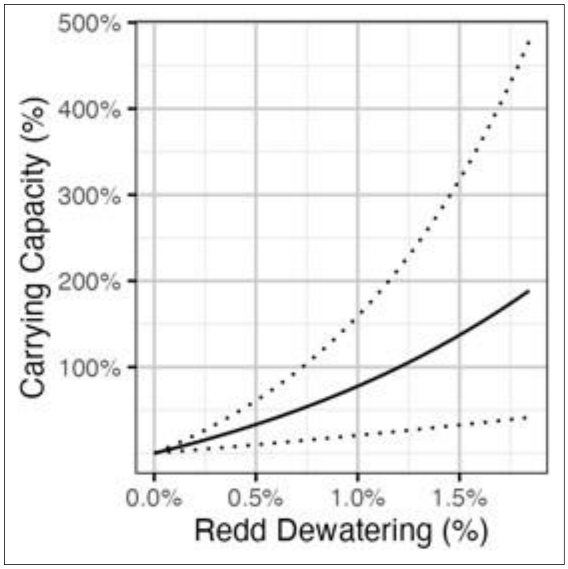

Figure 17. Predicted change in the age-1 recruits carrying capacity vs. percentage egg dewatering with 95% CRIs.

The stock recruitment curve for eggs shows a similar relationship, with the addition that it accounts for spawner fecundity (Figure 18). A similar positive correlation between dewatering and change in the carrying capacity is also observable (Figure 19).

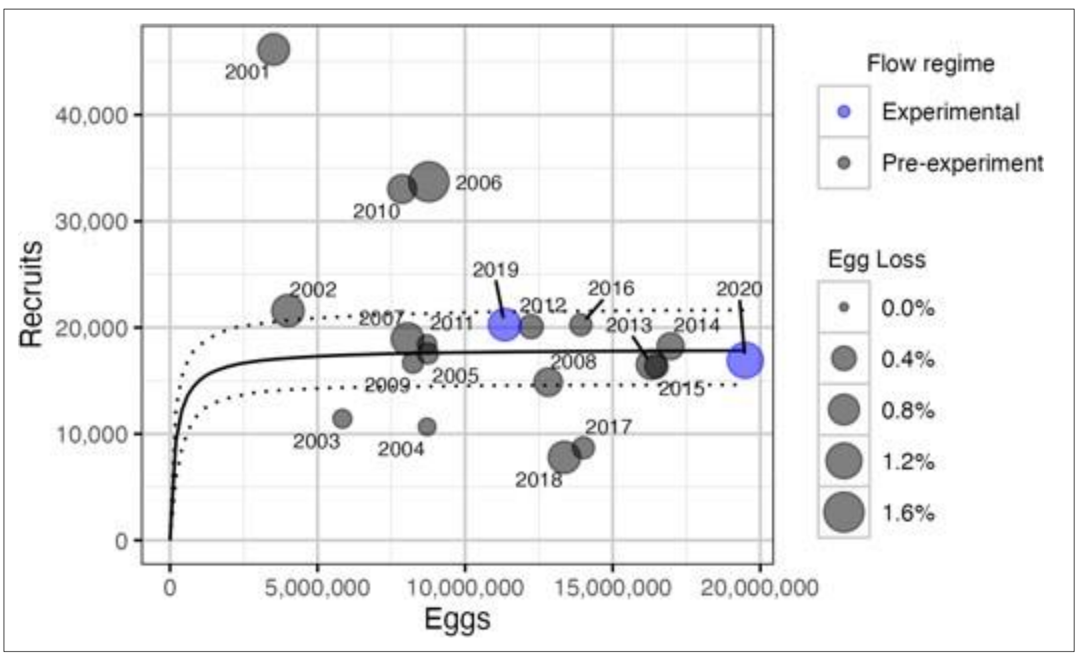

Figure 18. Predicted eggs to age-1 recruits stock-recruitment relationship by spawn year (with 95% CRIs).

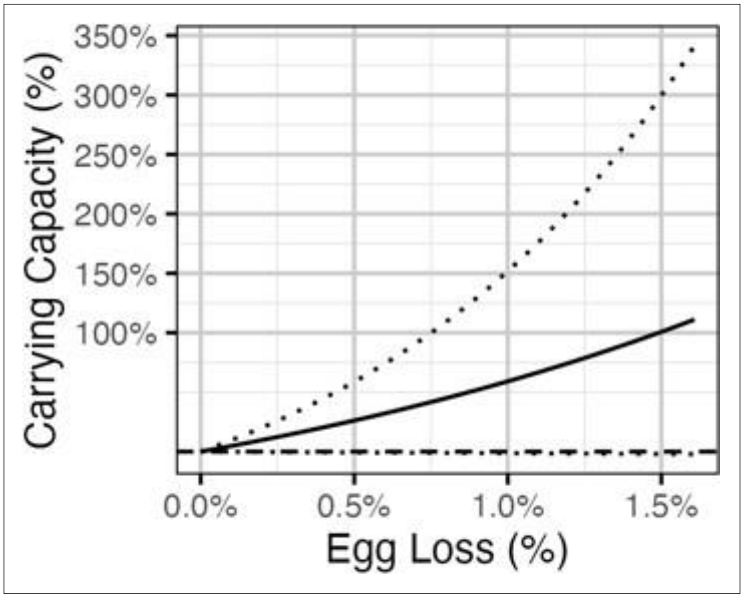

Figure 19. Predicted effect of egg loss on the age-1 carrying capacity (with 95% CRIs)

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. Primary mortality effects on eggs and alevins include predation, desiccation, overheating, freezing and oxygen starvation (Dahlberg 1979 and references therein). The predictors of egg mortality in dewatered redds are likely to include relative humidity, air temperature, solar radiation, sedimentation, burial depth and 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 (ºC)	Duration	Mortality	Source
Brown Trout	Egg	Yes	-	840	20	Bjornn and Reiser (1991)
Chinook	Alevin	Yes	-	32	100	Neitzel and Becker (1985)
Chinook	Alevin	Yes	10	6	95-99	Becker and Neitzel (1983)
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)
Chinook	Egg	Yes	10	288	0-20	Becker and Neitzel (1983)
Chinook	Egg	Yes	-	288	8	Becker and Neitzel (1983)
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)
Kokanee	Egg	Yes	-10	12	100	Neitzel and Becker (1985)
Steelhead	Alevin	No	15	-	0-5	Rombough (1988)
Steelhead	Egg	Yes	-	168-672	6	Reiser and White (1983)
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. 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.

Casas-Mulet et al. (2016) assumed mortality conditions for alevins occur when they are dewatered for 3 or more hours irrespective of air temperatures, while Becker and Neitzel (1983) observed that 'nearly' all alevin died when dewatered for 6 hours. 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.

Current mortality surveys take place opportunistically and may therefore be limited in their capacity to capture data that allows the relative contributions of the various environmental variables to mortality in dewatered redds to be quantified. 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 based on small sample sizes, 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. Excavations in 2022 showed 100% mortality in the six out of ten excavated redds that contained eggs. Four of these redds had been dewatered for ~ 46 days and experienced air temperatures as low as -9 ˚C. The remaining two redds had been dewatered for ~ 9 days and experienced air temperatures as low as -4 ˚C. Due to the extreme weather conditions during the extended periods of dewatering, it is unclear whether mortality was caused by freezing or by desiccation due to the duration of dewatering.

To estimate 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).

Additional Rainbow trout 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 air temperatures, duration of 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 dewatered coupled with particular air temperatures until high levels of mortality occur. To date, insufficient data is available to test or quantify thresholds found within background literature.

