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Technical Report Overview

Report: Upper Fording River Westslope Cutthroat Population Monitoring and Assessment 2021

Overview: Fish Monitoring of blue listed Westslope Cutthroat to provide support to environmental sustainability and monitor natural and mining influences on this isolated population

This report was prepared for Teck by Poisson Consulting Ltd. and Lotic Environmental Ltd.

For More Information

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UPPER FORDING RIVER WESTSLOPE CUTTHROAT TROUT POPULATION MONITORING 2021

FINAL REPORT

June 17, 2022

Prepared for: Teck Coal Ltd., Sparwood, BC

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The photograph is the upstream portion of a glide mesohabitat unit at EWI1 in Ewin Creek that was backpack electrofished on the 10th of September 2021.

EXECUTIVE SUMMARY

The upper Fording River is a mine-influenced system that contains genetically pure Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) above a natural barrier, Josephine Falls. After a substantial (~93%) decline in subadult and adult abundance between 2017 and 2019, a review concluded that the decline occurred in February–March 2019 and was caused by the interaction of extreme ice conditions (due to extreme, prolonged, cold air temperatures; seasonal, winter low flows; and low winter snowpack), sparse overwintering habitats and restrictive fish passage conditions during the preceding migration period in fall 2018. The snorkel data suggests that the subadult and adult population fell from ~ 5,200 fish in 2017 to ~330 fish in 2019 before increasing to ~1,500 by 2021.

Currently the carrying capacity (long-term average expected adult population abundance); productivity (population replacement at extremely low density) and viability (probability of persistence for 40 generations) are relatively uncertain. In order to better understand the extent to which climate, mining and other variables influence these three fundamental fish population metrics it is necessary to answer a series of secondary questions. The current report uses the available data from redd (2015, 2020, 2021), electrofishing (2013-2015, 2017, 2019-2021) and snorkel surveys (2012-2014, 2017, 2019-2021) as well as previous reports by Cope (2016, 2020) to attempt to answer ten questions. The answers are summarized in the Executive Summary Table on the following page. The extent to which climate, mining and other variables influence these carrying capacity, productivity and viability will be addressed in next year's report.

Executive Summary Table. Answers to the ten secondary questions considered in the current report from Thorley et al (in prep) which inform population carrying capacity, productivity and viability in the upper Fording River Westslope Cutthroat Trout.

Question	Subcategory	Answer
1. What is the geographic range of the fish population(s)?	Mainstem	52 km of the UFR from 20 km to 72 km.
	Tributaries	36 km of connected tributaries including LCO Dry, Chauncey, Fish Pond and Henretta creeks.
2. What are the life-history strategies within the fish population(s)?		~50% fluvial residents, ~40% fluvial migrants, ~10% adfluvial migrants.
3. What is the timing of life-history events?	Spawning	Begins between mid-May and early June with peak spawning between June 15 and July 8, depending on the water temperature.
	Incubation	Fry emerge after 575 to 600 degree days (accumulated temperature).
	Rearing	Growing season ends in October depending on when stream temperatures fall below approximately 5 degrees.
4. What are the sizes of the key life-stages?	Age-0	~ 28-57 mm on October 1 depending on the stream.
	Age-1	From 45 – 94 mm in Ewin Creek to 75 – 124 mm in Greenhills and Lake Mountain creeks in September.
	Subadult	≥ 200 mm
	Adult	Fish mature between 233 and 290 mm.
5. What is the growth rate of key life-stages?		Fish become subadult between age-3 and age-6.
6. What is the spatial distribution of key life-stages?	Redds	Most spawning activity is in mainstem sections S2 and S8-S10 and Chauncey Creek.
	Age-1	Highest densities around spawning areas and closest to the upper Fording River in tributaries.
	(Sub)adult	Highest densities in mainstem sections S7-S10 in 2017 and 2021.
7. What is the abundance of key life-stages?	Age-1	~ 27,000 in 2017, ~11,000 in 2019 and ~5,000 in 2021
	(Sub)adult	~5,200 in 2017, ~330 in 2019 and ~1,500 in 2021
8. What is the total number of eggs deposited?	2017	~750,000 eggs in 2017, ~45,000 eggs in 2019 and ~210,000 eggs in 2021
9. What is the survival of key life-stages?	Egg to Age-1	~2-16% with higher survival when less eggs
	(Sub)adult	~67%
10. What is the genetic diversity (H_E) and effective population size (N_E)?		H_E of 0.37 (1998) and 0.54 (2000) with provincial average of 0.56. N_E > 500 pre-2018 and > 50 post-2018.

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GLOSSARY

LIFE-STAGE PERIODS

Life-Stage Period Table. Definitions of the periods of the key life-stages and groupings. The sizes and ages of the key life-stages are discussed in the report and listed in the Executive Summary Table.

Life-stage	Period	Grouping
Egg	Spawning until hatch	
Alevin	Hatch until emergence from gravels	
Age-0	From emergence to December 31st	Juveniles
Age-1	Second calendar year	
Age-2+	Third calendar year until development of adult body form	
Subadult	Development of adult body form until maturity	(Sub)Adults
Adult	Maturity until death due to senescence	

INTRODUCTION

The Fording River is a tributary of the Elk River in the southeast corner of British Columbia (BC). Teck Coal Limited (Teck) operates three coal mines within the upper Fording River (UFR) watershed: Fording River Operations (FRO), Greenhills Operations (GHO) and Line Creek Operations (LCO). The watershed supports an isolated population of genetically pure Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) above Josephine Falls, a natural barrier to upstream fish movement (Cope et al. 2016)

Westslope Cutthroat Trout (WCT) are a species of Special Concern both provincially and federally. Identified threats include interbreeding with Rainbow Trout (*Oncorhynchus mykiss*), restricted fish passage due to culverts, mining, forestry and angling (Fisheries and Oceans Canada 2017).

Coal mining impacts on WCT can include habitat loss and fragmentation, physical changes to the stream channel and riparian areas, and changes in quantity and quality of water, including chemical leaching from waste rock (Fisheries and Oceans Canada 2017). Other potential anthropogenic impacts to WCT in the UFR include poaching and broad scale landscape factors related to forestry, recreation and transport corridors. Recreational angling has been prohibited in the UFR since 2010 (MFLNRORD 2021).

In addition to anthropogenic effects, fish population dynamics are also driven by environmental variation which can itself be exacerbated by climate change. Although Kennedy and Meyer (2015) found that bioclimatic indices, such as mean annual air temperature and mean winter stream flow were poor predictors of trends in WCT abundance for populations in Idaho, recruitment failure can occur due to a short growing season associated with low summer temperatures (Coleman and Fausch 2007a). Ice conditions can also limit available habitat in winter (Brown and Mackay 1995). Small isolated populations are also at risk of inbreeding depression (Soulé and Mills 1998; Taylor et al. 2003; Carim et al. 2016).

Cope (2020), reporting on data from 2012 to 2019, estimated an increasing trend in the UFR WCT population until 2017 whereupon the number of fish ≥ 200 mm declined by ~ 95%. This initiated a detailed review of the effects of environmental stressors (natural and anthropogenic) on the abundance of the UFR population (Evaluation of Cause Team 2021). More recently, Thorley et al. (in prep) outlined a conceptual and research framework which identifies three primary fish population metrics of interest:

1) carrying capacity (long-term average expected adult population abundance)
2) productivity (population replacement rate at extremely low density)
3) viability (probability of persistence for 40 generations).

As discussed by Thorley et al. (in prep) to estimate these three metrics it is necessary to answer a series of secondary questions, the first ten of which are as follows:

1. What is the geographic range of the fish population?
2. What are the life-history strategies within the fish population?
3. What is the timing of life-history events?
4. What are the sizes of the life-stages?
5. What is the growth rate of key life-stages?
6. What is the spatial distribution of key life-stages?
7. What is the abundance of key life-stages?
8. What is the total number of eggs deposited?
9. What is the survival of key life-stages?
10. What is the genetic diversity and effective genetic population size?

This report attempts to answer these ten questions and identifies key uncertainties or inconsistencies and provides recommendations for future data collection. The carrying capacity, productivity and viability of the WCT populations in the UFR will be estimated in future years using the population model of ESSA Technologies Ltd. and Ecofish Research Ltd. (Lodmell et al. 2017; Ma and Thompson 2021) with updates based on the results of the monitoring program.

METHODS

STUDY OVERVIEW

The UFR WCT Population Monitoring program was initiated in 2012 with (sub)adult snorkel surveys. These were repeated in 2013-2014, 2017 and 2019-2021. Removal-depletion electrofishing to elucidate age-1 and age-2+ densities began in 2013 and subsequently occurred in the same years as snorkel surveys. Spawning surveys to identify redds have taken place in 2013-2015, 2020 and 2021.

To address the data gaps identified in Thorley et al. (2021b) the monitoring program was expanded in 2021 to include additional redd surveys as well as single-pass electrofishing at large (~300 m) open sites. The ten secondary questions, and the data sources and analytic methods used to answer them, are outlined below in Table 1. The stream network and stream distances, which measure the upstream distance from the mouth of a stream, are derived from the Freshwater Atlas of BC and all spatial coordinates are for UTM Zone 11N (NAD83). All fish lengths are fork lengths unless otherwise stated.

Table 1. Summary of Methods and Analysis.

		Electrofishing	Snorkeling	Redd Surveys	GIS	Water Temperature	Telemetry	Genetics	Angling
Question	Analytic Method	Data							
1. What is the geographic range of the fish population?	Professional judgement based on fish observations and barriers and stream size.	X			X				
2. What are the life-history strategies within the fish population?	Professional judgement based on fish size and movement, available habitat and genetic differentiation.	X			X		X	X	
3. What is the timing of life history events?	Water temperature and redd fading and area-under-the-curve (AUC) models			X		X			
4. What are the sizes of the life stages?	Professional judgment based on length frequency plots and gonadal development.	X							X
5. What is the growth rate of key life stages?	Growth model parameterized using inter-annual PIT tag recaptures.	X							X
6. What is the spatial distribution of key life stages	Distribution of electrofishing captures and snorkel and redd observations.	X	X	X	X		X		
7. What is the abundance of key life stages?	Removal-depletion model of electrofishing captures and mark-recapture model of snorkel counts.	X	X		X				
8. What is the total number of eggs deposited?	Calculated from (sub)adult abundance and (sub)adult size using literature-based length-fecundity relationship.		X						
9. What is the survival of key life stages?	Calculated from age-1 abundance and total egg deposition the previous year	X	X						
10. What is the genetic diversity and effective population size?	Estimated from fin clips by analyzing allele data.	X						X	

STUDY AREA

The Fording River drainage basin is located on the west slope of the Rocky Mountains and encompasses an area of ~ 620 km^2 with a mean annual discharge of 7.96 m^3/s (Water Survey Canada Station 08NK018, 1970-2020). The spatial boundary of the monitoring program was defined as the UFR watershed - the portion of the Fording River (including tributaries) located upstream of Josephine Falls, which forms a barrier to upstream fish movement (Figure 1). WCT are the only species of fish found above Josephine Falls.

To facilitate population monitoring the mainstem of the UFR, Henretta Creek and Fish Pond Creek were stratified into 11, three and one sections, respectively (Cope 2020b; Figure 1). The sections in the mainstem, which are approximately 5 km in length, do not correspond to geomorphological reaches, but instead represent sampling units that can be covered in a day on foot or snorkeling.

The WCT population in the UFR occupies approximately 52 km of the mainstem UFR from Josephine Falls at ~20 km to the limit of the fish distribution at a stream distance of ~72 km (Cope 2020b). The population also occupies approximately 36 km of connected tributaries. The tributary habitat includes Chauncey Creek above the road crossing at 0.6 km which was isolated from the mainstem population by culverts until August 2021. A culvert/spillway on Greenhills Creek at 0.5 km currently isolates the fish in the upstream 8 km of fish bearing habitat (Table 2). The fish in Kilmarnock Creek, isolated by South Spoil, were salvaged in 2011; subsequent salvages have failed to catch any fish.

Table 2. Known fish barriers on the UFR including stream, stream distance, type and location.

