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Technical Report Overview

Report: Upper Fording River Westslope Cutthroat Population Monitoring Report 2022

Overview: This report is the annual synopsis of status and trends data for the report on results of Upper Fording River Westslope Cutthroat Trout population. This program has been redesigned to better support population statistics and predictive fish population modelling, as well as identify data gaps and research needs to better understand high elevation fish populations.

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

For More Information

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UPPER FORDING RIVER WESTSLOPE CUTTHROAT TROUT POPULATION MONITORING 2022

FINAL REPORT

June 09, 2023

Prepared for: Teck Coal Ltd., Sparwood, BC

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The photograph is the upstream portion of a riffle mesohabitat unit at CHA1 in Chauncey Creek that was backpack electrofished on the 18th of August 2022.

EXECUTIVE SUMMARY

The upper Fording River (UFR) is a mine-influenced system that contains genetically pure Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*; WCT) above a natural barrier, Josephine Falls. This population has been monitored since 2012 to inform land use and fisheries management actions. 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.

To provide decision-makers with the information they need, the monitoring program was expanded in 2020 to address 10 specific questions (Executive Summary Table). These questions provide the basis for understanding the population characteristics as well as the status and trends in the population's vital rates of growth, survival, reproduction, and movement. Snorkel data indicate a continued increase in the subadult and adult population in 2022, now up to ~2,300 fish from ~330 in 2019. Adult snorkel surveys also suggest the number of fish in the 100 to 200 mm range has increased from 2021, which bodes well for continued increases in adult abundance, although the increase is not apparent in the electrofishing data. The age-1 abundance, estimated using the electrofishing data, is similar to the past two years. In contrast, the estimated number of eggs deposited has increased steadily since 2019 (based on adult abundance and size and an assumed probability of spawning of 0.5), although the number of redds counted in 2022 was approximately half of those counted in 2021. As a result, the estimated egg to age-1 survival has declined presumably due to a density-dependent response as the population approaches its carrying capacity.

There is a large range of growth rates and densities in the early life-stages that appear to be associated with the presence of ponds in tributaries. In particular, the presence of an upstream pond is associated with higher growth rates of age-0 fish and higher densities of age-1 fish. Although flow stabilization, lower turbidity and instream works likely contribute to the increased growth and survival the available information suggests that the increased summer water temperatures are likely a key driver and should be investigated further.

Recommendations for future work include increased night-time snorkel surveys to reduce uncertainty in the abundance of fish in the 100 to 200 mm range, passive integrated transponder (PIT) tagging of WCT to better understand growth and movement, and continued scale aging to identify cohorts. Modeling recommendations include the separation of fish binned historically as ≥ 200 mm into subadults and adults, the use of size-specific capture efficiencies from electrofishing and snorkeling data, the inclusion of subpopulation-specific temperature information and the use of an integrated life cycle model to improve the abundance and survival estimates.

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, intrinsic 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	~57 km of the UFR including side channels
	Tributaries	~45 km including LCO Dry, and Chauncey Creek. The fish in upper Greenhills and Gardine Creek are isolated from the main population by a culvert/spillway.
2. What is the genetic diversity (H_E) and effective population size (N_E)?	Main	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.
	Greenhills	Unknown
3. What are the life-history strategies within the fish population(s)?		~50% fluvial residents, ~40% fluvial migrants, ~10% adfluvial migrants.
4. What is the timing of life-history events?	Spawning	Begins between mid-May and early June with peak spawning between July 4 and July 14, 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.
5. What are the sizes of the key life-stages?	Age-0	From 23 mm in Chauncey Creek to 64 mm in lower Greenhills on October 1 depending on the stream.
	Age-1	From 40 – 74 mm in Chauncey and Ewin Creeks to 75 – 114 mm in lower Greenhills in September.
	(Sub)Adult	≥ 200 mm
	Adult	Fish mature between 233 and 290 mm.
6. What is the growth rate of key life-stages?		Fish become adults between age-3 and age-6.
7. What is the spatial distribution of key life-stages?	Redds	Most redds observed in mainstem UFR sections 10-11 and Fish Pond and Chauncey Creeks.
	Age-1	Highest densities in Fish Pond Creek and Tributary, lower Henretta, lower Greenhills and UFR 8-9
	(Sub)Adult	Highest counts in UFR 7-10 in 2017 and 2021. Relatively evenly distributed throughout UFR in 2022.
8. What is the abundance of key life-stages?	Age-1	~ 7,500 in 2017, ~4,800 in 2019 and ~2,300 in 2022
	(Sub)Adult	~5,200 in 2017, ~330 in 2019 and ~2,000 in 2022
9. What is the total number of eggs deposited?		~970,000 eggs in 2017, ~60,000 eggs in 2019 and ~430,000 eggs in 2022 based on (sub)adult abundance and length.
10. What is the survival of key life-stages?	Egg to Age-1	~0.5-3% with higher survival when less eggs
	(Sub)adult	~67% (2012-2015)

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GLOSSARY

CARRYING CAPACITY

The average number of (sub)adults the habitat can support in the long-term.