During shallow water surveys on February 7th, 2022 the field crew enumerated two large redds in the vicinity of early Rainbow Trout redds at Norns Creek Fan. Subsequent observations following dewatering and egg mortality excavations in April 2022 revealed no eggs or casings in the two large redds suggesting that they may have been Chinook redds constructed in the Fall of 2021 and emergence had already occurred. This supposition is supported by at least one prior observation of Chinook salmon in the LCR in recent years. On September 17th, 2020 the field crew (Jeremy Baxter and Clint Tarala) observed a Chinook Salmon in shallow water with an approximate fork length of 65 cm at Norn's Creek Fan that was dark in pigment and had fungus on its back.

The lack of exclusion fencing at Channel E at Genelle was intended to provide opportunities to excavate redds after longer periods of dewatering and to facilitate a better understanding of the effects of BRD load shaping on dewatering. However, the LCR hydrograph remained outside of the vulnerable range of discharges during the majority of BRD load-shaping events and Channel E experienced only one relatively short period of dewatering in April. BRD load shaping events were observed at BIR in April and May and not detected in Channel E until April 16th (Figure 10). If the water level of Channel E in April had been closer to the elevation of the head of the channel, then the load-shaping events from BRD would have allowed spawners to enter and construct redds each day as the water elevation rose above the channel head. The spawners would potentially then be stranded as load shaping dewatered the head end of the channel. Based on the snowpack, precipitation, inflows, and melt timing, the discharge and elevation is different each year in April and spawning is only vulnerable in Channel E from load shaping at BRD when the river stage is close to the cut-off, or 3.28m at BIR in Figure 10.

In summary, the results continue to support that, given the large number of spawners, a substantial proportion of the redds on the LCR could be dewatered and experience 100% mortality with negligible effect on the number of age-1 fish the following year. The results also tentatively suggest that, during the egg stage, redds could be dewatered for at least six days with relatively low levels of mortality provided air temperatures remain above freezing and below 16°C.

5.0 RECOMMENDATIONS

- Continue with helicopter and boat-based surveys to estimate Rainbow trout spawner abundance and timing with the addition of drone flights over Norn’s Creek Fan as a supplementary method of assessing spawning distribution.

- 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 2023 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 implementation of spawner salvage operations to prevent fish stranding in Channel E.

- Conduct an opportunistic LiDAR or photogrammetry-based drone survey at both Norns Creek Fan and Genelle Chanelle E during low flows in the spring to capture up-to-date elevational data of the spawning habitat.

- Develop a model to predict Rainbow Trout hatch and emergence timing based on existing temperature data.

- 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.

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.

Report prepared by:
Mountain Water Research
Jeremy Baxter A.Sc.T.
Fisheries Research Technologist

Report prepared by:
Poisson Consulting Ltd.
Evan Amies-Galonski R.B.Tech
Intermediate Computational Biologist

Report prepared by:
Poisson Consulting Ltd.
Joseph Thorley, Ph.D. R.P. Bio.
Senior Computational Biologist

Report prepared by:
Nupqu Limited Partnership
Mark Fjeld, BSc, R.P. Bio.
Biologist/Project Manager

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APPENDIX A
MAPS OF PEAK FISH AND REDD COUNTS 2022

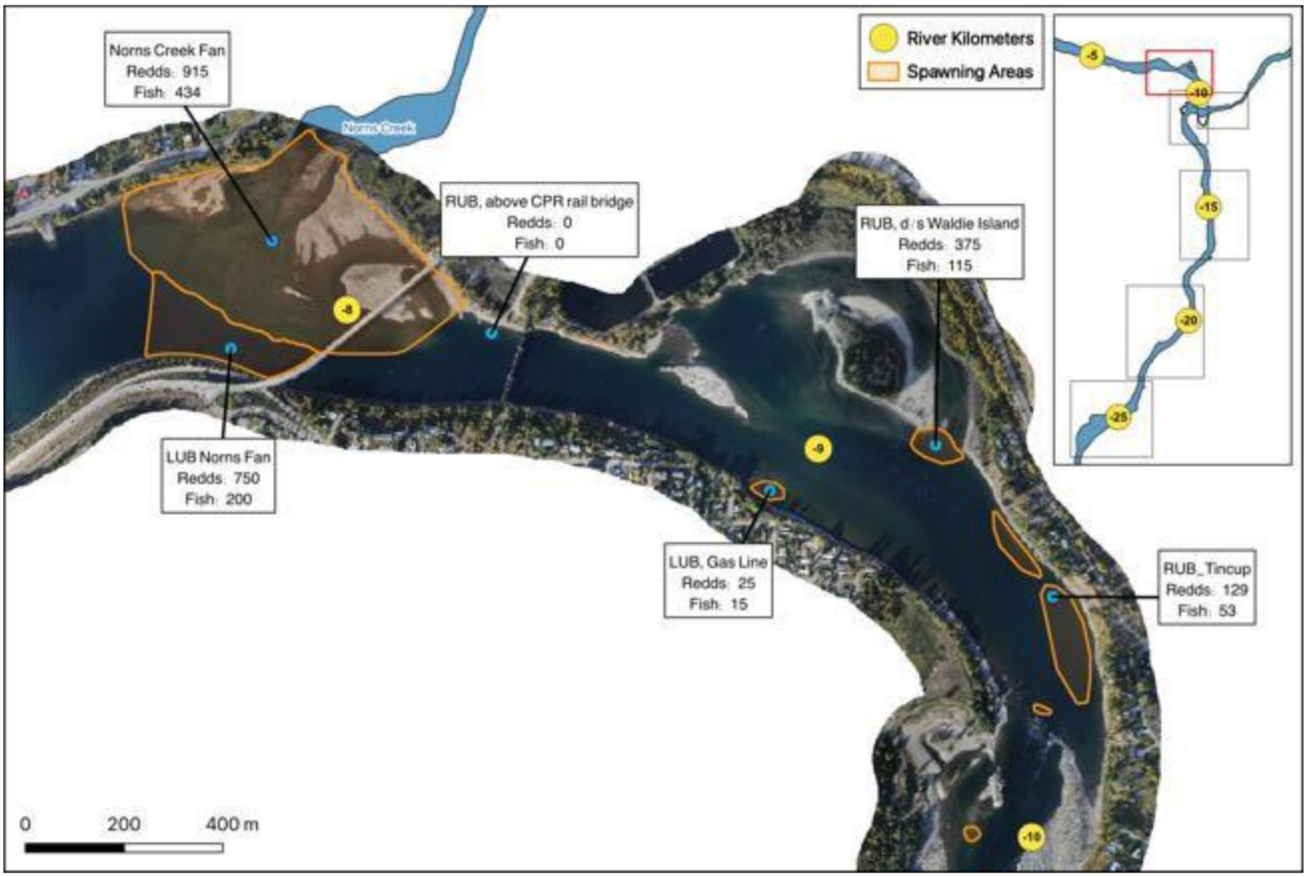


Figure A1. Fish and redd peak counts in the Norn's Creek Fan and Robson Bridge area.