Barrier	Stream	Distance (m)	Type	Easting	Northing
Cataract Falls	Cataract Creek	60	falls	652557	5557605
Clode Culverts	Clode Creek	115	culvert	650884	5564283
Josephine Falls	Fording River	20,170	falls	652083	5543275
Greenhills Culvert	Greenhills Creek	535	culvert	653573	5545832
LMC Outfall	Lake Mountain Cr	30	outfall	650861	5563287
LMC Culvert	Lake Mountain Cr	165	culvert	650741	5563312
Dry Pond Spillway	LCO Dry Creek	5,545	spillway	658155	5541198
Kilmarnock Ponds	Kilmarnock Creek	685	outfall	652386	5559402
Porter Gradient	Porter Creek	640	gradient	653326	5555358
Swift Falls	Swift Creek	105	falls	652079	5558540
Turn Gradient	Turn Creek	180	gradient	651954	5566088

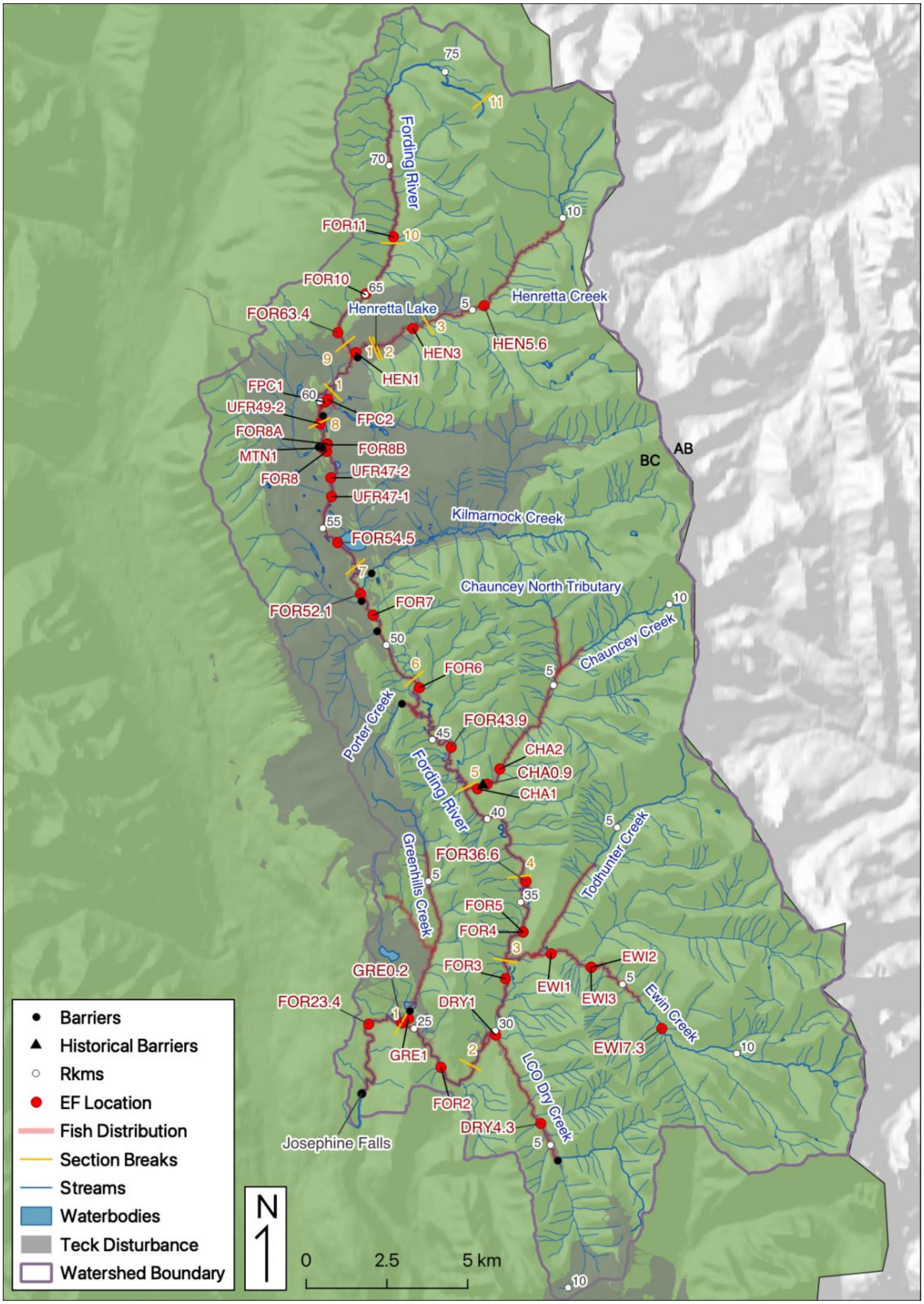

Figure 1. UFR study area with upstream historical and current barriers, stream distances (km), electrofishing locations, the fish distribution and section breaks. Smaller tributaries such as Porter Creek (at 46.8 km) and Fish Pond Creek (at 59.7 km) are not labelled.

DATA COLLECTION

SPAWNING (REDD) SURVEYS

Redd surveys, which record disturbances in the gravels from spawning activity, are used to assess spawning activity.

In 2013-2015 and 2020, core areas identified in Cope et al. (2016) were surveyed. These were reported to include but not be limited to the following:

1) UFR in the area of the section S8/S9 break (historically called “Clode Flats”) and associated tributary habitat (Clode Creek, West Exfiltration Ditch, Fish Pond Creek),
2) UFR in section S6 groundwater upwelling area and side-channels (also named “Fording River Oxbows”),
3) UFR around the mid-river log jams in section S4,
4) LCO Dry Creek Reach 1 and confluence with UFR in section S3/S2, and
5) Greenhills Creek Reaches 1 and 2.

Prior to 2021, survey effort in the watershed outside the core areas was variable and dependent on spawning activity. Areas within the watershed that had been associated with very little activity were also opportunistically checked, however the timing and extent of redd surveys were not recorded.

In 2021, suitable gravels in areas of historically high spawning were monitored for spawning activity starting in the first week of June. Once spawning activity had been observed, surveys were conducted once a week in the key areas until spawning activity was judged to have ceased. The key areas included the Fording River from approximately 23 km (3 km upstream of Josephine falls) to the upstream extent of section S9 at 63 km (Figure 1) and Chauncey Creek above the road culverts at 0.6 km to about 5 km. If turbidity levels reduced visibility in the mainstem, crews would either move upstream until visibility improved or switch to a tributary with lower turbidity levels. In 2021, when spawning was judged to be at its peak, additional surveys were conducted throughout the mainstem UFR and in the lower sections of major tributaries such as Greenhills, LCO Dry, Ewin, Fish Ponds, Porter and Henretta creeks. Repeated redd surveys to estimate the effects of calcite concretion on spawning activity were also conducted at particular sites in the UFR and several tributaries (Hocking et al. 2021).

Redd surveys consisted of crews of two trained observers who surveyed all lotic habitat for fish related gravel disturbances. The crew lead had extensive experience in WCT spawning surveys. Prior to 2021, the observers flagged and only recorded the locations of all newly encountered redds with “*defined excavated pits and loose gravel. In cases where there were multiple nests within the same excavation these were enumerated as one redd; unless more than one spawning pair was observed*” as cited from Cope and Cope (2020). In 2021, following a review of the study design (Thorley et al. 2021b) observers recorded their start and end locations and dates and times and recorded all encountered individual nests within redds (irrespective of flagging) which they classified as potential (gravel disturbance that appears to have been constructed by a fish but without a defined pit and loose gravel), definitive (defined pit and loose gravel) and faded (previously flagged redds that no longer has a defined pit). The crews also recorded the number of spawning fish. To allow individual identification of redds, the crews measured the distance to the left bank (to 0.1 m) and took georeferenced and date-time stamped instream and shoreline photographs.

ELECTROFISHING SURVEYS

The densities of age-1 and age 2+ (referring to fish from the age of 2 until the development of the adult body form) WCT in the UFR were assessed through fall backpack electrofishing.

Removal-depletion electrofishing used stop nets at three single mesohabitat (pool, riffle, glide or cascade) sites of about 10 to 35 m in length (and 100 m^2 in wetted area) at 25 different index locations (75 sites total), covering approximately 1% of fish-bearing habitat. The sites at each location are visually selected. which may introduce bias with crews tending to avoid habitat that cannot easily be classified by meso-habitat unit. See Cope et al. (2016) for a description of mesohabitats. Between one and three passes were conducted at each site to estimate capture efficiency based on the decline in catches.

Backpack electrofishing, which surveyed wadeable habitat (<0.6 m), was conducted by teams of three equipped with an LR-24 Smith-Root backpack electrofisher, fibreglass poled dipnet and 1 m wide pole seine. Crews enclosed approximately 100 m^2 of mesohabitat with block nets. Where wetted width did not exceed net length, nets were anchored perpendicular to the shoreline and spanned upstream and downstream of the sample area. Nets were configured into stable positions with ropes, bipod stays, and anchors, with the lead line adjoined to stream bed contours using boulders as weights. If wetted width exceeded net length, crews would place one net downstream, one upstream, and one parallel to shore, enclosing the mesohabitat unit. Electrofishing was initiated at the downstream net and proceeded upstream in a systematic bank to bank sweep, followed by a sweep back towards the downstream net. Downstream nets were monitored for drifting fish. Similar search patterns were repeated in each successive electrofishing pass.

Electrofishing effort (seconds) was recorded at the end of each pass. Fish captured were weighed (to 0.1 g from 2013 to 2020 and 0.01 g in 2021), measured (to mm), inspected for any external physical anomalies following the DELT protocol (Ings and Weech 2020; results addressed in a separate document) or injuries, and photographed in a fish viewer. To obtain accurate fry and small fish weights, a container was filled with water and placed on the scale. The scale was zeroed and the fry was added to this container. All fish captured were scanned for PIT tags. Fish were held in a dark, aerated bucket before being released in the site after the last pass.

In 2021, a second electrofishing methodology was implemented to address the potential bias in site selection introduced by removal-depletion methods and allowed an increase in the proportion of habitat sampled. The method consisted of a single open (without stop nets) pass at long (~300 m) sites. Eleven long opens sites were sampled: six in the mainstem Fording River, and one site each in Greenhills, LCO Dry, Ewin, Chauncey and Henretta creeks. The starting point for each site was randomly generated. These sites covered an additional 3,300 m of habitat within the fish distributional range.

During the long, open passes, two crew members electrofished in an upstream direction while a third crew member processed fish. The fourth crew member recorded the start and end locations and times and recorded the locations and times of all observed and captured fish. On larger streams, electrofishing was limited to one bank. If the channel split, the channel with the higher discharge was shocked. Large, deep pools with large numbers of (sub)adults were not shocked to avoid unnecessary stress. These pools were also not included in the small, closed sites. All captured fish were measured (to mm), weighed (to 0.01 g), inspected following the DELT protocol and photographed in a fish viewer. Captured fish were released within 5 m of their point of capture in habitat with a suitable depth and velocity.

SNORKEL SURVEYS

To assess subadult and adult numbers using downstream snorkel surveys were conducted in September. In 2021 the surveys were initiated on August 30th and continued until September 4th (Table 3).

Table 3. (Sub)adult snorkel dates by year.

Year	Start Date	End Date
2012	Sep-16	Sep-22
2013	Sep-04	Sep-09
2014	Sep-02	Sep-08
2017	Sep-05	Sep-12
2019	Sep-04	Sep-11
2020	Sep-07	Sep-12
2021	Aug-30	Sep-04

Snorkel surveys were conducted using the boundaries as start and end locations of the 15 UFR sections (see Cope et al. 2016 for a detailed description) These include 11 mainstem upper Fording River sections plus three sections in Henretta Creek, including Henretta Lake and one section in Fish Pond Creek. In 2017, sections S1 and S2 in Henretta Creek and sections S7-S10 along the Fording River were further subdivided into 23 treatment and control sub-sections. The purpose of these sub-sections was to monitor and enable more detailed fish distribution, habitat use and trend monitoring data to evaluate restoration effectiveness.

The following areas have not been snorkelled in any of the surveys since 2012 (Cope 2020).

- The uppermost section (S11) in the UFR representing 11 km of headwater stream channel habitat due to the low water volume and high gradients,
- The lowermost 370 m of section S1 above Josephine Falls due to obvious safety concerns, and
- Other potential fish bearing tributaries (*i.e.*, Chauncey, Ewin, and Dry Creeks) due to low water volume and small stream size. These tributaries are sampled as juvenile rearing tributaries using removal-depletion electrofishing techniques.

If any braids or side channels were encountered, the channel with most discharge was surveyed. Logjams were surveyed to the best of the crew's ability, but some logjams were not surveyed due to safety concerns.

Crews consisted of two snorkellers and one onshore data recorder, with the exception of Henretta Lake where four or five observers were employed. Snorkellers wore dry suits. During daylight hours, snorkelers started at the upstream point of their survey and snorkelled downstream. A crew included at least one experienced snorkeler who was familiar with the site. Prior to starting the survey, a water sample was taken to measure Nephelometric Turbidity unit (NTU) and the visibility (m) was estimated with a secchi disk.

Each snorkeler was assigned to a "lane" in the stream channel, incorporating an approximately 3 – 5 m width from the center of the channel to nearest streambank. In narrow channels (<15 m width) a single snorkeler was used with a second observer on shore. Crew members frequently stopped to discuss observations, compare length estimates, and to discuss whether duplication in observations had occurred. Suitable habitat was identified based on water depth (i.e., sufficient depth for mask submersion and suitable WCT habitat) and available cover (including tertiary habitat, log jams, undercut banks, etc.). Survey start and end points were recorded along with all sighted fish locations and fork lengths to the nearest 10 mm. Any abnormalities were noted. Crew members calibrated fork length estimates using strings knotted at 10 mm intervals.

Estimates of observer efficiency relied on the mark-recapture program of previous years (2012, 2013, 2014; see Cope 2020b). Observer efficiencies are affected by changes in water clarity from peak discharge and flood events (Figure 2), however in 2021 these conditions were consistent with previous years.