GROWTH

The rate of change in fish size (length and weight) for a defined period of time. This varies by life stage and can be affected by multiple factors.

INTRINSIC PRODUCTIVITY

The average number of adults that each adult would produce in its lifetime when the amount of habitat is not limiting (at very low population densities).

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 between age-3 and age-6	(Sub)Adults
Adult	Maturity until death due to senescence	

MOVEMENT

The rate at which animals move from one area to another in a given period of time. Population level movement rates include the number of outmigrants per year. At the other extreme, diurnal migration between cover and feeding habitat is a movement rate. From a population perspective only movement that affects the other vital rates is important; for the UFR fish movements among spawning, rearing and overwintering areas are of interest.

POPULATION DYNAMICS

The changes in the abundance of fish over time.

REPRODUCTION

The reproductive rate is the number of eggs deposited by the population per year. This is a product of the number of reproductive adults, the sex ratio, the probability of spawning and the fecundity (mean number of eggs per female). Fecundity in turn depends on the size (length and weight) of the females.

SUBPOPULATION

An arbitrary spatially-delimited subset of individuals from within a population (Wells and Richmond 1995). Subpopulations are not isolated from the main population. Throughout this document the term subpopulation is used to refer to a subset of the larger population. The subpopulations are defined with respect to stream sections or tributaries that represent groups of fish that can be treated as having similar growth, survival, reproduction and/or movement for modeling purposes based on our current understanding of habitat (physical, chemical, and biological). As such the subpopulations reflect life-stage(s) and vital rate(s) under consideration as well as the presence of fish barriers and available data.

SURVIVAL

The proportion of individuals that survive from one time period to the next is the survival rate. Survival may be estimated between particular age classes (e.g., age-1 to age-2) or life stages (e.g., egg to adult).

POPULATION VIABILITY

The probability of population persistence for 40 generations (~ 200 years) given chance events and environmental variation.

VITAL RATES

The population dynamics depends on four processes: reproduction, growth, survival and movement. Each process is associated with a vital rate.

INTRODUCTION

BACKGROUND

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 to the species 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 stream loss and fragmentation, physical changes to the stream channel and riparian areas, and changes in water quantity and quality (Fisheries and Oceans Canada 2017). Other potential anthropogenic impacts to the WCT populations 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 or mitigated by climate change. Most notably, Coleman and Fausch (2007a) documented how poor age-1 recruitment can occur due to a short growing season associated with low summer temperatures. 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).

In 2012 Teck Coal Limited initiated a project led by Westslope Fisheries Ltd. (Cope et al. 2016) to assess the WCT populations in the UFR for the purposes of land use planning and fisheries management. Reporting on data from 2012 to 2019, Cope (2020), estimated an increasing trend in the number of fish ≥ 200 mm in the mainstem of the UFR prior to a severe decline (~93%) in 2019. This decline initiated a detailed review by a multidisciplinary team of subject matter experts of the effects of environmental stressors (natural and anthropogenic) on the abundance of the UFR population (Evaluation of Cause Team 2021). The Evaluation of Cause process concluded the decline was due to *"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."*

Anthropogenic change in the UFR watershed is dynamic and ongoing, and concerns remain about operational impacts on WCT fish populations. As a result, targeted information is required to further reduce uncertainties about the impacts of projects to fish and fish habitat, and to guide decision-making. A Framework is being developed to perform this role (Thorley et al. in prep). The framework identifies three primary fish population metrics of interest for evaluating fish population dynamics:

1) carrying capacity (long-term average expected adult population abundance)
2) intrinsic productivity (population replacement rate at extremely low density)
3) viability (probability of persistence for 40 generations. If the generation time is five years, this corresponds to 200 years).

As discussed by Golder et al. (2022) to estimate these three metrics it is necessary to answer a series of secondary questions. Some of these questions relate to population characteristics that vary little from year to year, such as:

1. What is the geographic range of the fish population?
2. What is the genetic diversity and effective genetic population size?
3. What are the life-history strategies within the fish population?
4. What is the timing of life-history events?
5. What are the sizes of key life-stages?

Other questions relate to vital rates (and their associated endpoints) that vary over annual or shorter timescales, such as:

6. What is the growth rate of key life-stages?
7. What is the spatial distribution of key life-stages?
8. What is the abundance of key life-stages?
9. What is the total number of eggs deposited?
10. What is the survival of key life-stages?

The intent of the annual fish population monitoring report is to update the population characteristics as more information becomes available; quantify the yearly status and long-term trends in each population's vital rates of reproduction, survival, growth, and movement; identify key uncertainties or inconsistencies; and provide recommendations for future data collection. When combined with studies of the effects of habitat (physical, chemical or biotic) on WCT population vital rates in the Elk Valley, this information may enable the consequences of alternative management actions on the long-term dynamics of the fish populations to be estimated. The carrying capacity, intrinsic 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 2019-2022. Removal-depletion electrofishing to elucidate age-1 and age-2+ densities began in 2013 and subsequently occurred in 2014-2015, 2017 and 2019-2022. Spawning surveys to identify redds have taken place in 2013-2015 and 2020- 2022.