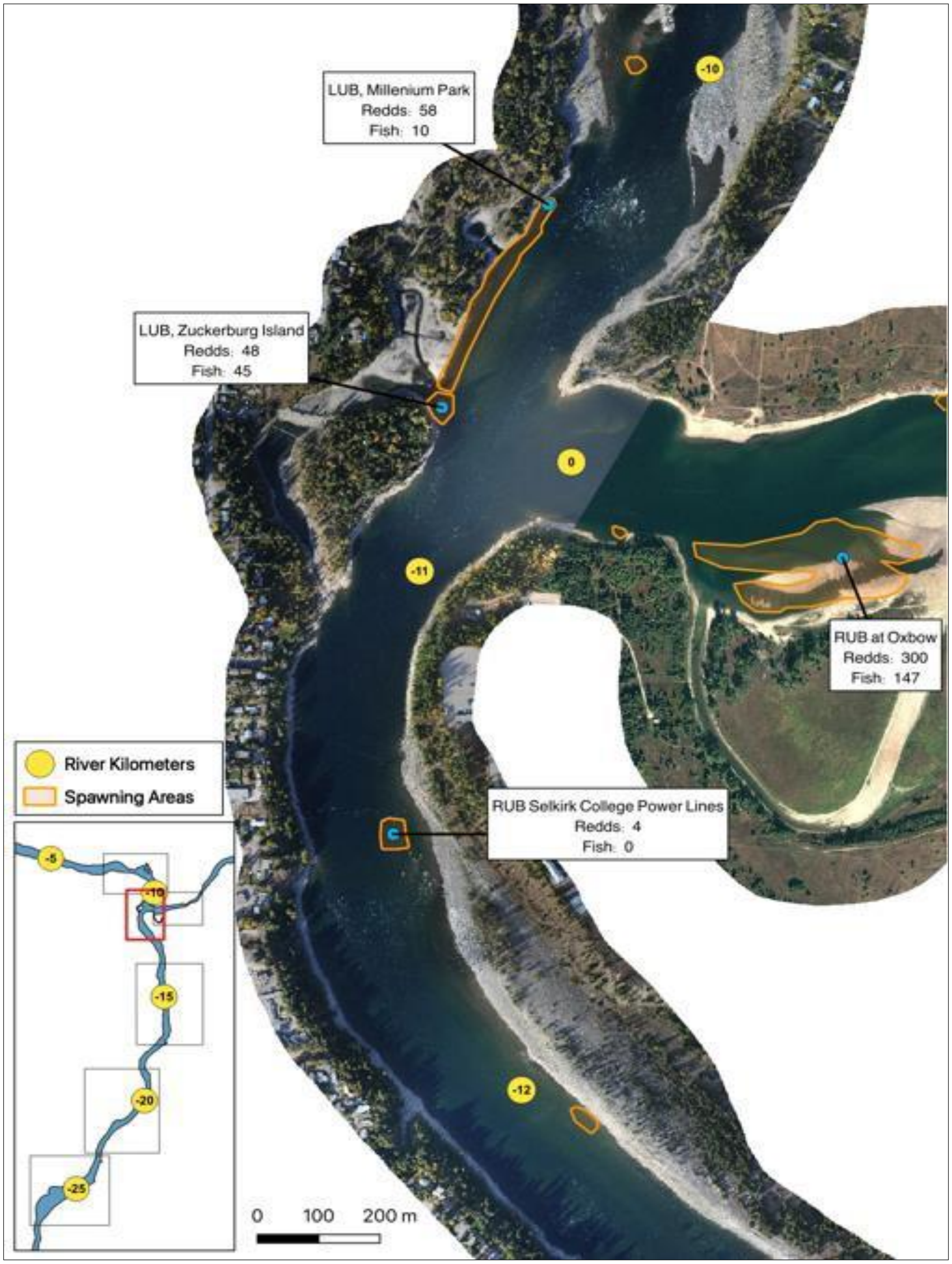


Figure A2. Fish and redd peak counts in the Zuckerberg and Millennium Park area.

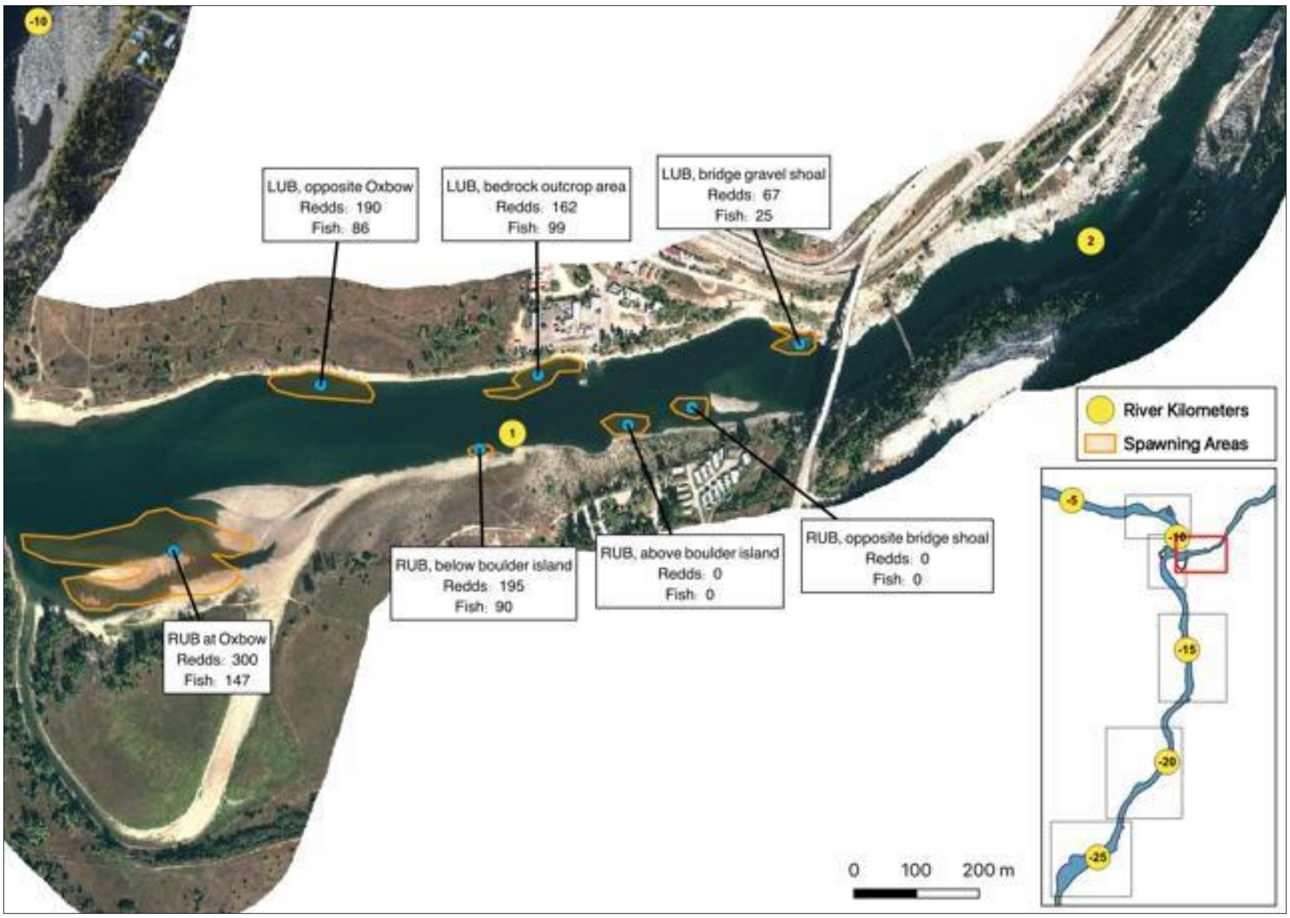


Figure A3. Fish and redd peak counts in the Lower Kootenay River area.