DISCHARGE

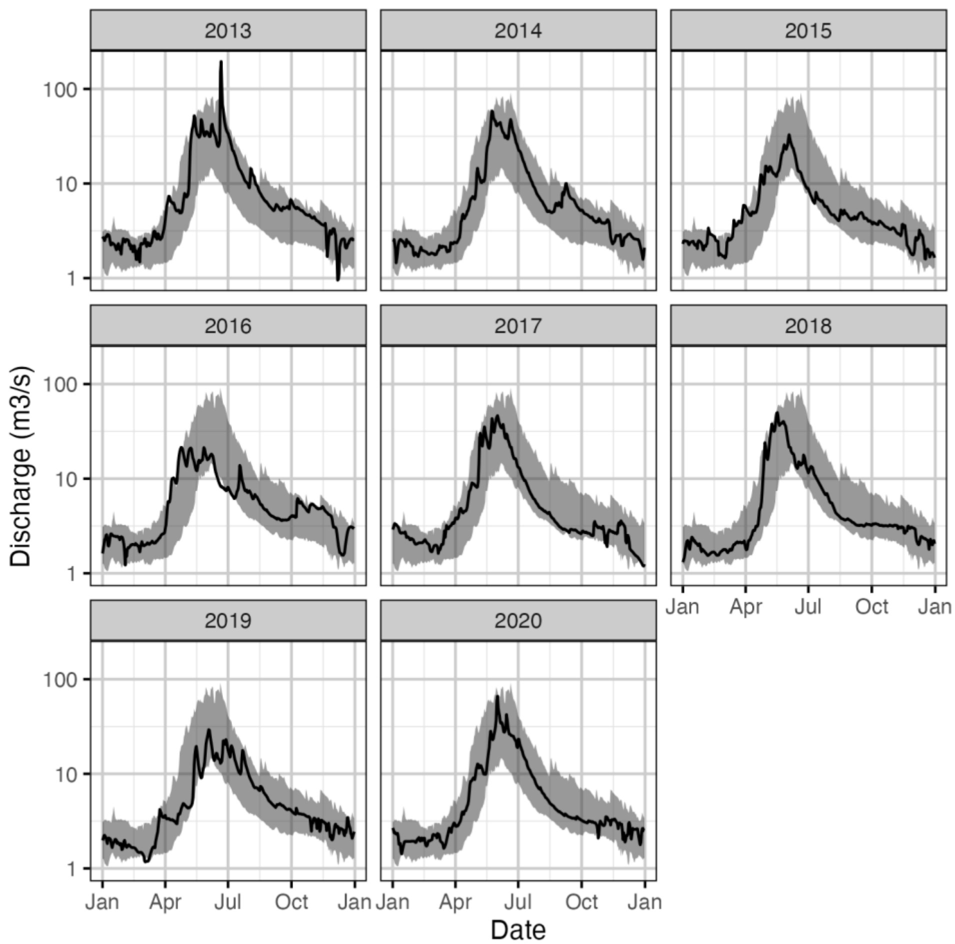

Figure 2. The mean daily discharge on a log scale by date and year at Water Survey of Canada station Fording River at the Mouth (08NK018). The grey band indicates the 95% quantiles from 1970 to 2020. The 2021 discharge data was not available at the time of reporting.

DATA PREPARATION

The historical (pre-2020) field data and the 2020 redd data were provided by Teck Coal Ltd. as an assortment of Excel spreadsheets and shape files. The 2020 snorkel and electrofishing and the 2021 field data were provided by Lotic Environmental Ltd. as Excel spreadsheets, gpx and kmz files. The 2021 redd data at the smaller repeated sites were provided by Ecofish Research Ltd. as Excel spreadsheets. The watershed, stream, lake and manmade waterbody spatial objects were downloaded from the BC Freshwater Atlas. The data were extracted and cleaned and tidied before being stored in a purpose-built SQLite database using R version 4.1.2 (R Core Team 2020).

STATISTICAL ANALYSIS

Model parameters were estimated using Bayesian methods. The estimates were produced using JAGS (Plummer 2015). 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 $\hat{R} \leq 1.05$ (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 summarised in terms of the point *estimate*, *lower* and *upper* 95% credible limits (CLs). The estimate is the median (50th percentile) of the MCMC samples while the 95% CLs are the 2.5th and 97.5th percentiles.

The results are displayed graphically by plotting the modeled relationships between particular variables and the response(s) with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their mean and first level values, respectively, while random variables are held constant at their typical values (expected values of the underlying 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% credible intervals (CIs, Bradford et al. 2005). Credible intervals are the Bayesian equivalent of the confidence intervals used in frequentist statistics.

The analyses were implemented using R version 4.1.2 (R Core Team 2019) and the mbr family of packages.

MODEL DESCRIPTIONS

REDD FADING

Redd surveys provide counts of recorded gravel disturbances that were classified as definitive redds by a crew lead on particular days. To estimate the expected count of unique definitive redds (if surveys were conducted every day and all redds were marked to avoid double-counting) an estimate of the number of days until a redd fades (is no longer definitive) is required. Since a subset of redds were flagged in 2021 and their subsequent status recorded, it was possible to estimate the number of days until 50% of redds had faded based on a simple exponential model.

Key assumptions of the redd fading model include:

- The daily probability of fading is constant.

REDD COUNTS

The redd counts were analysed using a hierarchical Bayesian Area-Under-the-Curve (AUC) model (Hilborn et al. 1999; Su et al. 1999), to estimate the expected total redd count. This is the number of definitive redds that an average observer would be expected to count if they went out every day and marked every definitive redd they encountered to prevent double-counting. For the purposes of the analysis the UFR was divided into five redd divisions (see Figure 3 below).

Key assumptions of the redd counts model include:

- The expected total redd count varies by survey division and/or creek.
- Spawning activity is normally distributed through the season.
- Definitive redds fade after 19 days (based on redd fading rates).
- The variation about the expected redd count is normally distributed.

Due to the lack of information on where and when surveys were conducted it was not possible to include the redd counts from 2013-2015 or 2020.

LIFE STAGES

Distinguishing fish life stages is essential for evaluating the drivers of a population's dynamics. The current report recognizes the following seven life-stages: eggs, alevins, age-0 (fry), age-1, age-2+, subadults and adults (as defined in the Glossary). For the purposes of the current report, fish increase in age by one year on January 1st. Thus, an egg that is deposited in the gravel in the spring and emerges as a fry in the late summer is age-0 until the end of the calendar year whereupon it becomes an age-1 individual. Following Cope et al. (2016), subadults and adult which we collectively refer to as (sub)adults are fish ≥ 200 mm. Based on visual examination of length-frequency plots of fish caught by backpack electrofishing, the sizes of age-0 and age-1 fish appear to be stream dependent (Table 4). For example, age-1 fish in Ewin Creek were judged to be between 45 and 94 mm compared to age-1 fish in Greenhills Creek which were judged to be between 75 and 124 mm. In the current report age-2+ fish are individuals which are too big to be age-1 and too small to be (sub)adults.

Table 4. The age-1 minimum and maximum inclusive fork length boundaries by stream name based on visual inspection of length-frequencies. Absent streams have the same boundaries as the UFR.

Stream Name	Min	Max
upper Fording River	65	114
Greenhills Creek	75	124
LCO Dry Creek	50	99
Ewin Creek	45	94
Chauncey Creek	70	119
Lake Mountain Creek	75	124
Henretta Creek	55	104

LENGTH-AT-AGE

The length of the age-0 fish captured by electrofishing was estimated using a generalized linear mixed effects model. Fry length is an important predictor of their overwintering survival. The lengths of the age-1 and age-2+ fish were not analyzed due to their sensitivity to the length boundary between age-1 and age-2+ fish and because age-2+ fish consist of multiple cohorts.

Key assumptions of the length-at-age model include:

- Fork length varies randomly by stream and year.
- The residual variation in the fork lengths is normally distributed.

Preliminary analysis indicated that day of the year and year within stream as a random effect were not informative predictors of the fork length.

BODY CONDITION

The electrofishing length and weight data were analysed using an allometric mass-length model to evaluate body condition (He et al. 2008). Body condition, which reflects a fish's weight relative to its length, is a measure of health and growth potential (Bentley and Schindler 2013). Fish < 65 mm were excluded from the analysis as the error in their weight measurements was a relatively high proportion of their absolute weight.

The model was based on the allometric relationship

$$W = \alpha L^{\beta}$$

where W is the weight (mass), α is the coefficent, β is the exponent and L is the length.

To improve chain mixing the relation was log-transformed, i.e.,

$$\log(W) = \log(\alpha) + \beta \cdot \log(L)$$

Key assumptions of the condition model include:

- α varies randomly by year.
- The residual variation in weight is log-normally distributed.

Preliminary analysis indicated year as a random effect was not an informative predictor of β.

ELECTROFISHING

The single and multipass electrofishing data for age-1 and age-2+ fish were analysed by life stage using a hierarchical Bayesian removal model (Wyatt 2002). Between 2013 and 2021 three different mesohabitat sites were sampled at each index location. The new sites in 2021 represent 300 m long open single pass sites. All passes were used in the analysis under the assumption that the site was closed. This assumption was considered reasonable given the longer length of the open sites allowing for less fish movement out of the site. Young-of-year fish (age-0) were excluded due to the high temporal and spatial variability associated with their late emergence from clustered redds as well as their low capture efficiency and the fact that their numbers have yet to be thinned by density-dependent mortality (Johnston and Post 2009; Dauwalter et al. 2009).

Key assumptions of the model include:

- Lineal density varies randomly by year and location.
- The number of fish at each site in each year is described by an over-dispersed Poisson distribution.
- The capture efficiency varies with the electrofishing effort.
- The catch on each pass is binomially distributed.

Preliminary analysis indicates that habitat type (mainstem vs tributary), site width and mesohabitat type are not informative predictors of density.

SNORKEL

The snorkel counts for the upper Fording River population were plotted by year and section for (sub)adult$s$. The abundance of (sub)adult fish from 2017 to 2021 was calculated assuming the intermediate observer efficiency of 32% from Cope (2020b).

FECUNDITY

Fecundity, the number of eggs per spawning female, is a key predictor of subsequent recruitment. Following Ma and Thompson (2021) the fecundity was calculated based on the average (sub)adult length (L) and using the following allometric relationship from Corsi et al. (2013).

$$E = \exp_{10}(-4.265 + 2.876 \cdot \log_{10}(\frac{L - 1.69}{1.040}))$$

The annual fecundity was estimated by calculating the number of eggs for each (sub)adult observed by snorkeling based on length or the mid-point of its size category when fish sizes were binned, up to a maximum of 400 mm (the largest consistently used upper bound) and then taking the arithmetic mean.

RECRUITMENT

The total annual egg deposition was calculated from the fecundity (eggs per female) and the estimate of the (sub)adults assuming a 1:1 sex ratio and repeat spawning every other year (Liknes and Graham 1998). The egg to age-1 survival (Pulkkinen et al. 2013) was calculated by dividing the estimate of the age-1 individuals by the total egg deposition the previous year. The egg deposition was plotted in terms of the number of eggs per 100 m of stream length to allow comparisons among systems.

POPULATION MODEL

The egg-to-age-1 survival required for population replacement was taken from the Excel workbook provided by Ma and Thompson (2021; Table 5) with one modification. The proportion mature by age (P_{age}) was calculated using the following equation (as opposed to a lookup table to allow the uncertainty in the maturation schedule to be quantified through a single parameter - see below).

$$P_{\text{age}} = \frac{\text{age}^{12}}{A_s^{12} + \text{age}^{12}}$$

The uncertainty in the egg-to-age-1 survival required for population replacement was quantified by independently sampling from the uncertainty for each parameter assuming a truncated normal distribution of the form:

$$N(\text{estimate}, \frac{\text{upper} - \text{lower}}{3.92})\text{T}(\text{lower,upper})$$

The uncertainty in the length-at-age (L_{age}) was calculated using the same approach. The estimates of the Von Bertalanffy growth parameters (L_inf, k and a0) in the population model of Ma and Thompson (2021) are based on Cope et al. (2016).

$$L_{\text{age}} = \text{L\_inf}\,(1 - \exp\,(-\text{k} * (\text{age} - \text{a0})))$$

Table 5. The life-history parameter estimates for the upper Fording River population from Ma and Thompson (2021).

parameter	estimate	lower	upper	description
S_J	0.3835	0.20	0.574	Juvenile Survival
S_A	0.733	0.68	0.79	(Sub)adult Survival
A_max	14	12	16	Maximum age (yr)
L_inf	462.77	270	464	Mean maximum fork length (mm)
k	0.15	0.11	0.195	Growth rate (yr-1)
a0	-0.45	-0.10	0.212	Age at zero length (yr)
As	3.9	2.9	5.0	Age at 50% maturity

REPLACEMENT

To facilitate further comparisons the expected replacement rate was calculated by dividing the estimated egg to age-1 survival by the estimated egg to age-1 survival for replacement based on the parameters from the population model.

RESULTS

SPAWNING (REDD) SURVEY

REDD FADING

The redd fading model estimated that 50% of redds are no longer definitive after 19 days (95% CI 14-26).

REDD COUNTS

Spawning was first recorded in early June in the UFR, Ewin and Greenhills Creek, and lasted until early August in Chauncey Creek (Figure 3). Based on the AUC model spawning was estimated to start on June 5th and continue until August 11th (Table 6).