To address the data gaps identified in Thorley et al. (2021b) the monitoring program was expanded in 2021 to include more systematic redd surveys as well as single-pass electrofishing at large (~300 m) open sites. In 2022 the program was further expanded to include increased electrofishing coverage as well as night snorkeling, as an alternative and less invasive method of enumerating juveniles; night-time dip-net surveys, to inform the length distributions of age-0; and Passive Integrated Transponder tagging captured fish, to better understand capture efficiencies, movement, growth, and survival. The methods for 2022, which followed Teck's Standard Operating Procedure documents, are described in detail in Thorley et al. (2022a).

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 Teck's stream network 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.

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

STUDY AREA

The Fording River watershed, which is located on the west slope of the Rocky Mountains, encompasses an area of ~ 620 km^2 with a mean annual discharge of ~8 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.

The WCT population in the UFR occupies approximately 57 km of the mainstem UFR, including side channels, from Josephine Falls at a stream distance of ~21 km to the limit of the fish distribution at ~75 km (Cope 2020b). The population also occupies approximately 45 km of tributaries, but there have been both recent and historical changes in the connectivity of this river and its tributaries. The tributary habitat includes:

- Henretta Lake is a 2.5 ha flow-through lake on Henretta Creek created in 1999 by flooding a reclaimed mining pit. Henretta Lake was impacted by a flood in 2013 and underwent further construction and modification of lentic and lotic components in 2017, to improve fish habitat (Smeaton and Robinson 2018).
- Fish Pond Creek is fed by groundwater seepage and was created as a series of three ponds and connecting channels for WCT habitat in 1993. Fish Pond Tributary was created in 2017 as a second series of ponds and channels connected to Fish Pond Creek. Throughout this report Fish Pond is used to refer to Fish Pond Creek and Fish Pond Tributary.
- A section of Clode Creek below the screened culvert to Code Ponds remains connected to the UFR and was reconstructed in 2022.
- The fish above the sedimentation ponds in Kilmarnock Creek, which were isolated by South Spoil, were salvaged in 2011; subsequent salvages have failed to catch any fish (Clipperton 2018; Harwood and Vogt 2022).
- A portion of Porter Creek remains connected to the UFR below a sedimentation pond. Fish use of the sedimentation pond was minimal, and a fish barrier precluding further use was constructed in 2022.
- Chauncey Creek above the road crossing at 0.6 km which was isolated from the mainstem population by impassible culverts until 2020. Fish were provided access when construction began on an open span bridge, completed in August 2021.
- Ewin Creek and Todhunter Creek lack anthropogenic barriers and are not mine-influenced.
- Approximately 1 km from its confluence with the upper Fording River, LCO Dry Creek[1] has highway and railway culverts that are not considered to prevent upstream fish movement under average monthly flow conditions (AJM Environmental Inc. and Higher Ground Consulting 2023). Between 2015 and 2020, water in LCO Dry Creek was fed from two sedimentation ponds, after 2020 these ponds were bypassed, except at high flow periods.

[1] The name "LCO Dry Creek" is used to distinguish the Dry Creek in the upper Fording River watershed near the Line Creek Operations (LCO) mine from a different tributary called Dry Creek ("EVO Dry Creek") located near the Elkview Operations (EVO) mine in the Grave-Harmer watershed.

- A culvert/spillway on Greenhills Creek at 0.5 km currently isolates the fish in the upstream 8 km of fish bearing habitat which includes Gardine Creek (**Error! Reference source not found.**).

Table 2. Known fish barriers on the UFR including stream, stream distance (from mouth in m), type and location (from 2012 to 2022).

Barrier	Stream Name	Stream Distance	Type	Easting	Northing
Cataract Falls	Cataract Creek	0	falls/treatment	652578	5557615
Clode Culverts	Clode Creek	~230	culvert	650884	5564283
Josephine Falls	Fording River	21150	falls	652083	5543275
Greenhills Creek (Culvert/spillway)	Greenhills Creek	565	culvert	653573	5545832
Henretta Cascade 2	Henretta Creek	9610	cascade	658302	5570406
Kilmarnock Ponds primary	Kilmarnock Creek	625	outfall	652127	5559657
Kilmarnock Ponds secondary	Kilmarnock Creek	200	outfall	652376	5558416
Lake Mountain Creek Outfall	Lake Mountain Creek	10	culvert	650861	5563287
Lake Mountain Creek Culvert	Lake Mountain Creek	155	culvert	650741	5563312
Dry Pond Spillway	LCO Dry Creek	5610	spillway	658155	5541198
Porter Gradient	Porter Creek	645	gradient	653326	5555358
Porter outflow	Porter Creek	212	constructed barrier	653577	5555324
Swift Falls	Swift Creek	20	dewatered/treatment	652079	5558540
Turn Gradient	Turn Creek	615	gradient	651954	5566088
Smith Creek Falls	Smith Creek	240	outfall	650977	5560566

To facilitate population monitoring the mainstem of the UFR, Henretta Creek, and Fish Ponds were stratified into 11, three and two 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.