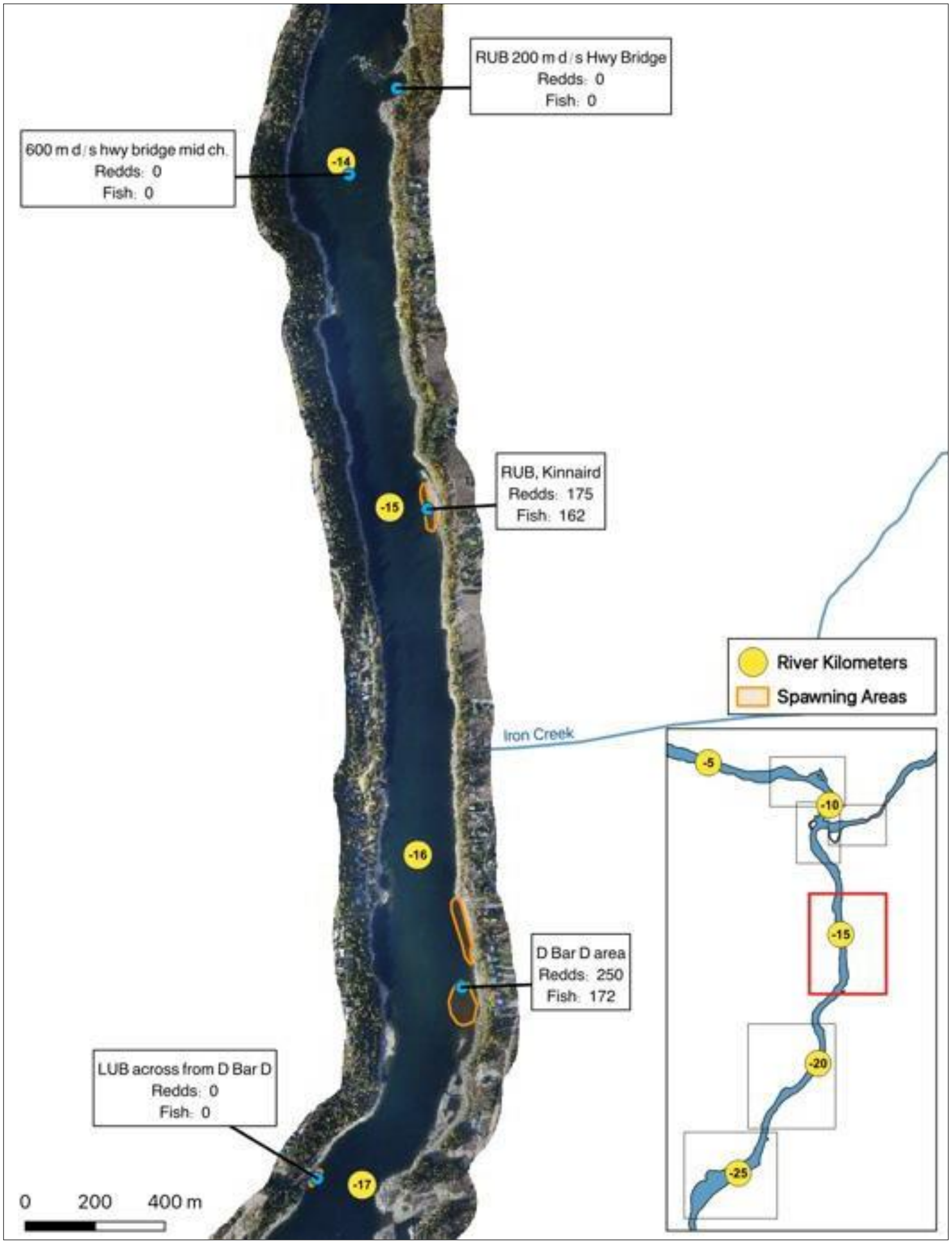


Figure A4. Fish and redd peak counts in the Kinnaird area.

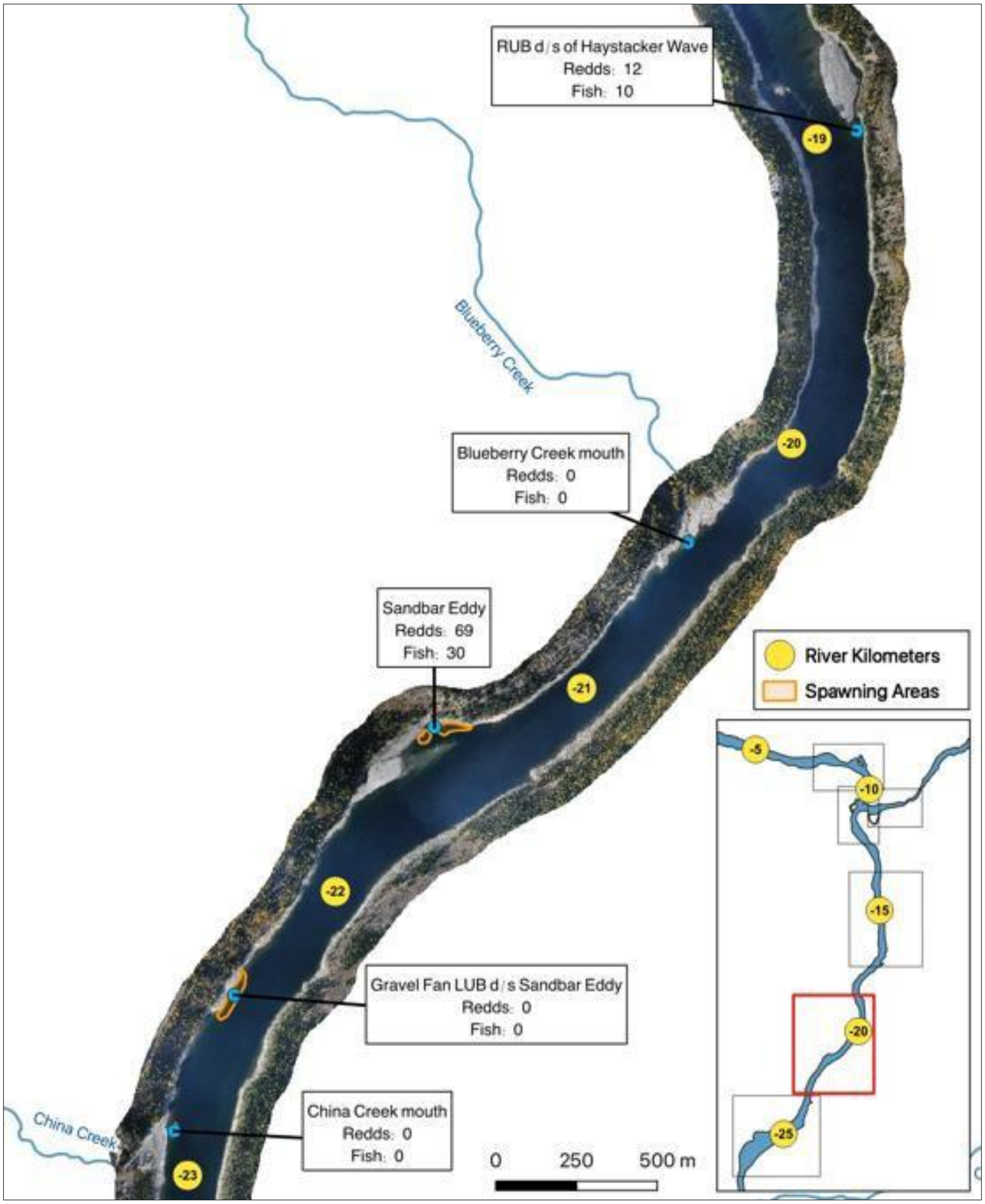


Figure A5. Fish and redd peak counts in the Blueberry and China Creek area.