Table 6. The estimated timing of start (2.5% of spawning complete), peak (50% of spawning complete) and end (97.5% of spawning complete) spawning in the mainstem and tributaries combined with 95% CIs.

timing	estimate	lower	upper
start (2.5%)	05-Jun	28-May	11-Jun
peak (50%)	08-Jul	02-Jul	17-Jul
end (97.5%)	11-Aug	29-Jul	29-Aug

In 2021, the densities of redds in the mainstem UFR were highest in sections S2, S6, S8-S9 and S10-S11 (Figure 4). Redd densities were also high in the lower 0.6 km of Greenhills Creek below the culvert, Chauncey Creek and Porter Creek. As the extent of the surveys in years prior to 2021 is unknown, redd count data for 2021 cannot be reliably compared to historical counts. The estimated expected total count of definitive redds in 2021 was 320 (95% CI 215-516) with most redds located on the mainstem of the UFR (Figure 5).

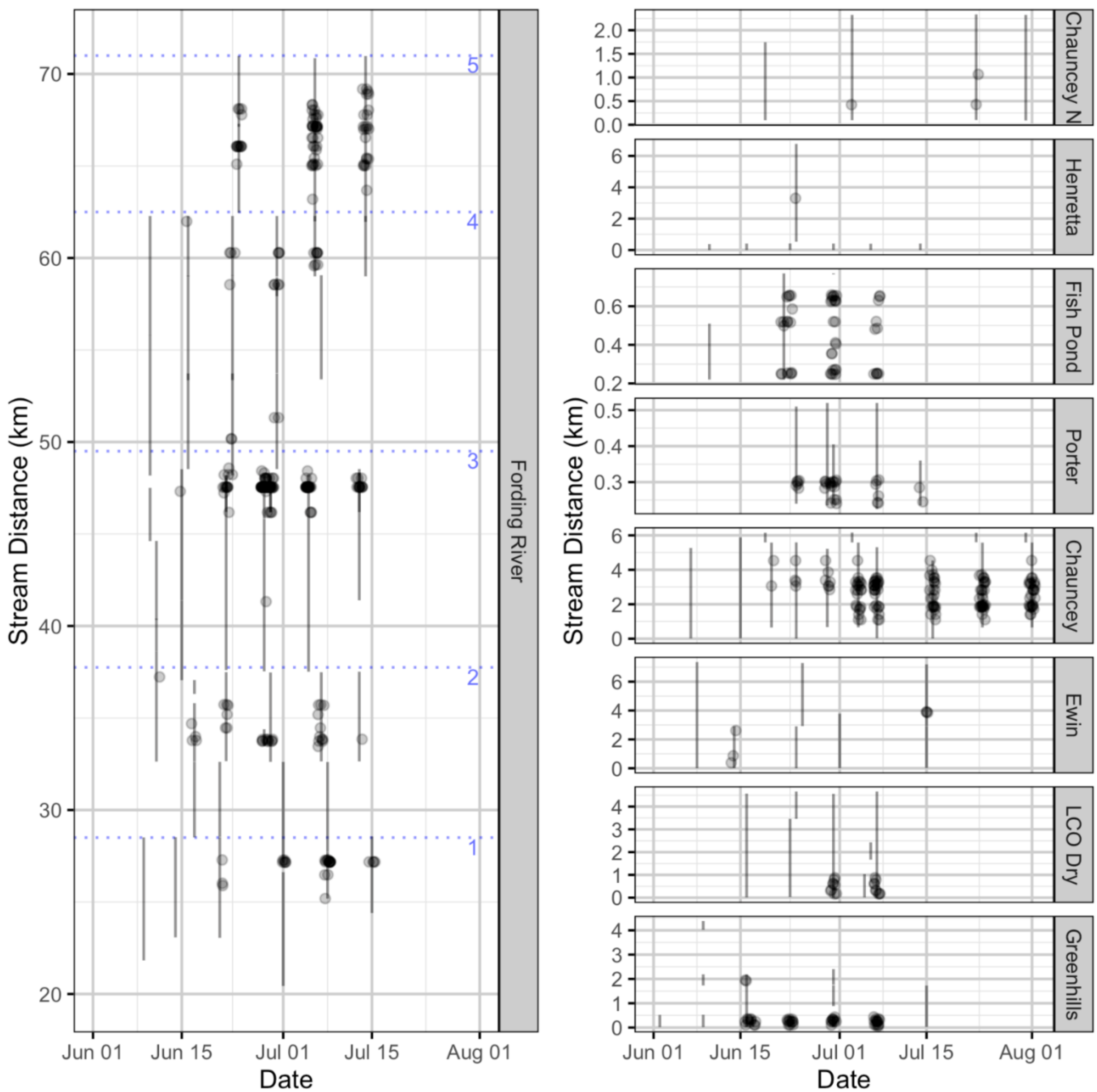

Figure 3. Definitive redds in 2021 by date, stream distance and stream. Visits are indicated by vertical lines. For the purpose of estimating the total expected redd counts the upper Fording River was divided into five redd divisions. The points are jittered and partially transparent to better indicate the redd densities.

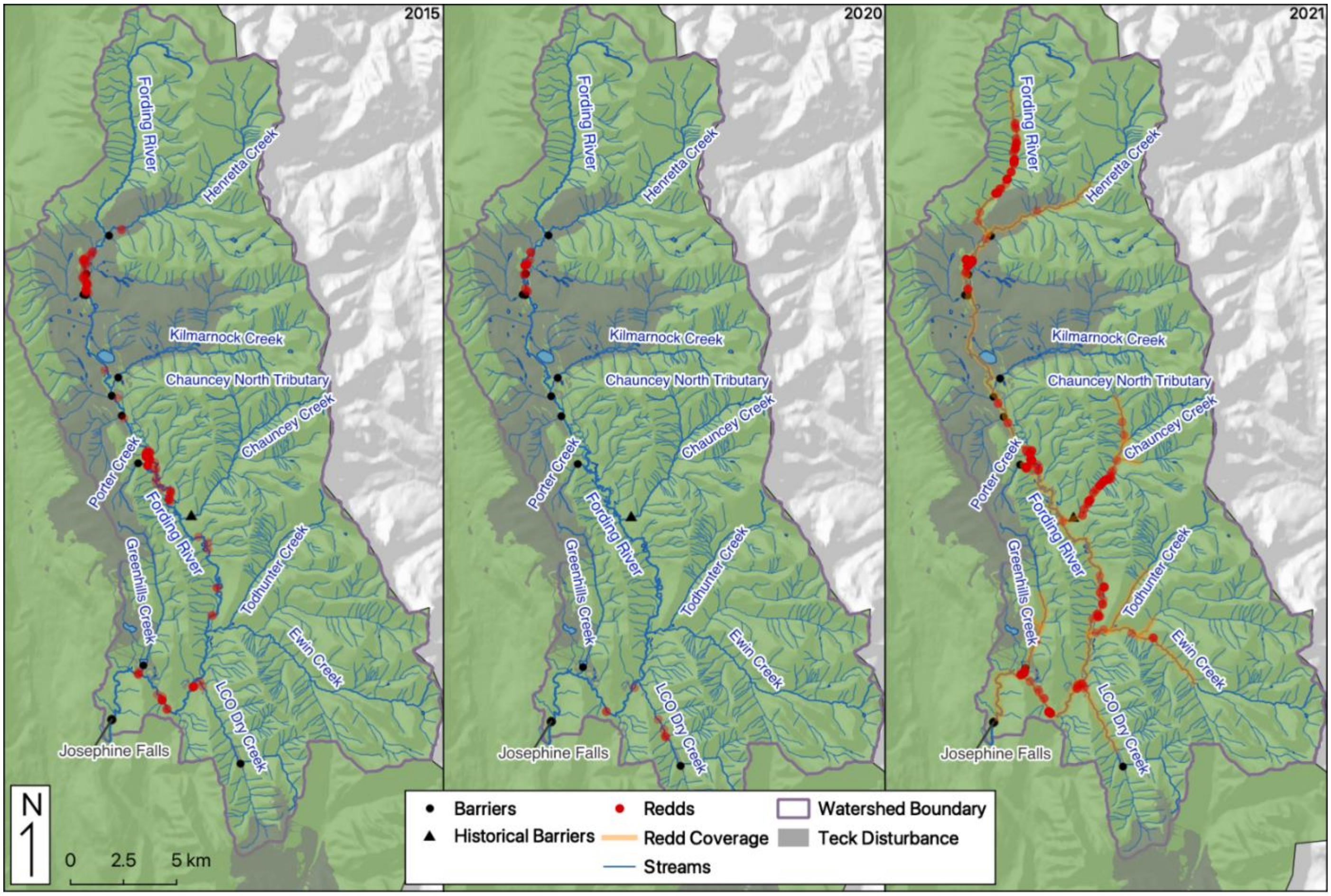

Figure 4. The spatial distribution of definitive redds by year. Redds are indicated as transparent points so that more intense color indicates higher densities.

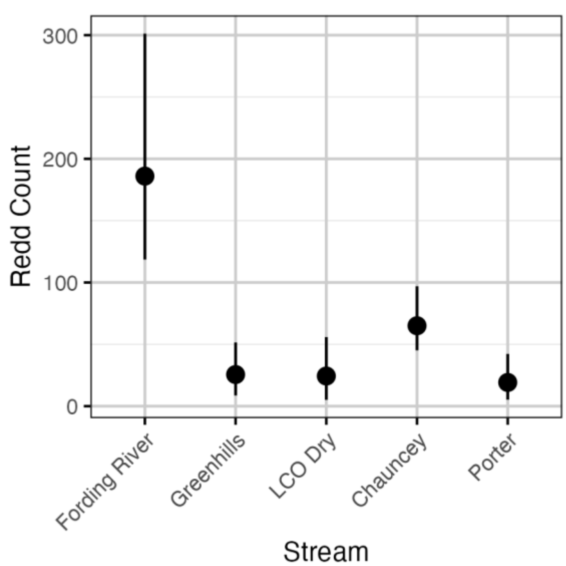

Figure 5.The estimated expected total count of definitive redds in 2021 by stream (with 95% CIs).

LCO DRY CREEK

Five unique definitive redds were recorded above the culvert and one below the culvert on LCO Dry Creek in 2020. In 2015 and 2021 nine and ten definitive redds were recorded below the culvert, respectively, and no redds were recorded above the culvert (Figure 6).

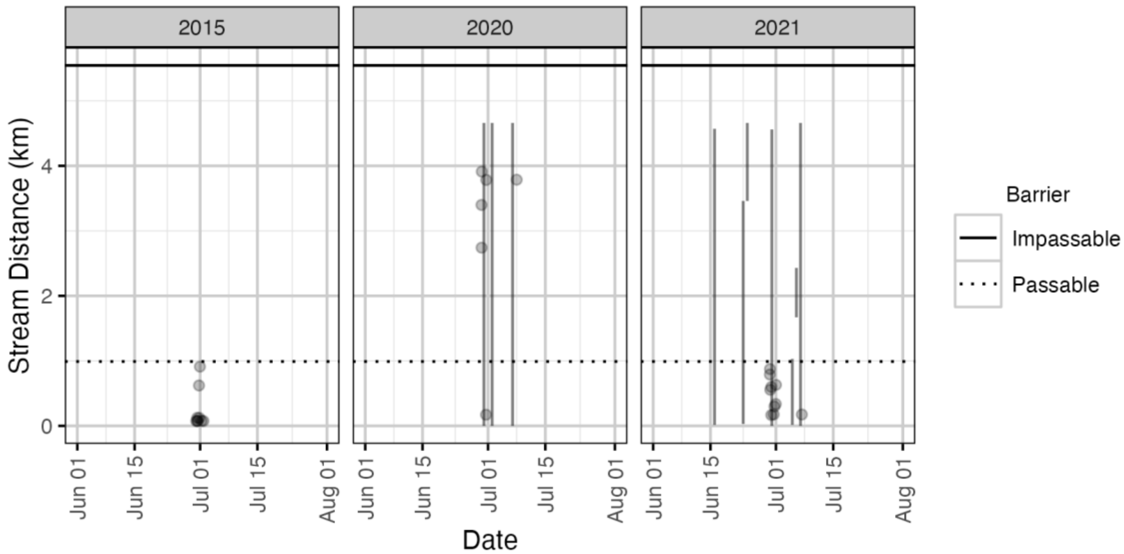

Figure 6. The unique definitive redds in LCO Dry Creek by stream distance, date and year with respect to the barriers. Visits are indicated by vertical lines. The dates and coverage of the surveys in 2015 are unknown. Redds are partially transparent and jittered to better convey information on redd density.

ELECTROFISHING

In 2021, the backpack electrofishing surveys covered 4.2 km which corresponds to approximately 5% of the habitat used in the calculation of the population abundance (Table 7). Previous years covered ~1% of the habitat.

Table 7. The total site length, percent habitat coverage and number of fish caught on the first pass by year and life stage in the UFR.