For the purposes of the current report, the habitat above Josephine Falls is divided into 13 main subpopulation areas as indicated in Table 3, plus miscellaneous small remnant creek sections. Stream lengths vary widely between subpopulation areas (Table 3). For some analyses, these subpopulations are further grouped into mainstem, tributaries, and tributaries below ponds (as well as sedimentation ponds and/or pit lakes; Table 4).

Table 3. The habitat (km) within the potential WCT distribution by subpopulation (lotic habitat only)

Grouping	Subpopulation	Habitat (km)
Mainstem	UFR 1-7	37.52
	UFR 10-11	10.23
	UFR 8-9	9.35
Tributary	Ewin	9.94
	Chauncey	8.84
	Upper Henretta	8.50
	Upper Greenhills	7.90
	LCO Dry	5.54
Tributary below pond	Porter	0.64
	Lower Greenhills	0.58
	Fish Ponds	0.56
	Lower Henretta	0.41
Miscellaneous[2]	Grassy Creek, Turn Creek, Clode Creek, Lake Mountain Creek	1.60

Table 4.The habitat (km) within the potential WCT distribution by subpopulation grouping in 2022. Length extends to confluence with higher order stream.

Grouping	Habitat (km)
Mainstem	57.10
Tributary	42.3
Below Ponds	2.19

[2] Includes tributary habitat both above and below ponds

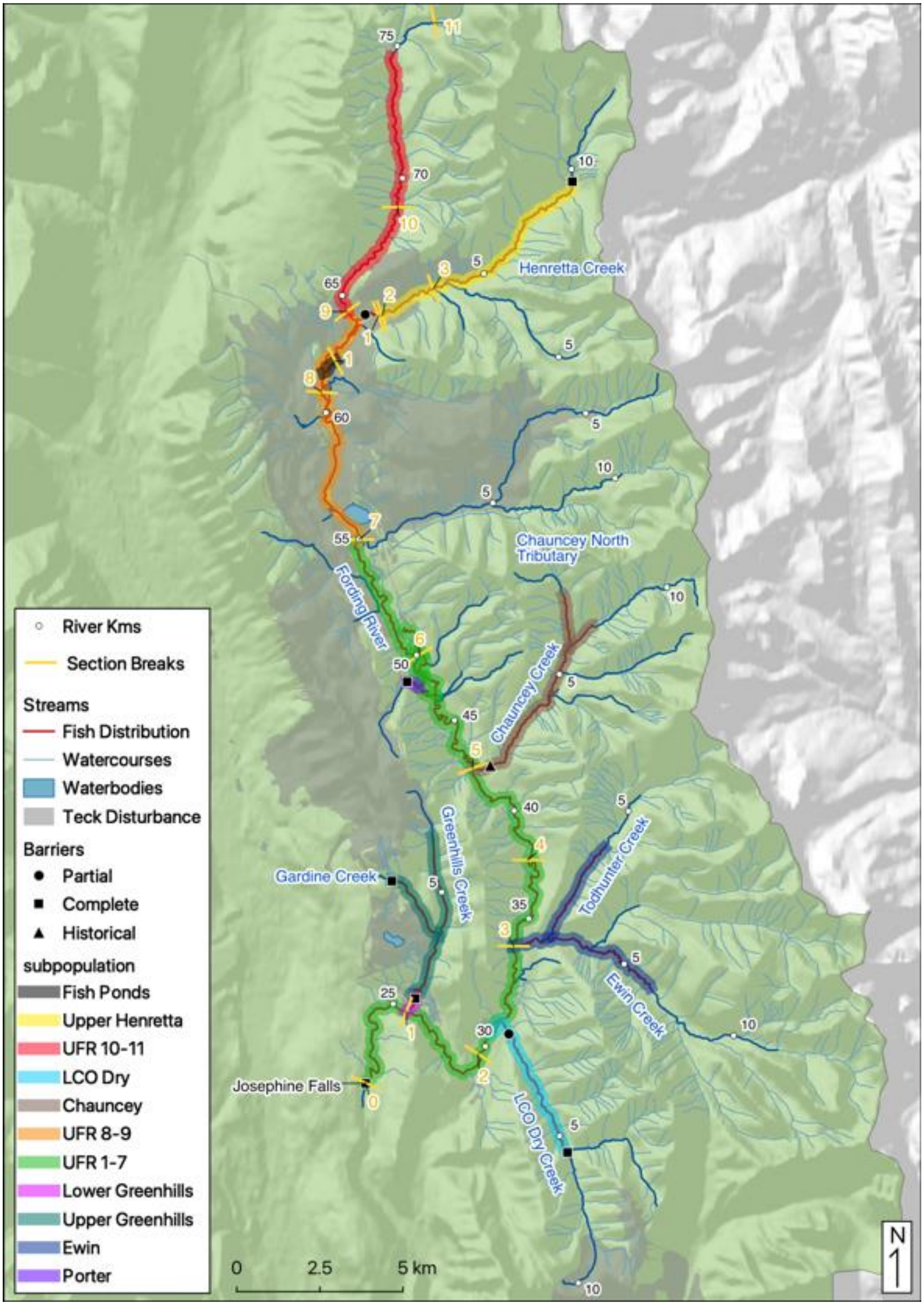

Figure 1. The study area with river kms, section breaks, barriers, and subpopulation groupings within the assumed fish distribution.