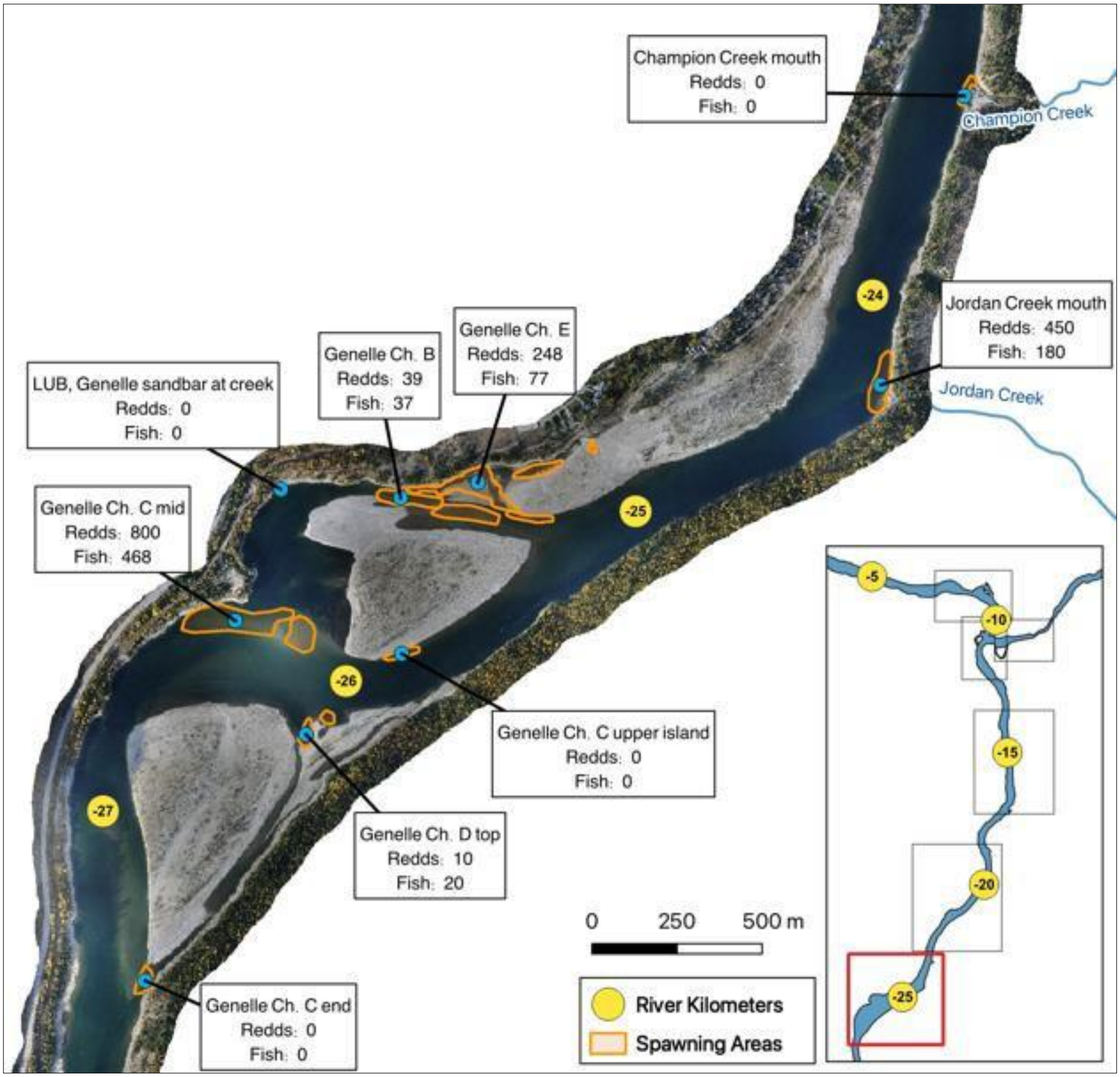


Figure A6. Fish and redd peak counts in the Genelle area.

APPENDIX B

AREA-UNDER-THE-CURVE PLOTS

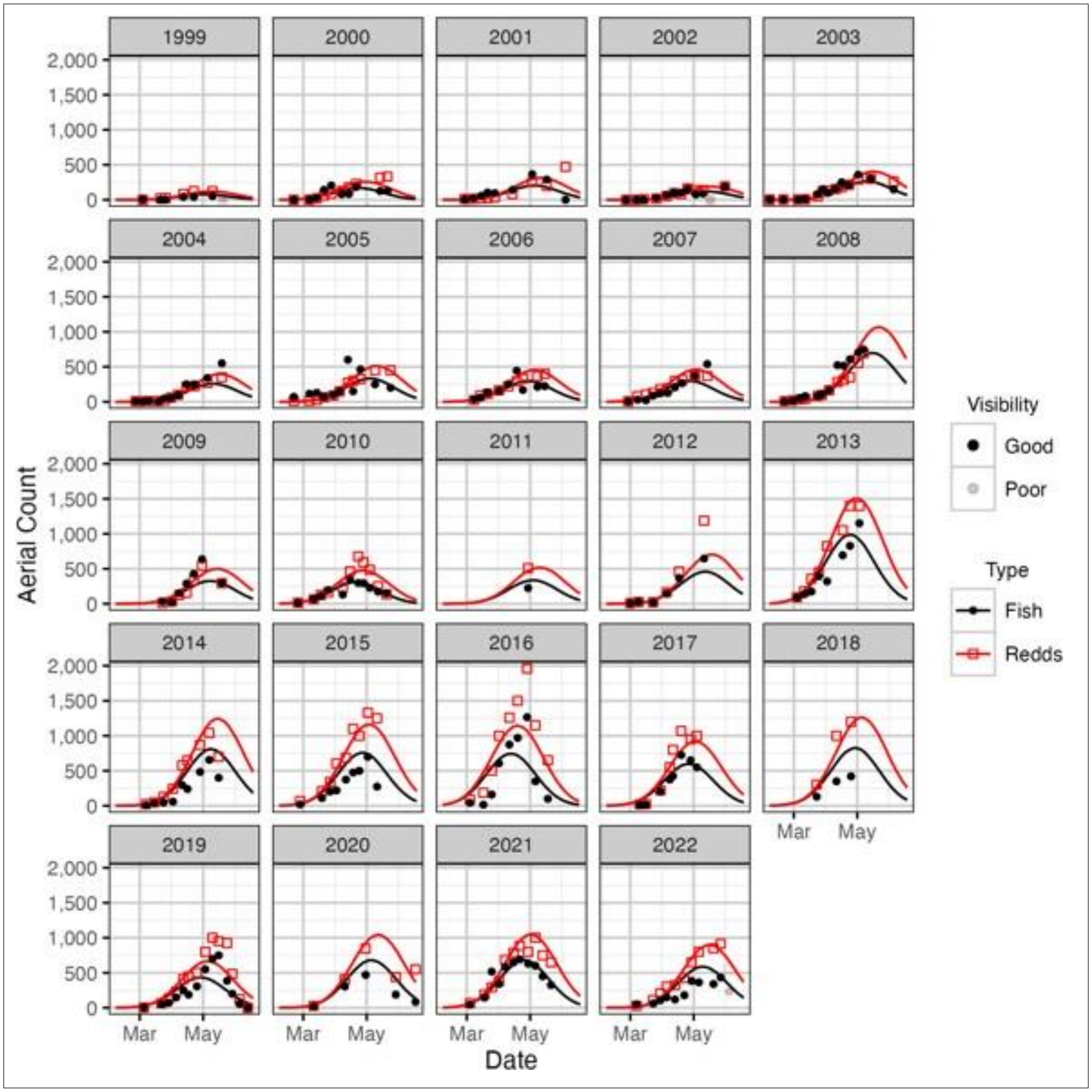


Figure B1. Predicted and actual aerial fish and redd counts at Norn's Creek Fan by date and year.