Year	Start Date	End Date	Length (m)	Percent of habitat	Age-0	Age-1	Age-2+	(Sub)adults (≥200 mm)
2013	Sep-16	Oct-01	980	1.1	20	36	34	2
2014	Sep-15	Oct-03	896	1.0	28	46	49	13
2015	Sep-14	Sep-29	877	1.0	97	110	115	13
2017	Aug-19	Aug-28	905	1.0	106	126	176	29
2019	Aug-19	Aug-28	1278	1.4	4	58	64	9
2020	Sep-14	Sep-19	1021	1.2	19	23	60	4
2021	Sep-07	Sep-23	4203	4.7	22	36	65	6

LENGTH FREQUENCIES

As detailed in the methods, fish were categorized into life stages according to length thresholds (Figure 7; Table 4). Age-1 length thresholds varied by stream, likely due to differences in water temperature. The length range for age-1 fish was as low as 45 to 95 mm in Ewin Creek and as high as 75 to 124 mm in Greenhills Creeks. In the UFR mainstem, age-1 fish were considered to be between 65 mm and 114 mm.

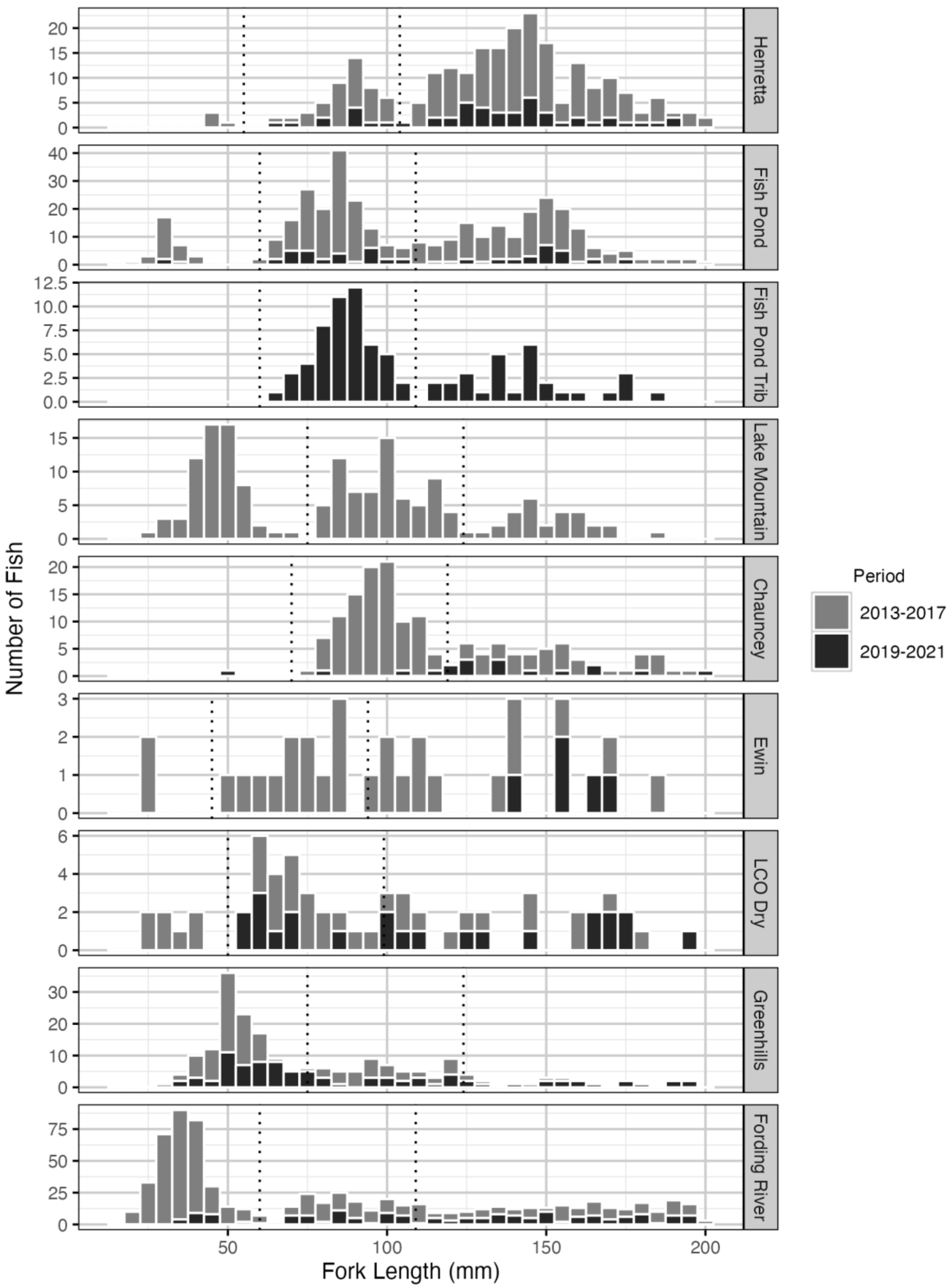

Figure 7. Electrofishing WCT captures for the upper Fording population by fork length, stream and period. The vertical dotted lines indicate the selected age-1 life-stage boundaries.

LENGTH-AT-AGE

AGE-0

The average length of an age-0 fish in the mainstem UFR on October 1st varied between a low of 33 mm (95% CI 25-42) in 2017 and a high of a 43 mm (95% CI 31-54) in 2015. In 2021 the estimate was 42 mm (95% CI 31-53). Insufficient age-0 fish were captured in 2019 to allow the size to be reliably estimated (Figure 8).

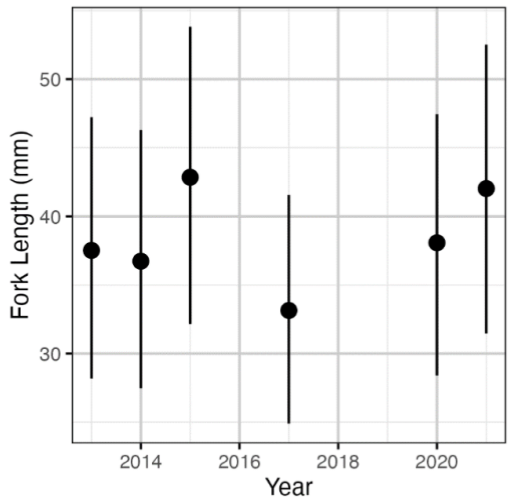

Figure 8. Estimated annual average fork length of age-0 fish in the mainstem upper Fording River, October 1st. Error bars represent 95% CIs.

Fork lengths for age-0 fish are shortest in Ewin Creek at 28 mm (95% CI 19-37) and LCO Dry Creek at 29 mm (95% CI 24-34) and longest in Greenhills Creek at 57 mm (95% CI 51-63; Figure 9).

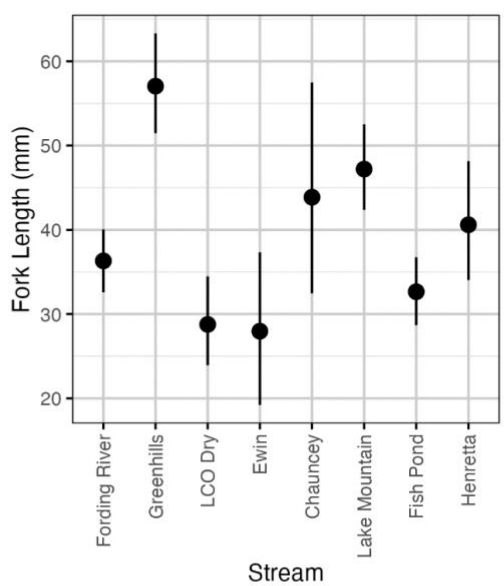

Figure 9. Estimated fork length for typical age-0 fish on October 1 in a typical year by stream (with 95% CI).

GROWTH

The Von Bertalanffy growth curve based on Cope et al. (2016) suggests that fish become subadults (200 mm) between age-3 and age-6 (Figure 10).

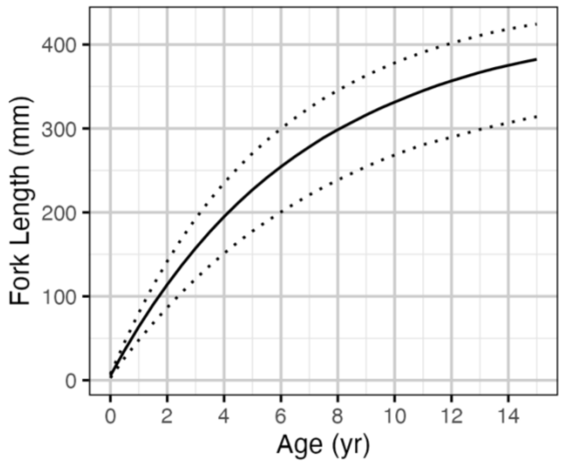

Figure 10. The length-at-age assumed by the population model of Ma et al. (2021) based on the Von Bertalanffy growth parameters estimated by Cope et al. (2016).

BODY CONDITION

Fish body condition, relative to the mean, varied between a high of 4% (95% CI -0.5-8) in 2014 and a low of -5% (95% CI -9--1) in 2015. Reliable weight measurements were not available for 2017 (see Thorley et al. 2021a). Body condition has been near or above average in the past three years of monitoring with a value of 1% (95% CI -3-6) in 2021 (Figure 11).

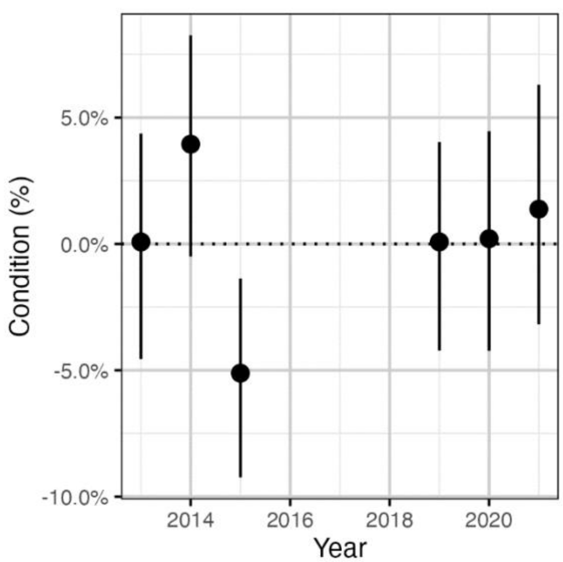

Figure 11. The percent change in the body condition (weight) for a 100 mm fish relative to a typical year (0% change) by year (with 95% Cis).

CAPTURE DENSITIES

The electrofishing data indicate high annual variability in capture densities both among and within electrofishing locations (Figure 12). The most consistently high capture densities for both age-1 and age-2+ life stages occurred in Fish Pond Creek, Henretta Creek and Chauncey Creek. However, the plot must be interpreted with caution since it represents raw data and does not account for capture efficiency.

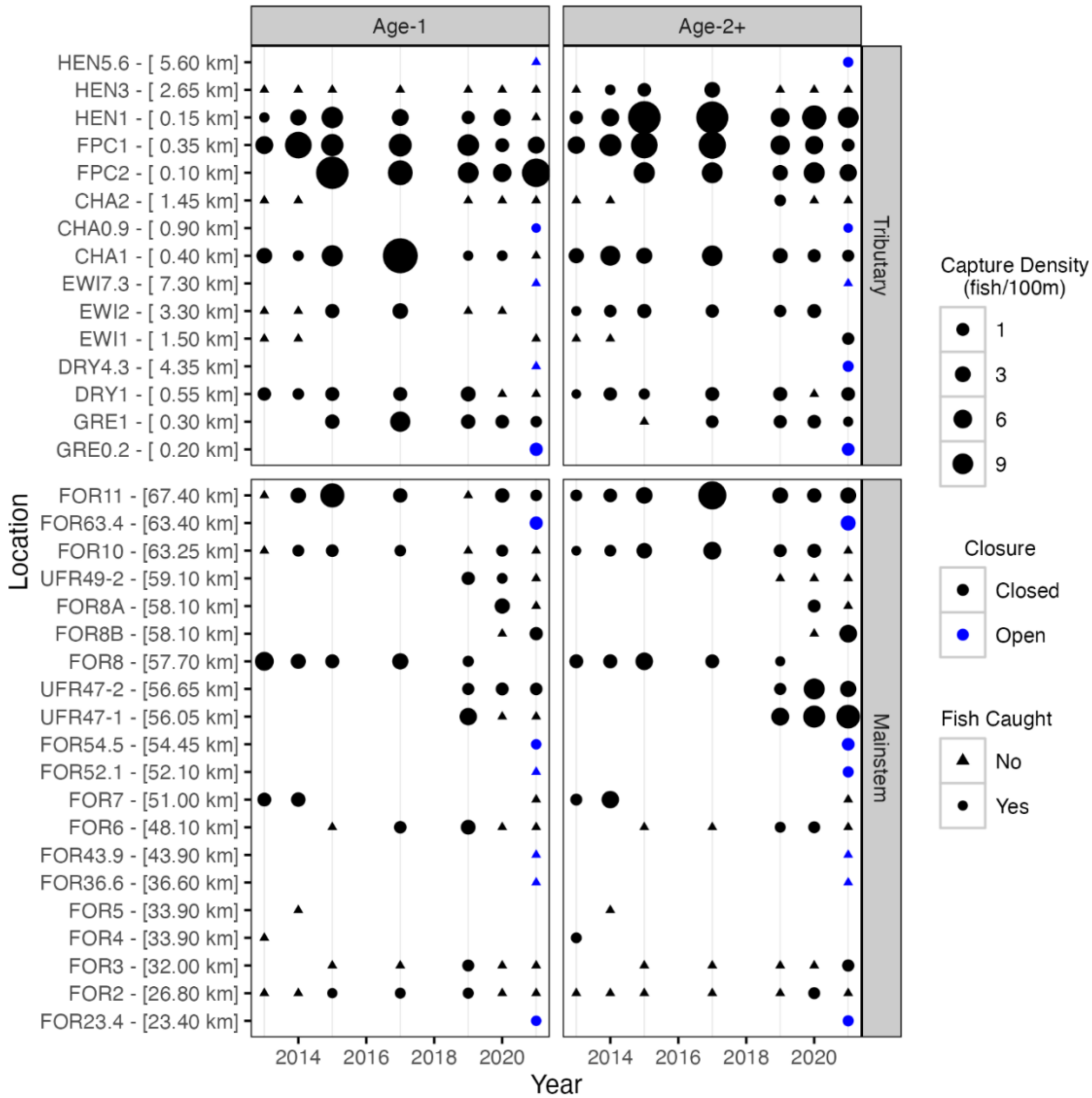

Figure 12. The electrofishing capture density across all completed passes by year, location, life stage, and habitat. Locations on the y axis are listed in an upstream direction as indicated by the stream distance (km) in square brackets (refer to Figure 1 for a map of the stream distances).