DATA COLLECTION

SPAWNING (REDD) SURVEYS

Redd surveys, which record disturbances in the gravels from spawning activity, are used to assess the relative amount, spatial distribution, and timing of spawning activity.

In 2022, suitable gravels in areas of historically high spawning were monitored for spawning activity starting in the first week of June. Once spawning was confirmed, surveys were conducted once a week in the key areas until spawning activity was judged to have ceased. The key areas included:

- Segments 1 to 11 of the of the Fording River. This includes mainstem habitat from approximately 25 to 75 km upstream of the confluence with the Elk River, and major side channels
- Chauncey Creek from its mouth to approximately 6 km upstream
- LCO Dry Creek from its mouth to approximately 4.5 km upstream
- Greenhills Creek from its mouth to approximately 3 km upstream (excluding the sedimentation pond)
- Porter Creek – The first 400 m

Around peak spawning (timing based on professional knowledge and judgment) surveys also included one survey in each of the following lower priority spawning areas. Priority was based on previously documented spawning occurrences and project information needs:

- Gardine Creek
- Ewin Creek from its mouth upstream to approximately 7 km upstream
- Todhunter Creek from its mouth upstream to end of suitable habitat or practical access
- Chauncey North Tributary from its mouth upstream to approximately 2.5 km upstream
- Henretta Creek from the Fording River to approximately 9 km, in 2022, 3 km immediately upstream of Henretta Lake were not surveyed due to safety reasons
- LCO Dry Creek East Tributary
- Fish Pond Creek

Spawning surveys utilized the standard methods for monitoring spawning near Teck sites (Smit et al. 2022). During the surveys, observers documented their start and end locations, dates, and times. Crews recorded all encountered redds, the number of nests within the redd and the number of adult fish associated with the redd. As multiple nests may be superimposed in the same redd, enumerating nests and not just redds provides a more accurate indication of spawning activity. All observed nests were classified as definitive, which are nests with a distinct pit upstream of a loose mound of clean pebbles and gravels, or potential, which includes test digs by females to evaluate the substrate, or older nests that are no longer distinct[3]. In 2022 all data were entered directly into the Teck Field Data Collector app.

[3] Prior to 2021, observers flagged and 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).

ELECTROFISHING SURVEYS

The size, densities, and distribution 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 backpack electrofishing using two different methods; removal-depletion electrofishing and single open pass, following the recommendations of the standard protocol for electrofishing at Teck sites (Thorley et al. 2022b). This combination of methods enables greater coverage of available habitat while facilitating comparison to previous years when only small, closed sites were surveyed. Details are provided in the following sections. In 2022, surveys for both methods began mid-August and continued until mid-September (Table 5).

Table 5. Start and end dates for electrofishing surveys.

Year	Start Date	End Date
2013	Sep-16	Oct-01
2014	Sep-15	Oct-03
2015	Sep-14	Sep-29
2017	Aug-19	Aug-28
2019	Aug-19	Aug-28
2020	Sep-14	Sep-19
2021	Sep-07	Sep-23
2022	Aug-15	Sep-20

SMALL CLOSED SITE REMOVAL DEPLETION ELECTROFISHING

Removal-depletion electrofishing used stop nets at three single mesohabitat (pool, riffle, glide or cascade; see Cope et al. 2016 for a description) sites of about 10 to 35 m in length (and 100 m^2 in wetted area) at 25 different index locations (75 sites total). Between one and three passes, randomly assigned prior to fieldwork, were conducted at each site to estimate capture efficiency based on the decline in catches. Electrofishing effort (seconds) was recorded at the end of each pass.

LARGE OPEN SITE MARK-RECAPTURE

In 2021, a second electrofishing methodology was implemented to address the potential bias in site selection introduced by removal-depletion methods and allowed a substantial increase in the proportion of habitat sampled. The method consisted of a single open (without stop nets) pass at long (~300 m) sites. In 2022, eleven open 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 prior to the field season. A subset of sites were resampled within 24 hrs to calculate capture efficiency from the ratio of recaptured fish with PIT tags.

FISH PROCESSING

Following methods provided in the standard protocol (Thorley et al. 2022d), captured fish were weighed (to 0.1 g), measured (to mm), scanned for a PIT tag (if ≥ 100 mm), and photographed in a fish viewer. Fish were inspected for any external physical anomalies following the DELT protocol (Ings and Weech 2020; results addressed in a separate document) and a PIT tag was inserted into all uninjured fish ≥100 mm (Thorley et al. 2022d). Processed fish were held in a dark, aerated bucket before being released as close to their capture site as possible in habitat with a suitable depth and velocity.

Dipnet surveys

Bank walk surveys using dip-nets to capture age-0 WCT were conducted near the end of the growing season, between Oct 11 and 30, when fry emergence was complete. Age-0 WCT, the priority for this survey, are patchily distributed and infrequently caught by backpack electrofishing. Dip-net surveys provide information about the size of these age classes at the end of the growing season which was used in the length-at-age analyses. The size of young-of-the-year is important because it has been linked to overwintering survival, particularly in small, cold, headwater streams (Coleman and Fausch 2007a, 2007b). The surveys also provide some information about the spatial distribution (occupancy but not relative density) of young-of-the-year and age-1 WCT (Table 1).