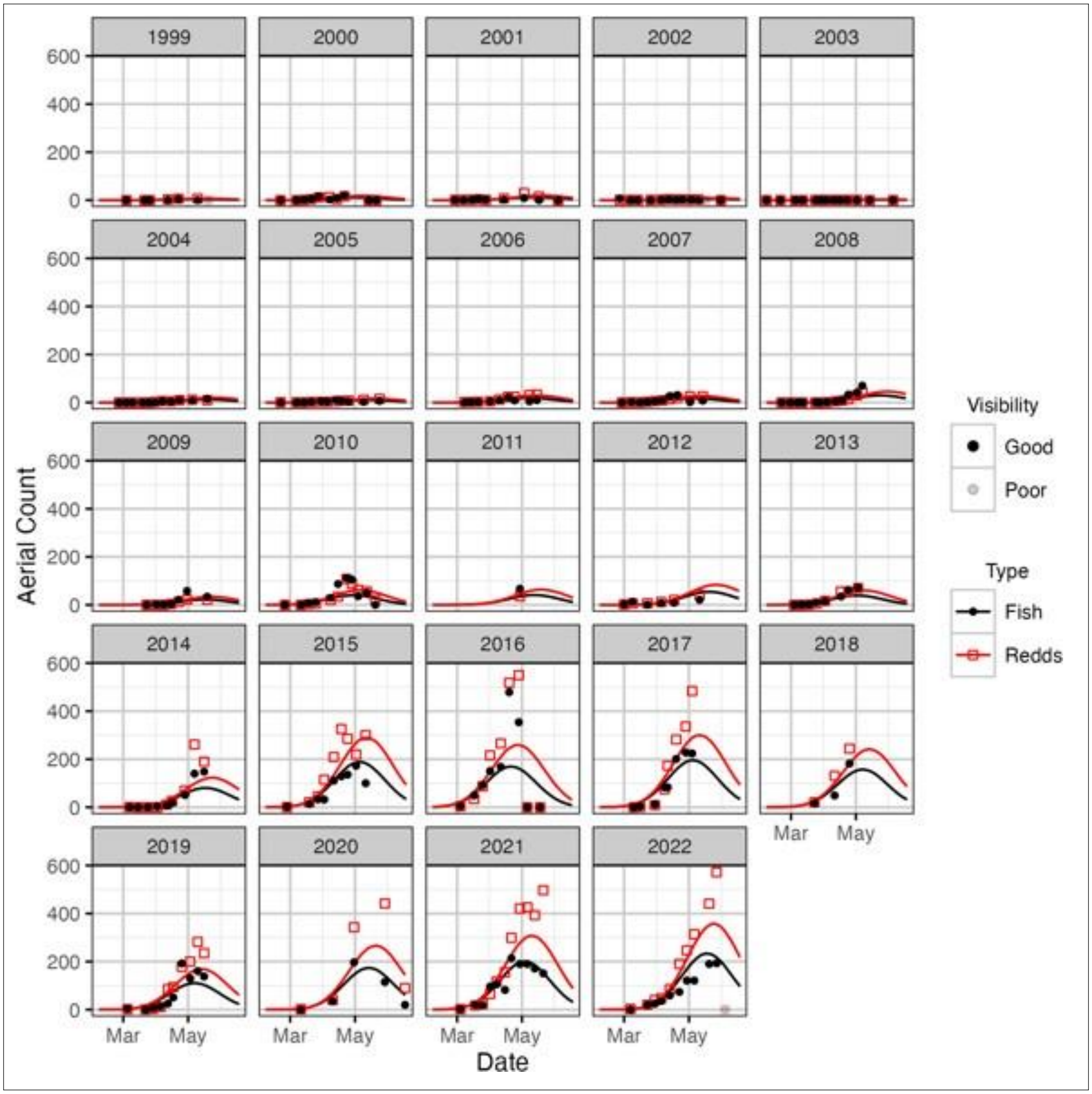


Figure B2. Predicted and actual aerial fish and redd counts in the section from Norn's Creek Fan to the Lower Kootenay River by date and year.

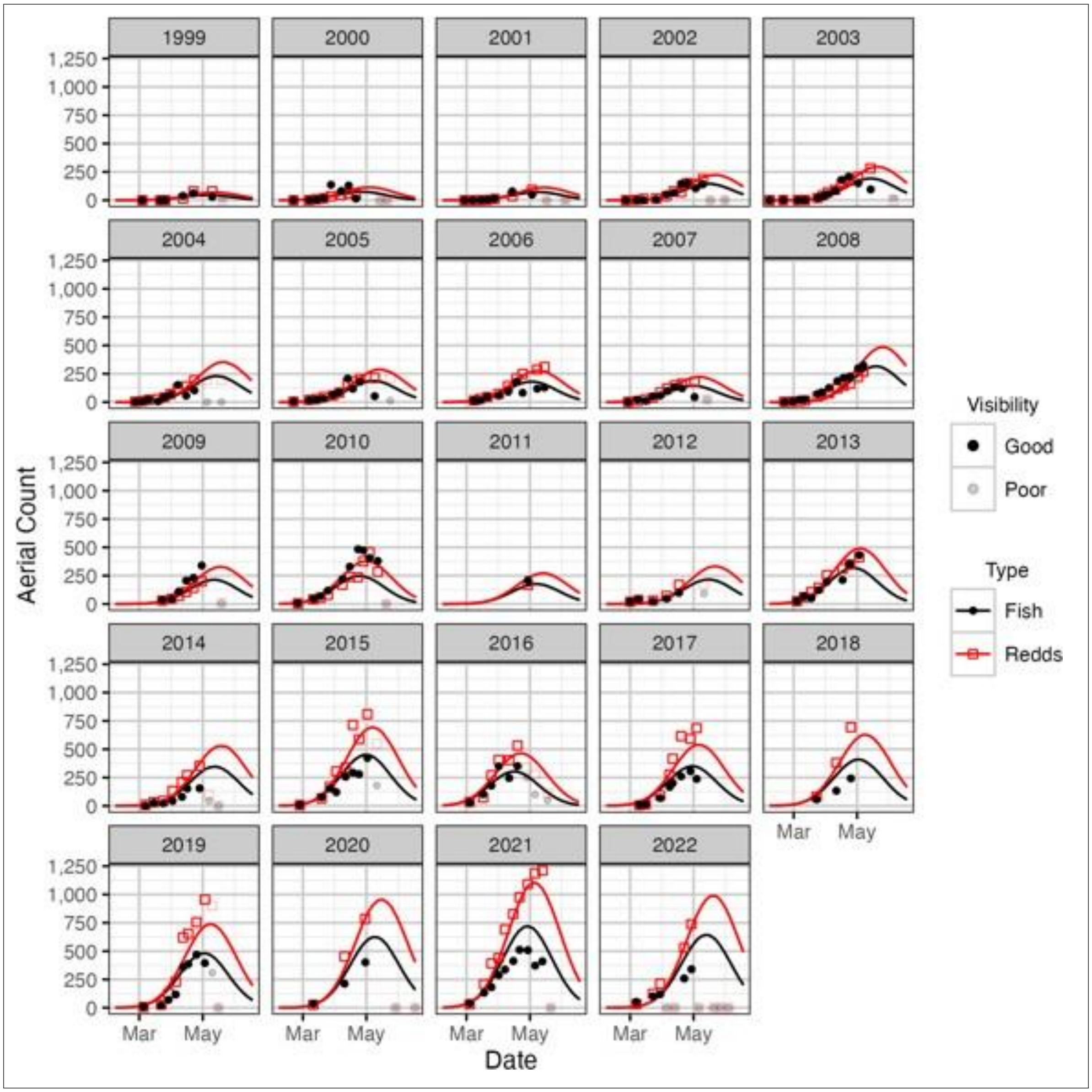


Figure B3. Predicted and actual aerial fish and redd counts at Lower Kootenay River by date and year.