CAPTURE EFFICIENCY

As expected the capture efficiency was higher for age-2+ fish relative to age-1 fish particularly at lower electrofishing effort (Figure 13).

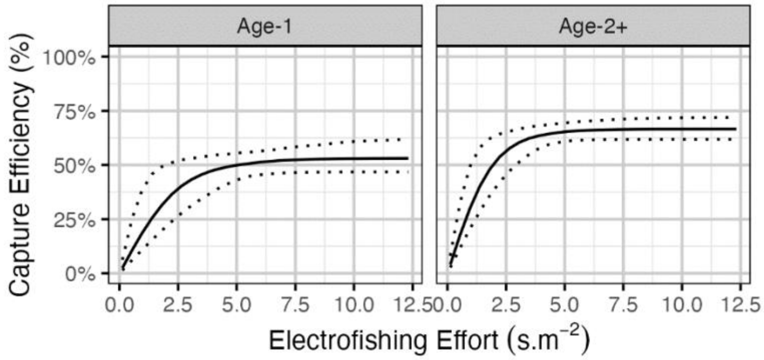

Figure 13. The capture efficiency by electrofishing effort and lifestage (with 95% CIs).

SPATIAL DISTRIBUTION

The spatial distribution of age-1 and age-2+ WCT in the UFR are similar. Densities are variable in tributaries but highest overall in Fish Pond, Chauncey and Henretta creeks and section S1 of the UFR. Densities tend to increase in the mainstem up to about section S8 (Figure 14, Figure 15).

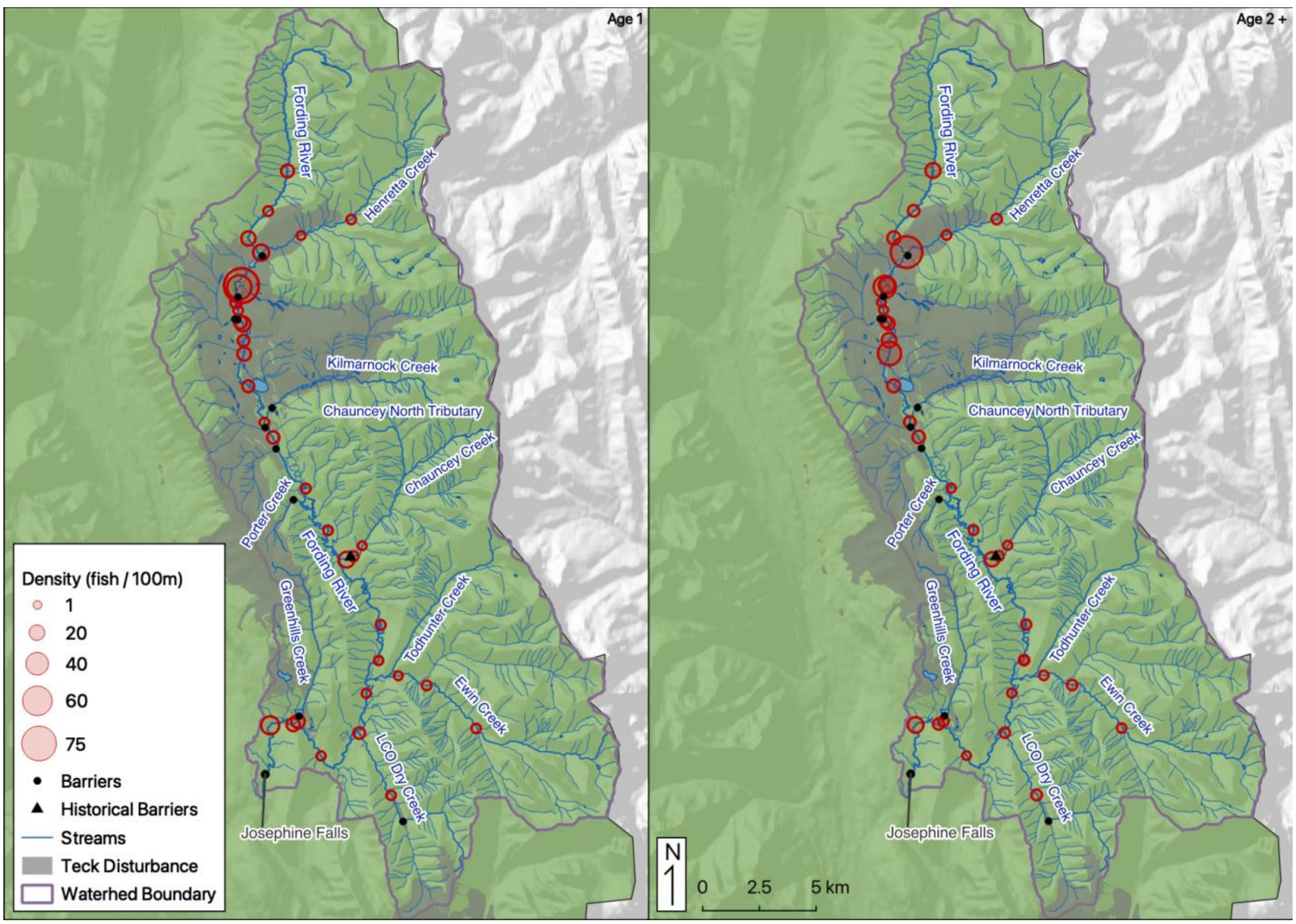

Figure 14.The estimated density in a typical year by location and life-stage.

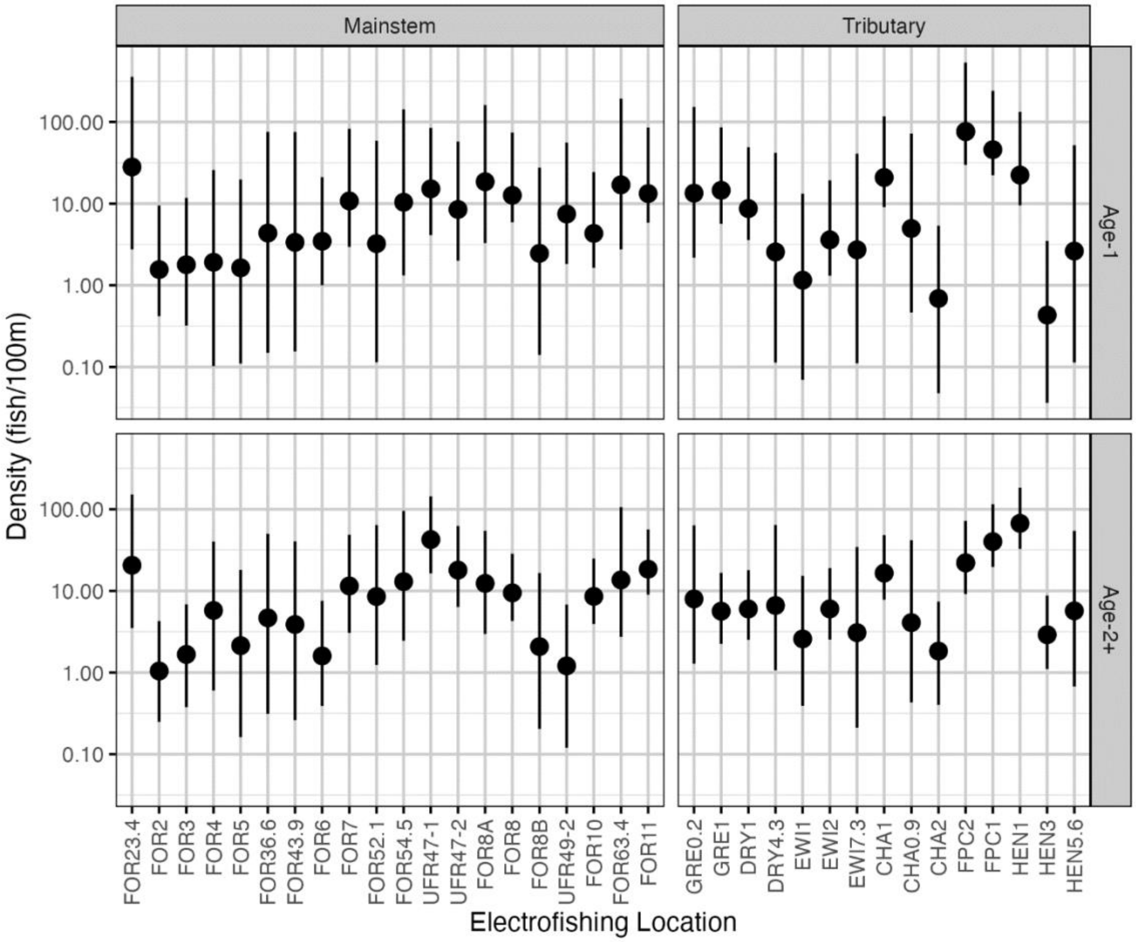

Figure 15.The estimated density of age-1 and age-2+ WCT in a typical year by location, habitat and life-stage (with 95% CIs). The densities are plotted on a logarithmic scale.

ABUNDANCE

AGE-1

The abundance of age-1 fish in the UFR was estimated to be 8,300 fish (95% CI 3,500-32,000) in 2013 rising to a peak of 25,000 fish (95% CI 11,000-96,000) in 2017. By 2019 numbers had dropped to an estimated 11,000 fish (95% CI 4,700-40,000) before continuing to decline to 5,100 fish (95% CI 2,100-18,000) in 2021 (Figure 16).

AGE-2+

The pattern and magnitude of the estimated abundance of age-2+ fish in the UFR is very similar to that of age-1 fish. Age-2+ fish abundance was estimated to be 4,900 fish (95% CI 2,100-14,000) in 2013, to peak at 26,000 fish (95% CI 12,000-69,000) in 2017, and drop to 8,700 (95% CI 4,300-23,000) in 2019 (Figure 16). More recently, the estimated abundance increased slightly to 12,000 fish (95% CI 5,500-33,000) in 2020 before dropping again to 6,700 fish (95% CI 3,300-19,000) in 2021.

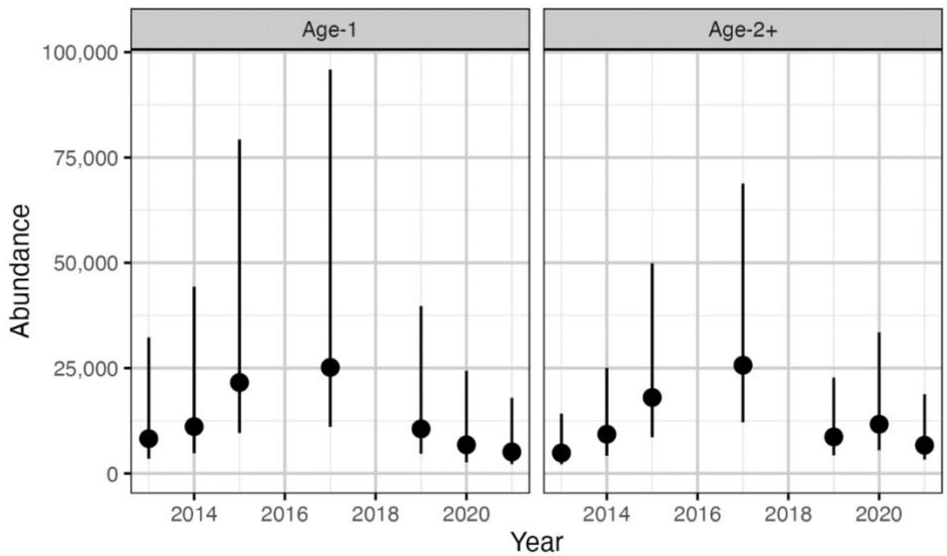

Figure 16. The estimated population abundance by year and life-stage (with 95% CIs).