Dip-net surveys were conducted at night. All observed fish less than 100 mm were captured with dip-nets, if possible, and then weighed (to 0.01 g), measured (to 1 mm) and released at the location of capture. Fish ≥ 100 mm were also scanned for a PIT tag. The time and locations of the start and end of the survey was recorded, along with the time, location, and estimated body length for all observed WCT.

Surveys occurred in each of the following 11 sections in the mainstem or key tributaries with suitable habitat for age-0 fish where redds had been constructed.

- Section 6 of the upper Fording River
- Section 8 of the upper Fording River
- Section 10/11 of the upper Fording River
- Henretta Creek between the mouth and Henretta Lake
- Henretta Creek upstream of lake and area of mine influence
- Chauncey Creek between road culverts at 0.6 km and 5 km
- LCO Dry Creek above culverts
- LCO Dry Creek in the lower 1 km
- Greenhills Creek below the barrier
- Greenhills Creek above the barrier
- Ewin Creek
- Todhunter Creek

Snorkel Surveys

Downstream Snorkel

Subadult and adult WCT numbers were assessed using downstream snorkel surveys during daylight hours.

In 2022 the surveys were initiated on August 29th and continued until September 5th (Table 6).

Table 6. (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
2022	Aug-29	Sep-05

As described by Thorley et al. (2022a) survey start and end points were recorded along with all sighted fish locations and fork lengths to the nearest 10 mm (where possible). Any abnormalities were noted. 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. Estimates of observer efficiency relied on the mark-recapture program of previous years (2012, 2013, 2014; see Cope 2020b).

Snorkel surveys were conducted using section boundaries as start and end locations for 16 river segments (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 as a separate section; one section in Fish Pond Creek, and one section in Fish Pond Tributary, both including the lentic areas. Prior to 2022 Fish Pond Creek and Tributary were considered one section. Other subsections within the 16 segments have been established and are used by other programs for monitoring restoration effectiveness.

UPSTREAM NIGHT SNORKEL

Upstream snorkel surveys enumerate small fish (age-1 and age-2+) in shallow habitats at night. Compared to electrofishing methods, upstream snorkel surveys cover more habitat in less time (because fish are not captured or processed) and just as importantly can sample deeper habitats, such as pools, more effectively.

Upstream snorkel surveys were conducted at night, at the same time of year as backpack electrofishing surveys (late summer to early fall). Counts were conducted at 7 of the large, open electrofishing sites, to compare densities of fish by life stage between the two methods. These included 5 segments from the UFR mainstem, the lower section of Henretta Creek downstream of Henretta Lake and the lower section of Chauncey Creek downstream of the culvert.

The survey follows a protocol detailed in Thorley et al. (2022a) . Fish are counted and individual lengths estimated to the nearest 10 mm for fish ≥100 mm fork length, and 5 mm for fish <100 mm fork length along with the time (to the second) and spatial coordinates.

DATA PREPARATION

The historical (pre-2020 program adjustments) 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, and by Ecofish Research Ltd. as Excel spreadsheets. The 2022 data were provided by Teck Coal Ltd. as geodatabase files. The watershed, stream, lake and manmade waterbody spatial objects were provided by Teck Coal Ltd. The data were extracted and cleaned and tidied before being stored in a purpose-built SQLite database using R version 4.2.2 (R Core Team 2020).

STATISTICAL ANALYSIS

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

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

The parameters are summarised in terms of the point *estimate*, *lower* and *upper* 95% compatibility limits (Rafi and Greenland 2020). 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 or n-fold 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 4.2.2 (R Core Team 2020) and the mbr family of packages.

MODEL DESCRIPTIONS

NEST FADING

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

Key assumptions of the nest fading model include:

- The daily probability of fading is constant.

NEST COUNTS

The nest 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 number of fish nests. This is the number of definitive nests that an average observer would be expected to count if they went out every day and marked every definitive nest they encountered to prevent double-counting.

Key assumptions of the nest counts model include:

- Nest count varies randomly by segment within stream within year.
- Spawning activity is normally distributed.
- Nests within redds are definitive for approximately 19 days.
- The variation about the expected nest count is normally distributed.

Due to limited information on where and when surveys were conducted it was not possible to include the nest count data prior to 2021.

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 (maturing between 4-6 years; 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, although fluvial and adfluvial fish are considered reproductively mature at lengths between 233- 290 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 subpopulation dependent (Table 7). For example, age-1 fish were judged to be between 50 and 89 mm in upper Greenhills but between 75 and 114 mm in lower Greenhills. In the current report age-2+ fish are individuals which are too big to be age-1 and too small (<200 mm) to be (sub)adults.

Table 7. The age-1 minimum and maximum inclusive fork length boundaries by stream name based on visual inspection of length-frequencies. Subpopulations for which insufficient data was available were assumed to have the same boundaries as LCO Dry Creek.