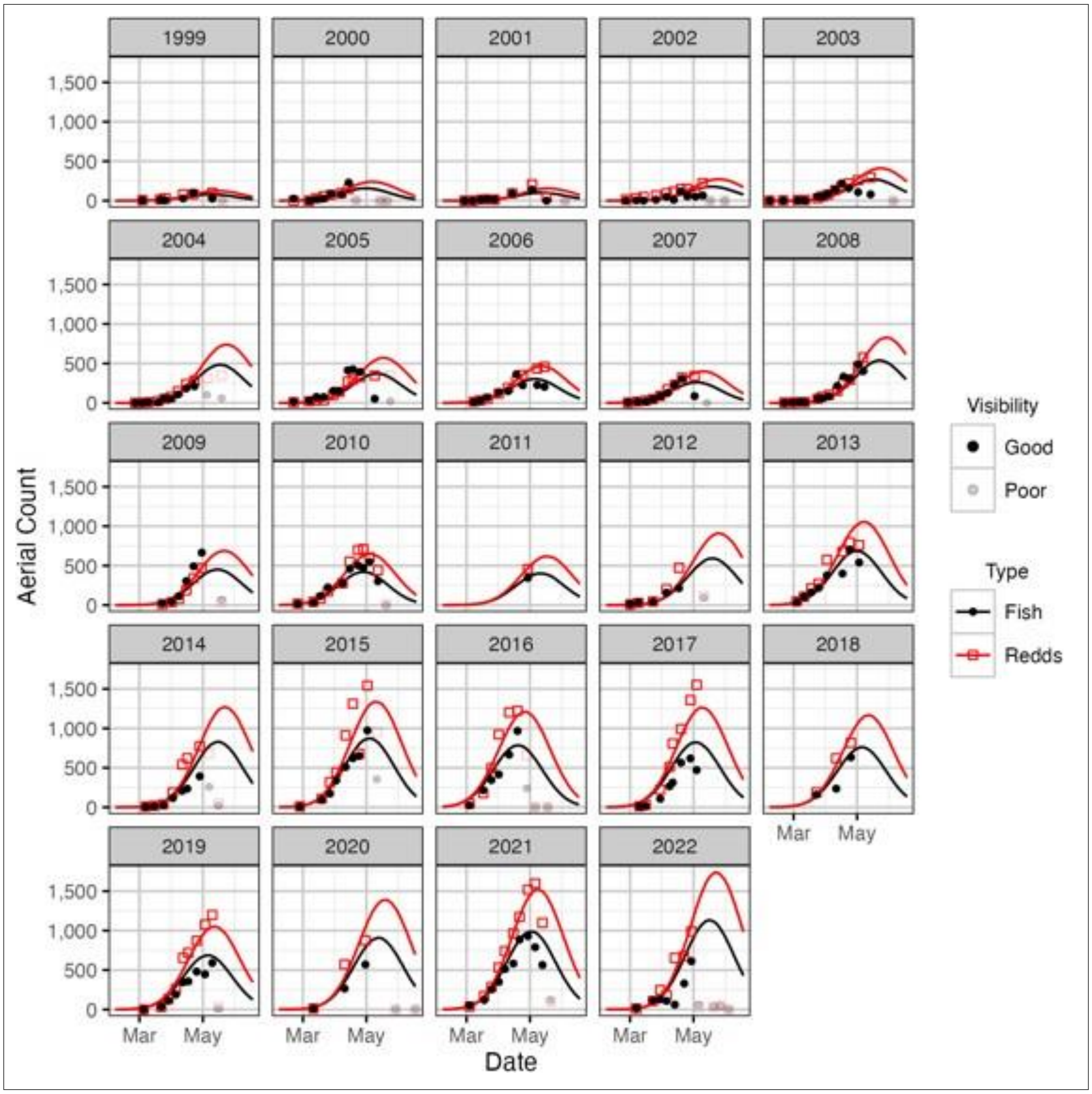


Figure B4. Predicted and actual aerial fish and redd counts in the section from Lower Kootenay River to Genelle by date and year.

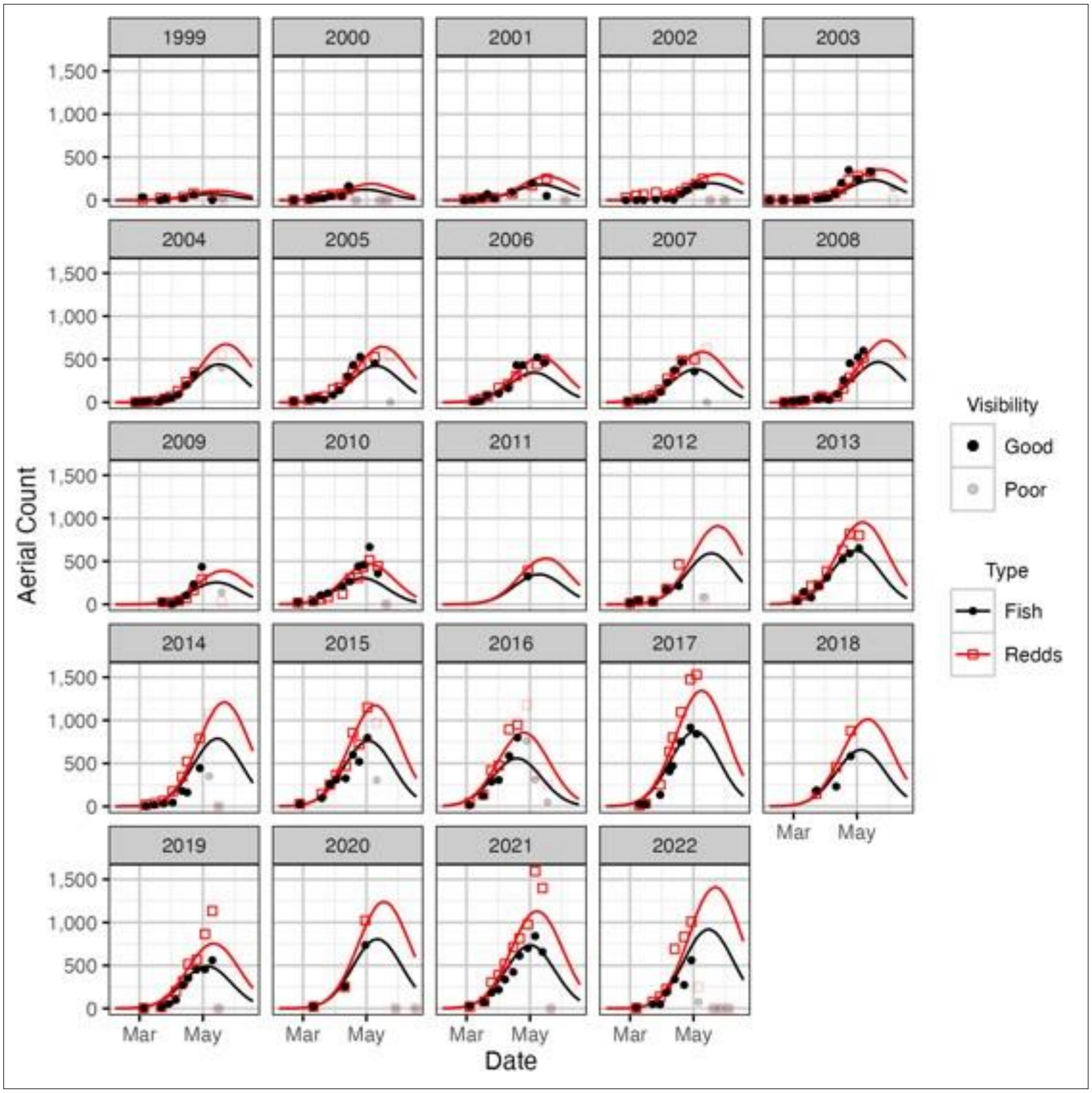


Figure B5. Predicted and actual aerial fish and redd counts at Genelle by date and year.