SNORKEL SURVEYS

(SUB)ADULT DISTRIBUTION

Between 2012 and 2014 (sub)adults were distributed relatively evenly throughout the mainstem UFR (Figure 17). However, in 2017, densities were substantially higher in the mainstem UFR between sections S7 and S10. After two low density years in 2019 and 2020, WCT again appear to be concentrated in the upper sections. The densities in Fish Pond Creek have followed a similar pattern to those in the upper sections of the mainstem.

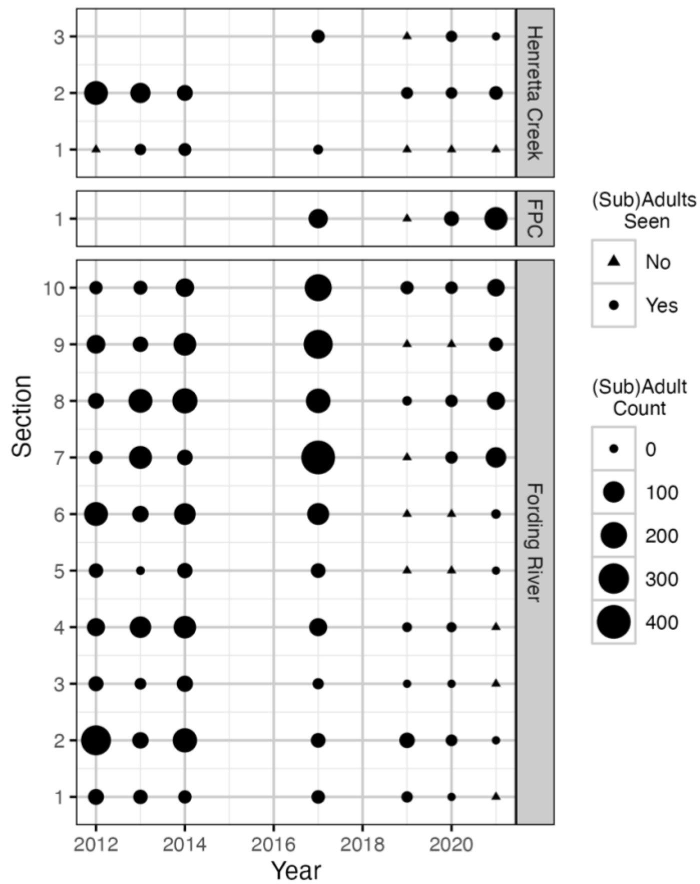

Figure 17. Raw total fall (sub)adult snorkel counts by year, section and stream. FPC is Fish Pond Creek.

(SUB)ADULT ABUNDANCE

(Sub)adult WCT abundance was estimated to be 2,600 fish in 2012. Similar to the numbers of age-1 and age-2+ fish, the (sub)adult abundance peaked in 2017 at 5,200 fish, before dropping by 94% to 330 fish in 2019. Since then, the estimated abundance has increased to 1,500 fish in 2021 (Figure 18).

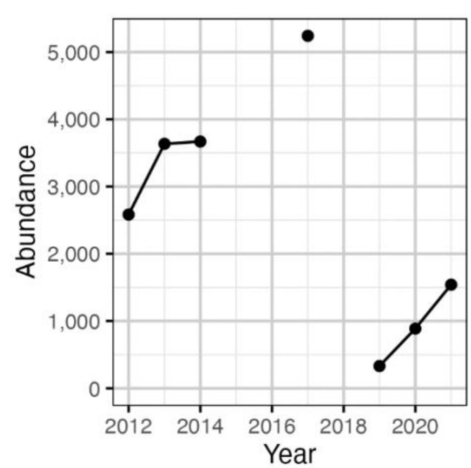

Figure 18. The estimated fall (sub)adult abundance by year assuming an efficiency of 42% for 2012, 23% for 2012 and 32% for 2014, 2017 and 2019-2021.

FECUNDITY

Based on the fecundity by fork length relationships from Corsi et al. (2013; Figure 19), the estimated annual fecundity shows a downward trend over the years monitored, varying from 780 eggs/female in 2012 to 550 eggs/female in 2021 (Figure 20).

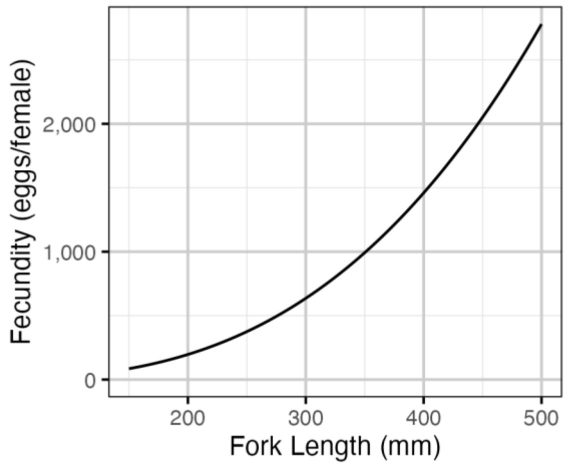

Figure 19. The assumed fecundity by fork length relationship from Corsi et al. (2013).

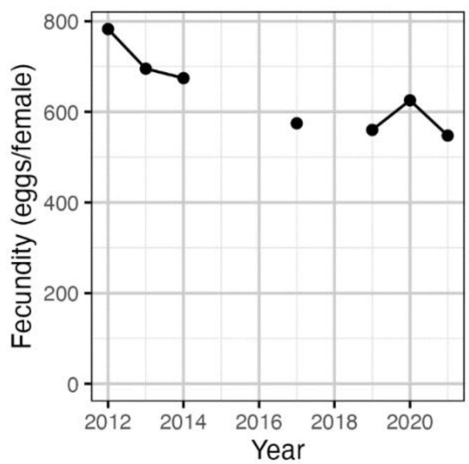

Figure 20.The estimated fecundity based on the snorkel data by year.

Not surprisingly, the estimated total egg deposition is primarily driven by the (sub)adult abundance. It was 500,000 in 2012, peaked at 750,000 in 2017 and then fell to just 46,000 in 2019 before rising steadily to 210,000 in 2021 (Figure 21)

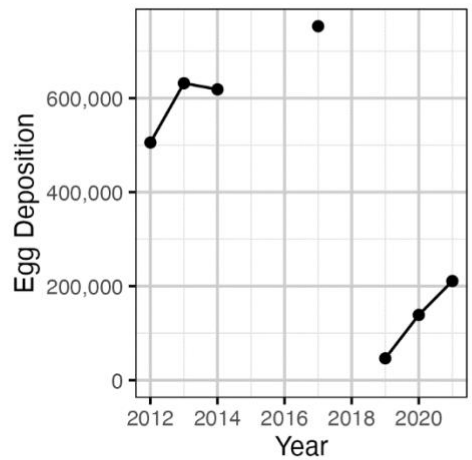

Figure 21.The estimated total egg deposition based on the snorkel data by year.

RECRUITMENT

The estimated egg to age-1 survival rates are plotted in Figure 22. The literature suggests that in a typical population an egg to age-1 survival of 5% is required for population replacement (Ma, pers. comm.) while the egg to age-1 survival required for replacement based on the parameter values provided by Ma and Thompson (2021) was estimated to be 2.5% (95% CI 1-8%).

The estimated egg-to-age-1 survival varied between 2 to 4% from 2012 to 2014. After the observed decline in population abundance in 2019, survival increased to 16% (95% CI 6-58) for 2019 and remained above replacement for 2020 at 4% (95% CI 2-15; Figure 22).

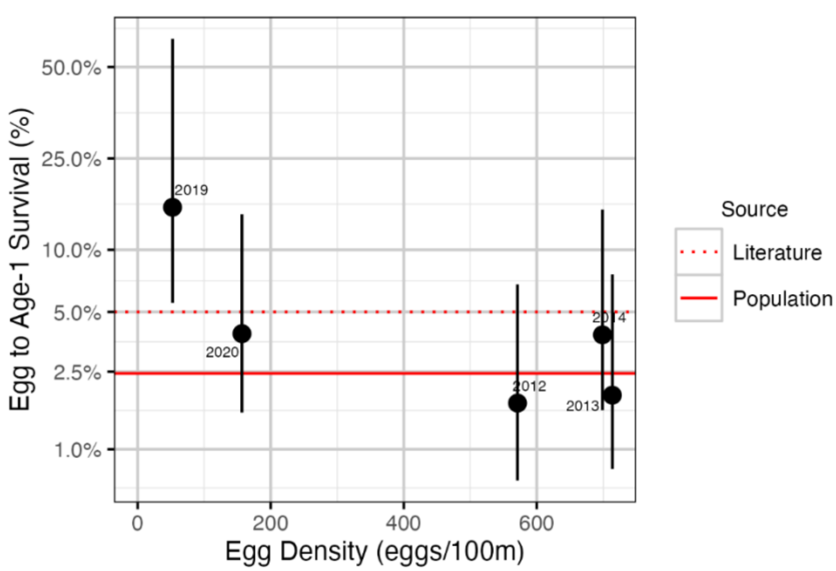

Figure 22. The egg to age-1 survival (on a logistic scale) by egg density and spawn year. The dashed red line indicates the egg-to-fry survival required for replacement based on the literature and the solid red line indicates the egg-to-fry survival estimated from population parameters (Ma and Thompson 2021). Error bars represent 95% CIs.

REPLACEMENT

To better understand the uncertainty regarding population replacement, the egg to age-1 survival rates were divided by the population-based replacement rate to give the percent replacement where 100% indicates that the egg to age-1 survival is sufficient for population replacement under typical conditions (Figure 23). The results indicate that the UFR population was most likely above 100% replacement for the 2014, 2019 and 2020 spawn years and slightly below replacement for the 2012 and 2013 spawn years.

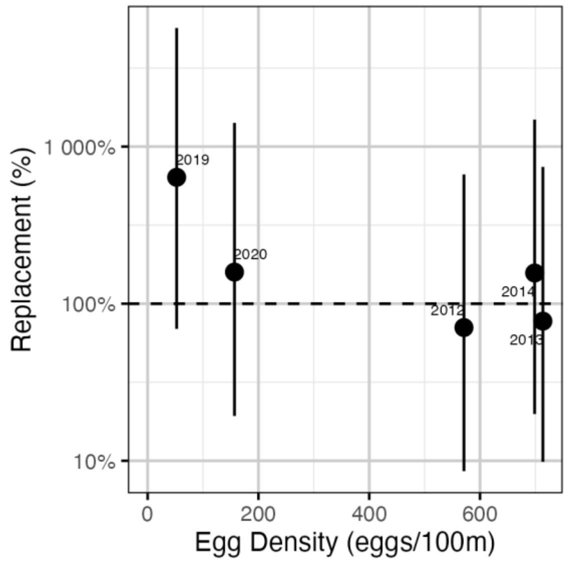

Figure 23. The population replacement rate on a log scale by egg density and spawn year (with 95% CIs representing the uncertainty in the age-1 abundance and the survival required for recruitment). The dashed line indicates population replacement.

The analytic appendix which includes model templates, parameter descriptions and parameter coefficient tables is available from:

Thorley, J.L. (2022) UFR WCT Population Monitoring 2021. A Poisson Consulting Analysis Appendix. URL: https://www.poissonconsulting.ca/f/177332170.

DISCUSSION

As outlined in the Introduction, to begin quantifying the key fish population metrics of carrying capacity, productivity and viability it is necessary to answer a series of secondary questions. We attempt to answer each question in turn and discuss key results and uncertainties.

1 WHAT IS THE GEOGRAPHIC RANGE OF THE FISH POPULATION(S)?

The geographic range of the WCT population in the mainstem UFR extends about 52 km upstream from Josephine Falls at 20 km to around 72 km and also extends into an estimated 36 km of tributary habitat. The population spans an elevational range of approximately 1,400 to 2,000 masl. The current report only considers the UFR population in the mainstem and connected tributary habitat. Key connected tributary habitat includes

- Greenhills Creek to the culvert at 0.5 km.
- LCO Dry Creek to the spillway at 5.5 km.
- Chauncey Creek.
- Porter Creek.
- Fish Pond Creek.
- Henretta Creek.

The fish in Chauncey Creek above 0.9 km were isolated from the main population by impassable culverts until August 20, 2021 (Jeff Hewitt, pers. comm.). An isolated population currently exists in about 8 km of habitat above the culvert on Greenhills Creek, and potentially in Kilmarnock Creek above the ponds. As the culverts and ponds were recently created the populations above them are demographically but not genetically distinct from the mainstem UFR. Based on a field survey by Lotic Environmental the culvert at 1 km on LCO Dry Creek was classified as passable by (sub)adults in some year. This classification is supported by the presence of redds above the culvert in 2020. Consequently the fish in LCO Dry Creek are considered to be demographically and genetically part of the UFR population. Additional large open site single pass backpack electrofishing to confirm the assumed upstream boundaries of the UFR and Greenhills populations and status of the Kilarnock population are recommended.