Stream Name	Min	Max
UFR 1-7	65	109
Lower Greenhills Creek	75	114
Upper Greenhills Creek	50	89
LCO Dry Creek	50	89
Ewin Creek	40	74
Chauncey Creek	40	74
Fish Ponds	55	104
UFR 8-9	65	114
Henretta Creek	60	104
UFR 10-11	60	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 (Coleman and Fausch 2007a, 2007b). The lengths of the age-1 and age-2+ fish were not analyzed due to the uncertainty surrounding the length boundary between age-1 and age-2+ fish and because age-2+ fish consist of multiple cohorts (2, 3 and some 4 year olds).

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

- Fork length varies by day of the year of capture.
- Fork length in LCO Dry varies pre (2015-2019) and post (2020 onwards) the bypassing of the sedimentation pond (they were considered to be separate subpopulations).
- Fork length varies randomly by year, subpopulation and subpopulation within year.
- The residual variation in the individual fork lengths is log-normally distributed.

Preliminary analysis indicated that observation vs capture and dip net vs electrofishing were not informative predictors of 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 that day of the year and life-stage (age-1 vs age-2+) were not informative predictors of α.

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). Lineal, rather than area-based density is the preferred estimate because fish are concentrated in the margins of water bodies rather than evenly distributed throughout the area, hence fish densities are better described by length rather area. Additionally, area based densities will fluctuate with stream flow levels, whereas lineal based densities do not.

Key assumptions of the model include:

- Lineal density varies by subpopulation grouping.
- Lineal density varies randomly by year, subpopulation, location and subpopulation grouping within year.
- 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, subpopulation grouping and method.
- The catch on each pass is binomially distributed.

The abundance in each subpopulation in each year was calculated by multiplying the estimated fish density (fish/100 m) at a typical location for that year by the amount of lineal habitat.

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 2022 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)[4]

$$\mathrm{F} = \exp_{10}\left(-4.265 + 2.876 \cdot \log_{10}(1.040 \cdot \mathrm{FL} + 1.697)\right)$$

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.

POPULATION MODEL

For a population to be stable each spawner must on average replace itself with another spawner over its lifetime. The egg-to-age-1 survival required for population replacement was taken from the Excel workbook provided by Ma and Thompson (2021;
Table 8) 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).

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

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:

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

[4] In Thorley et al 2021 the equation $\mathrm{F} = \exp_{10}(-4.265 + 2.876 \cdot \log_{10}(\frac{\mathrm{FL}-1.69}{1.040}))$ which underestimated the fecundity was erroneously used.

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 8. 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

RESULTS

SPAWNING (REDD) SURVEY

NEST FADING

The nest fading model estimated that 50% of nests are no longer visible after 19 days (95% CI 15-25).

NEST COUNTS

Based on the AUC model spawning was estimated to start on June 8th and continue until August 8th (Table 9). In 2022, spawning began later in the season in some streams than usual. Redds (and nests) were first recorded in early July in the mainstem UFR, rather than early June as seen in 2021 (Figure 2). Only Fish Pond Creek and Greenhills Creek recorded redds before mid-June. Compared to 2021, lower Greenhills Creek had a marked reduction in the number of nests found. Most nests were recorded in sections 10 and 11 in the mainstem UFR, Fish Pond Creek, Chauncey Creek, and Porter Creek (Figure 3, Figure 4). As the extent of the surveys in years prior to 2021 is unknown, nest count data for 2021 and 2022 cannot be directly compared to historical nest/redd counts.

Table 9.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%)	08-Jun	01-Jun	13-Jun
peak (50%)	09-Jul	04-Jul	14-Jul
end (97.5%)	08-Aug	30-Jul	22-Aug