APPENDIX C
HISTORICAL DISCHARGE PLOT

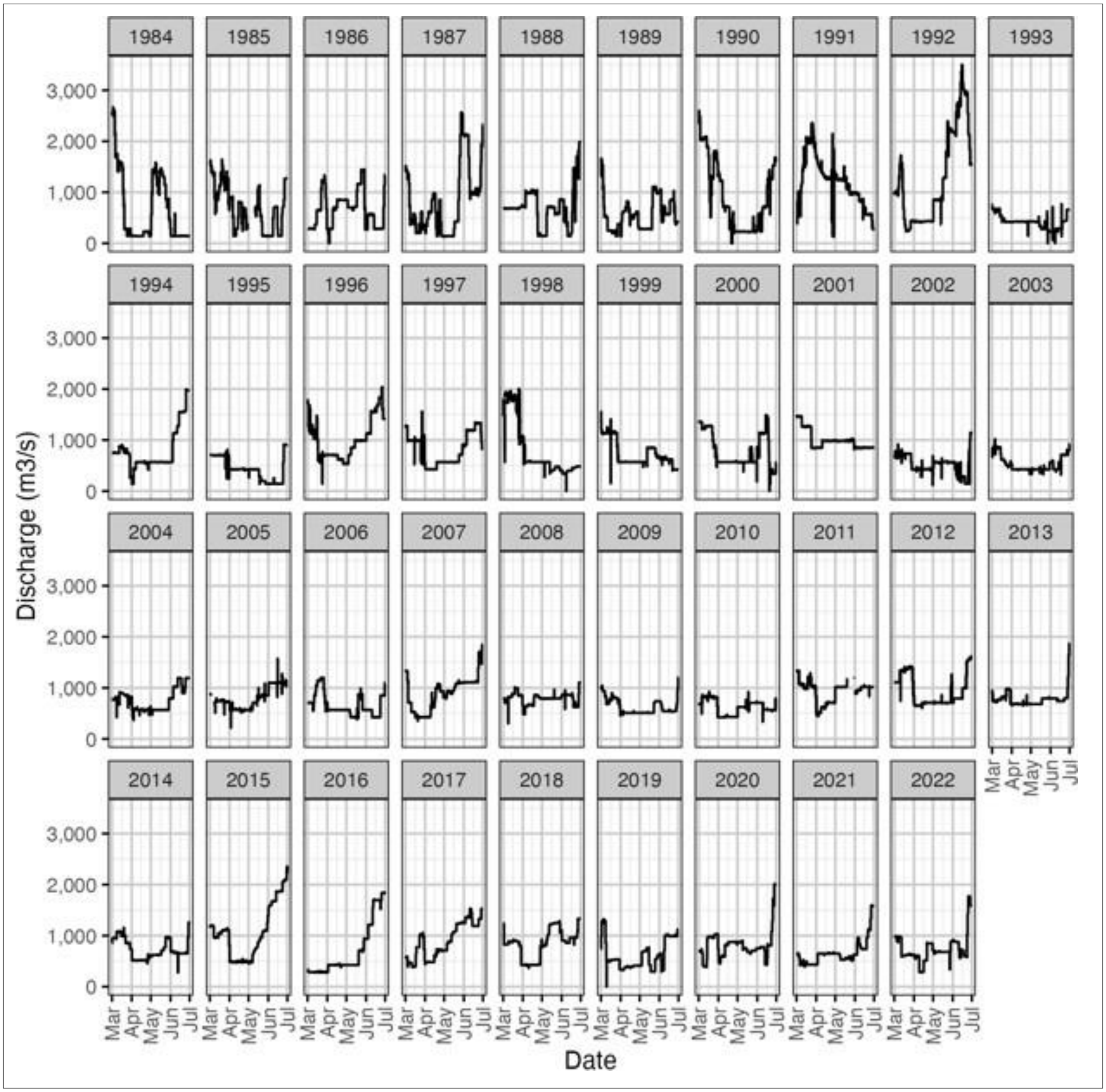


Figure C1. Hourly discharge at HLK Dam by date and year.

APPENDIX D

EGG AND ALEVIN MORTALITY SURVEYS AND STAGING GUIDE

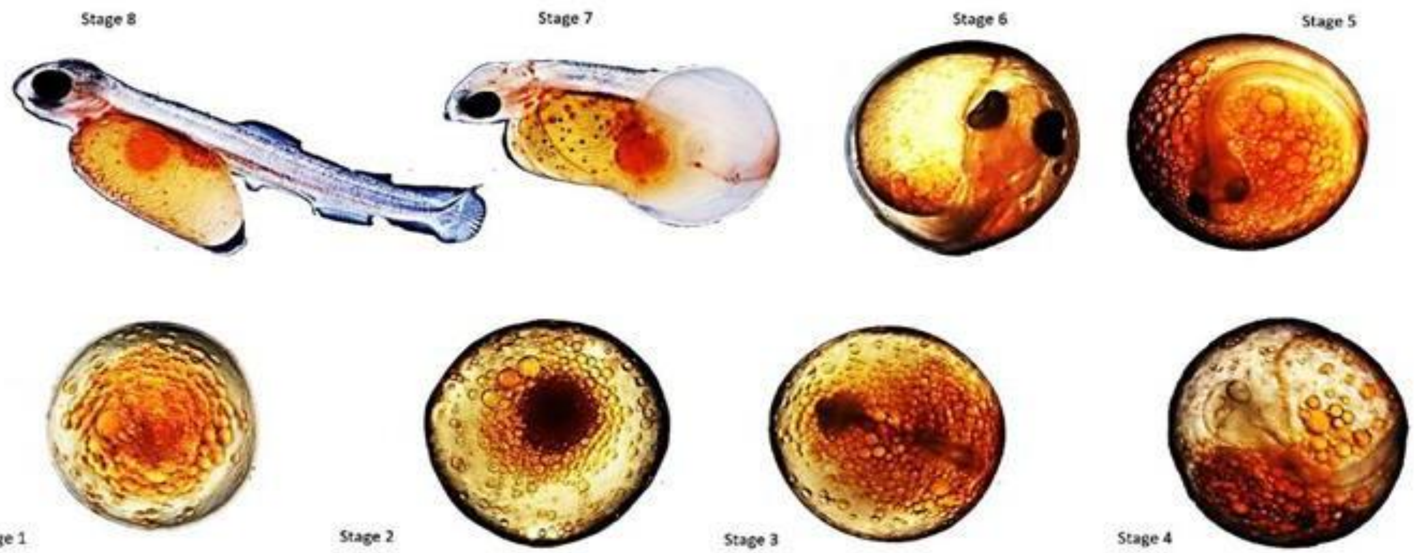
Egg and Alevin mortality surveys took place opportunistically in 2019, 2020, and 2022 when significant dewatering events occurred. Individual dewatered redds were marked using a uniquely numbered tag. Egg mortality percentages were monitored through consecutive redd excavations to better understand the 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 all 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. 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 #CB22-689220, issued by the Ministry of Forest, Lands and Natural Resource Operations, Kootenay – Boundary Region.

Rainbow Trout Egg and Alevin Development Field Guide

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

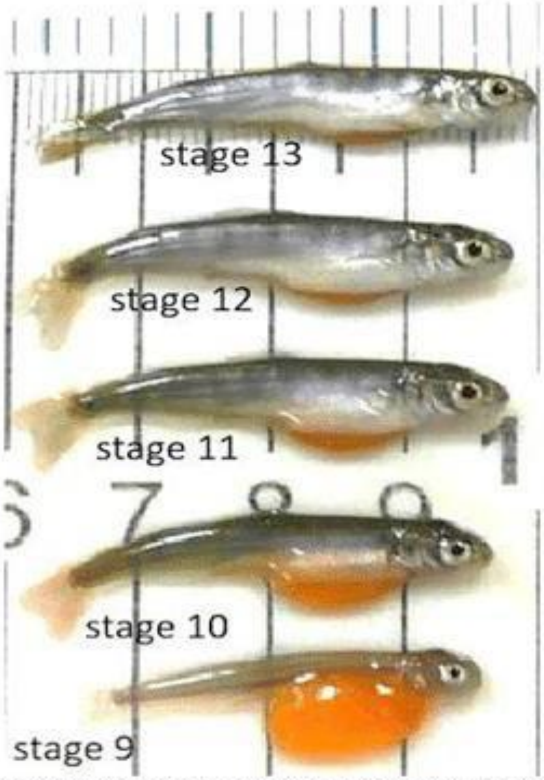


Stage	Description & development time based on 10°C (Days since fertilization)
1	Fertilization-Early Blastula (hours)
2	Blastula-Gastrula (12 hours to 6 days)
3	Embryo with ocular development (7 days)
4	Embryo with faint pigmentation of eyes (12 days)
5	Eyed - Full pigmentation of eyes (20 days)
6	Ready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