2 WHAT ARE THE LIFE-HISTORY STRATEGIES WITHIN THE FISH POPULATION?

WCT in the UFR exhibit a spectrum of life-history strategies from fluvial residents to fluvial and adfluvial migrants. Based on a telemetry study by Cope et al. (2016), approximately 40% of the tracked fish adopted a fluvial-migratory life-history strategy, spawning in tributaries but occupying the mainstem for the greater part of the year. Of the remainder about 50% showed little annual movement, indicative of fluvial residency. The remaining 10% were adfluvial migrants that only left Henretta Lake to spawn. Fluvial migrants had an average home range of approximately 18 km and residents ~5 km. Unlike many other systems, there was no discernable size difference between fluvial migratory and resident fish (Cope et al. 2016).

3 WHAT IS THE TIMING OF KEY LIFE-HISTORY EVENTS?

Cope et al. (2016) documented adult fish migrating to spawning areas in April and May. In a typical year, spawning commenced by May 15 and continued to about July 15 (Cope et al. 2016). In 2021, spawning was estimated based on the Area-Under-the-Curve model to begin around June 5 and peak around July 8. Cope et al. (2016) observed that spawning activity started once mean daily water temperatures were 5 ºC and daily maximums exceeded 7 ºC. Emergence of hatchery reared WCT occurs after the eggs have accumulated 575 to 600 thermal units (degree days; Kootenay Trout Hatchery pers. comm.) which is consistent with Coleman and Fausch's (2007a) estimate of 570 to 600 Accumulated Thermal Units (ATUs) for Colorado Cutthroat Trout (*Oncorhynchus clarkii pleuriticus*). Based on Cope et al. (2016), emergence and summer rearing begins in mid-July and lasted until the end of September. Migration toward overwintering areas begins in September and lasts until mid-October, while the overwintering period itself starts in mid-October and lasts to the end of March.

4 WHAT ARE THE SIZES OF KEY LIFE-STAGES?

The sizes of age-0 fish in the UFR population are variable by both year and stream, with typical fork lengths for a fry from Greenhills Creek over 50% greater than Ewin Creek (although the latter is based on a relatively small sample size). Age-0 fish from Ewin and LCO Dry Creeks were estimated to be less than 30 mm, suggesting poor overwintering survival (Sogard 1997; Coleman and Fausch 2007a, 2007b). The variation in the size of age-0 fish is also apparent in the size of age-1 fish. As discussed below all individuals < 200 mm captured by electrofishing should have scales taken to improve our understanding of the sizes of age-0 and age-1 fish.

Following Cope et al. (2016) subadults and adults were grouped together based on a size threshold ≥ 200 mm. However, based on internal examination, the smallest mature fish was 233 mm and the biggest immature fish 290 mm. Unfortunately, snorkel surveys prior to 2021 often simply recorded the length of fish as ≥ 200 mm. Consequently, the current report includes subadults with adults inflating the total egg deposition and deflating the egg to age-1 survival.

5 WHAT IS THE GROWTH RATE OF KEY LIFE STAGES?

Using combined length-at-age, length increment (recapture), and imputed length frequency data, Cope et al. (2016) estimated a growth rate parameter (k) for UFR WCT of 0.15 (95% CI 0.11-0.20), comparable to other WCT in headwater streams (range 0.13-0.20; Janowicz et al. 2018) in the Canadian Rocky Mountains. The fish were estimated to become subadults between age-3 and age-6. However, the growth rate likely varies substantially by stream and individual due to the diversity of temperature regimes and life history strategies. Evidence for this is apparent in the size of age-0 fish in different tributaries. As discussed below, increased PIT tagging of individuals to collect information on inter-annual growth is recommended.

6 WHAT IS THE SPATIAL DISTRIBUTION OF KEY LIFE-STAGES?

In 2021 the majority of the spawning activity occurred in sections S2, S8-S9 ("Clode Flats") and S10 of the UFR and Chauncey Creek. Redds were also recorded in Greenhills, LCO Dry, Ewin, Chauncey North Tributary, Porter, Fish Pond and Henretta creeks. Overall, there was no clear difference in the average densities of age-1 fish in the mainstem versus the connected tributaries although there was substantial variation between sites. In particular age-1 densities were highest in the lower part of section S2 and from sections S8 to S10. Age-1 densities in the tributaries were highest at the lowermost site in Greenhills, LCO

Dry, Chauncey and Fish Pond creeks. The spatial distribution of age-2+ fish was very similar to that for age-1 fish which is consistent with a relatively high degree of residency in juvenile fish.

From 2012 to 2014, (sub)adult WCT were distributed relatively evenly throughout the mainstem UFR, but beginning in 2017, fish appeared to concentrate in sections S7 to S10. Distribution was sparse in 2019, but 2020 and 2021 again saw a disproportionate number of (sub)adults in sections S7 to S10. The redistribution of (sub)adults could be a consequence of habitat restoration. As restoration was implemented as a series of treatment and control subsections, a before-after-control-intervention (BACI) analysis of fish densities from these units is recommended to evaluate whether habitat alterations may be the cause.

7 WHAT IS THE ABUNDANCE OF KEY LIFE-STAGES?

AGE-1

The estimated abundance of age-1 fish increased from ~ 9,000 in 2013 to over ~27,000 in 2017 before dropping to ~12,000 in 2019, ~7,000 in 2020 and ~5,000 in 2021. It is important to note that the number of age-1 fish is determined by the number of eggs deposited the previous year. Consequently, interpretation of these numbers is conducted with respect to the egg deposition the previous year in the section on survival below.

There is substantial uncertainty in the electrofishing population abundance estimates with, for example, the number of age-1 fish in 2021 varying by almost an order of magnitude from a lower 95% CL of 2,100 to an upper CL of 20,100. To reduce the uncertainty it is strongly recommended that removal-depletion at small, closed sites continue be replaced by single-pass and mark-recapture at large open sites.

AGE-2+

The estimated abundance of age-2+ fish was remarkably similar to the estimated abundance of age-1 fish in each year. To interpret the relationship between the age-1 and age-2+ abundances and separate changes in capture efficiency from changes in survival we recommend fitting a lifecycle model to the snorkel and electrofishing data. As discussed below this requires the separation of subadult and adult fish.

(SUB)ADULTS

The estimated abundance of (sub)adults increased by on average ~15% per year from ~2,500 in 2012 to over 5,000 in 2017 before declining by approximately 93% to ~ 300 in 2019. The subsequent sub(adult) abundance is estimated to have increased by approximately 125% per year. The saw-tooth pattern in the number of (sub)adults (Figure 18) suggest that the large decline between 2017 and 2019 was due to acute (short-term) as opposed to chronic conditions which is consistent with the conclusions of the Evaluation of Cause. The Evaluation of Cause Team (2021) concluded that the decline likely occurred in February–March 2019 and was caused by:

"the interaction of extreme ice conditions (due to extreme, prolonged, cold air temperatures; seasonal, winter low flows; and low winter snowpack), sparse overwintering habitats and restrictive fish passage conditions during the preceding migration period in fall 2018. While stressors such as cold weather are natural, mining development has altered the availability of overwintering habitats in portions of the river and has exacerbated the challenges to fish passage through water use, channel widening and aggradation."

8 WHAT IS THE TOTAL NUMBER OF EGGS DEPOSITED?

Based on the (sub)adult abundance estimates, length of the (sub)adults and the assumptions of a 1:1 sex ratio, and a 50% probability of spawning each year, the total egg deposition for the UFR population was estimated to have peaked at ~750,000 eggs in 2017 before falling to around 46,000 eggs in 2019, and then increasing to about 210,000 eggs in 2021. As discussed above these estimates are likely inflated by the inclusion of immature subadult fish in the abundance estimates.

9 WHAT IS THE SURVIVAL OF KEY LIFE-STAGES?

Prior to 2019 the estimated egg to age-1 survival rates were around 2.5%. Following the large reduction in (sub)adult abundance the estimated egg to age-1 survival increased to about 16% suggesting a density dependent response before dropping to about 4% for the 2020 spawn year.

The literature suggests that in fluvial populations an egg to age-1 survival rate of 5% is required for population replacement (Ma, pers. comm.) whereas calculations based on life-history parameters (Ma and Thompson 2021) from the population model suggest a rate of ~2.5%. However, despite the estimated egg to age-1 survival rates being around or below replacement prior to 2019 the (sub)adult population increased by ~15% per year. This discrepancy is consistent with deflation of the estimated egg to age-1 survival due to the inclusion of subadults in the adult population abundance estimates. Survival rates of radio tagged (sub)adult WCT in the UFR were 67% annually (Cope et al. 2016).

10 WHAT IS THE GENETIC DIVERSITY AND EFFECTIVE GENETIC POPULATION SIZE?

GENETIC DIVERSITY

The WCT in the upper Fording River above Josephine Falls are genetically pure. Based on four species-specific diagnostic nuclear loci for 30 WCT from the upper Fording watershed, Rubidge and Taylor (2005) found no evidence of hybridization with Rainbow Trout. Two of the markers were restriction fragment length polymorphisms (RFLPs) while the other two were simple sequence repeat (SSR) microsatellites. Carscadden and Rogers (2011) also found no evidence of introgression with Rainbow Trout based on nine species-specific microsatellites for 38 WCT from LCO Dry Creek and 36 WCT from Swift Creek.

Indigenous knowledge suggests that the WCT population in the upper Fording River existed prior to European contact (Jim Clarricoates pers. comm.). Except for the recently isolated WCT above the culvert on Greenhills Creek and above the ponds on Kilmarnock Creek, the WCT in the upper Fording appear to constitute a single interbreeding population. Analysis of six variable microsatellites for 38 and 36 fish from the lower reaches of LCO Dry Creek and Swift Creek, respectively, estimated the pairwise fixation index (F_{ST}) to be 0.008 indicating almost complete genetic mixing despite the streams being separated by more than 22 km (Carscadden and Rogers 2011). At the regional scale Taylor et al. (2003) reported that the upper Fording fish grouped closely with the sample from Connor Lake, whose outlet also drains into the upper Elk River, based on the eight microsatellite loci.

Taylor et al. (2003) also estimated the expected heterozygosity (H_E) for 28 WCT from 1998 and 27 WCT from 2000 from the UFR to be 0.37 and 0.54, respectively, based on the eight microsatellite loci. Across all samples which included non-hybridized individuals from 26 populations the mean expected heterozygosity was 0.56 suggesting that the genetic diversity for the upper Fording population is slightly below the provincial average. The lowest H_E was just 0.05 for WCT from Swift Creek a tributary of the Salmo River (not to be mistaken for the tributary of the Fording River with the same name).

EFFECTIVE GENETIC POPULATION SIZE

The effective genetic population size (N_E) is the number of individuals in an ideal population with equal sex ratios, random mating, non-overlapping generations, and a Poisson distributed family size that would experience the same amount of genetic drift as the observed population. The 50/500 rule states that an effective population size of 50 is required to avoid inbreeding depression in the short-term while an effective population size of 500 is required to maintain evolutionary potential in the long-term. In salmonid populations the effective population size is often assumed to be one-fifth the adult population size which puts the short and long-term minimum target adult population sizes at 250 and 2,500 individuals, respectively. The estimated (sub)adult population size was 330 at its lowest in 2019 and above 2,500 from 2012 to 2014. In 2021 the estimate was 1,600 individuals. Given an increasing population trend, genetic diversity in the UFR population does not appear to be a concern in the short term.

However, local inbreeding effects may be discernable in small populations in isolated tributaries. Eight fish in the Kilmarnock River that had been isolated from the Fording River by South Spoil were salvaged in 2011. All fish were > 200 mm in length and pale with very few spots

Figure 24. A WCT from the Kilmarnock River above South Spoil in 2011.

It is possible that the absence of juveniles and unusual phenotype were due to inbreeding depression. Genetic samples from five of the fish have been preserved in ethanol since 2011. Subsequent salvages have failed to catch any fish.

CONCLUSIONS AND RECOMMENDATIONS

Overall, the available fish monitoring data, including the replacement rates, genetic heterozygosity, and increasing number of adults are consistent with a relatively large, diverse, productive population of genetically pure WCT with a range that currently includes about 52 km of the mainstem upper Fording River and 36 km of connected tributaries. The environmental data as reviewed by the Evaluation of Cause Team (2021) indicates that the decline occurred in February–March 2019 and was caused by the interaction of extreme ice conditions (due to extreme, prolonged, cold air temperatures; seasonal, winter low flows; and low winter snowpack), sparse overwintering habitats and restrictive fish passage conditions during the preceding migration period in fall 2018. Following the large reduction in abundance the (sub)adult population appears to be rebounding at a rate of 125% per year.

To better understand the drivers of the population dynamics it is recommended that the fish monitoring program continue to replace removal-depletion at small, closed sites with single pass and mark-recapture at large, open sites; take scales from fish < 200 mm; PIT tag fish ≥ 70 mm and determine the upstream fish distributional limits. Future analyses of the fish monitoring data should seek to estimate the effect of habitat restoration on snorkel densities, incorporate water temperature into the growth and potentially survival models; attempt to retroactively separate subadult and adult fish and integrate the electrofishing and snorkeling density estimates through a lifecycle model.

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