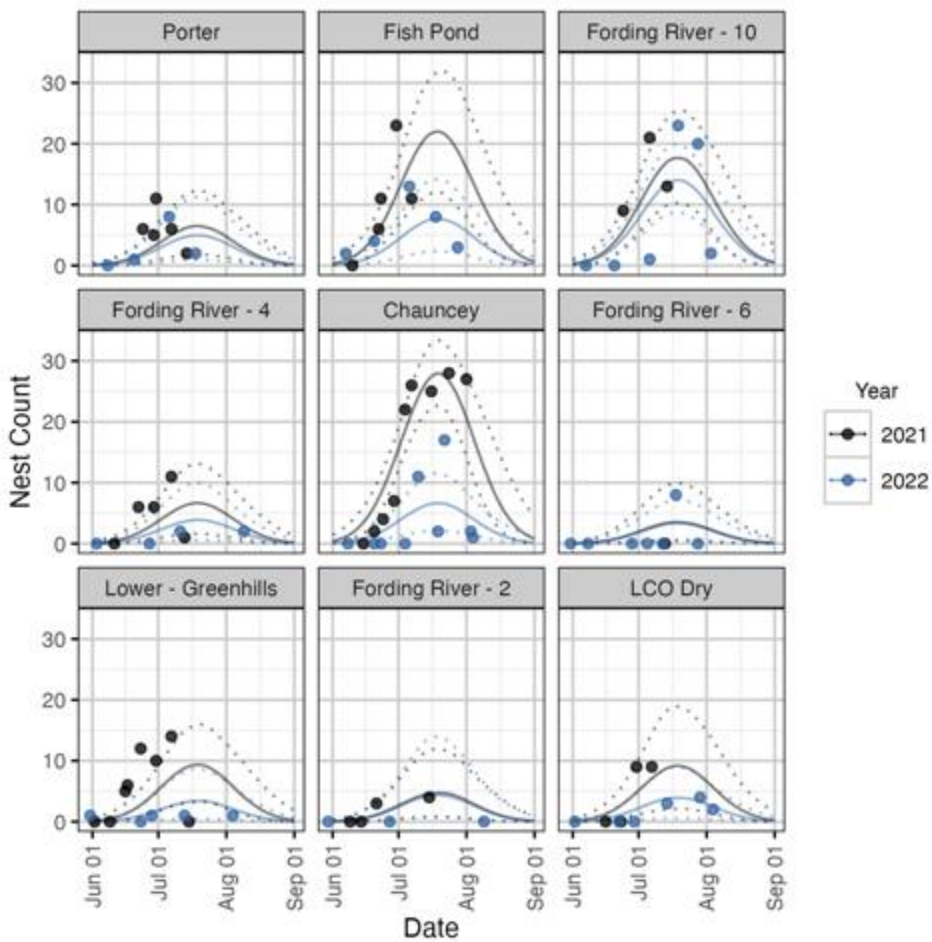

Figure 2. The daily nest count by date, year, stream and section.

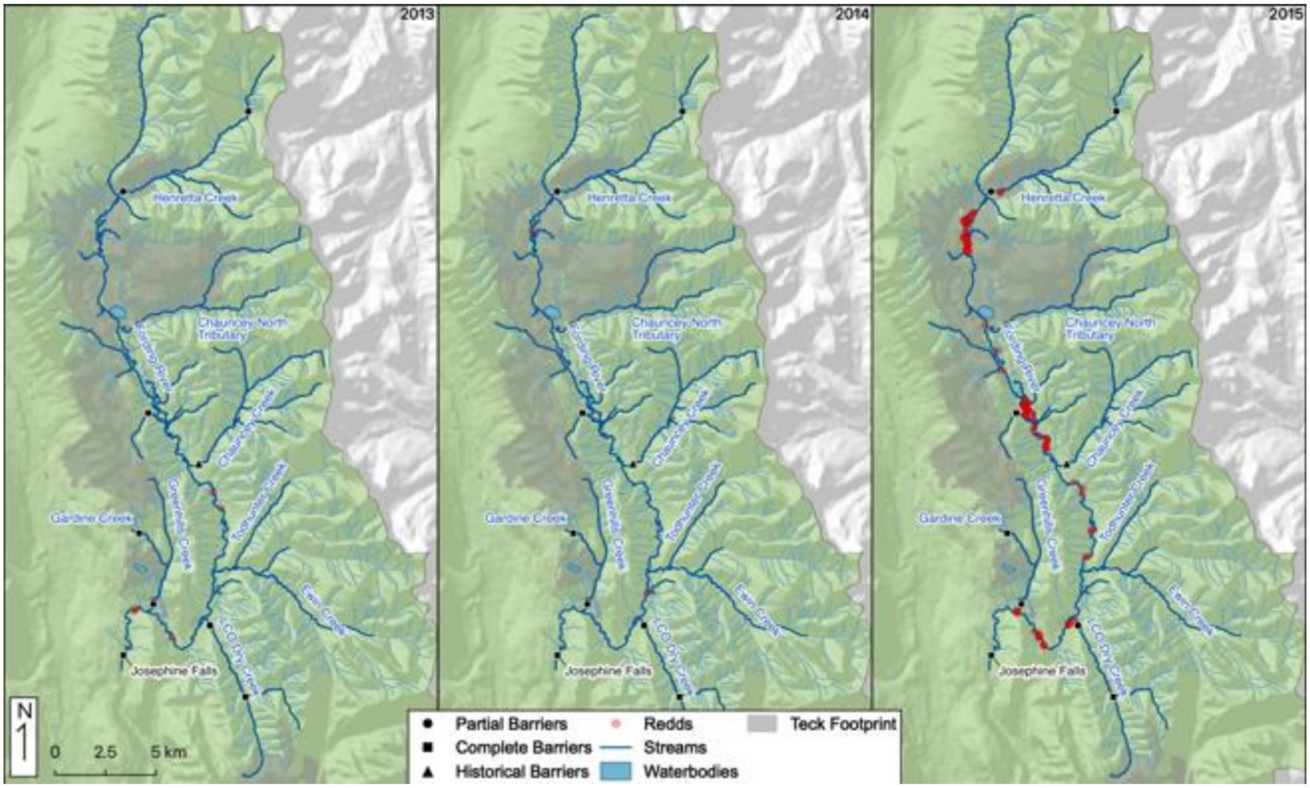

Figure 3. The recorded definitive redds by year (2013-2015). Extent of survey coverage is unknown. Redds are indicated as transparent points so that more intense color indicates higher densities.

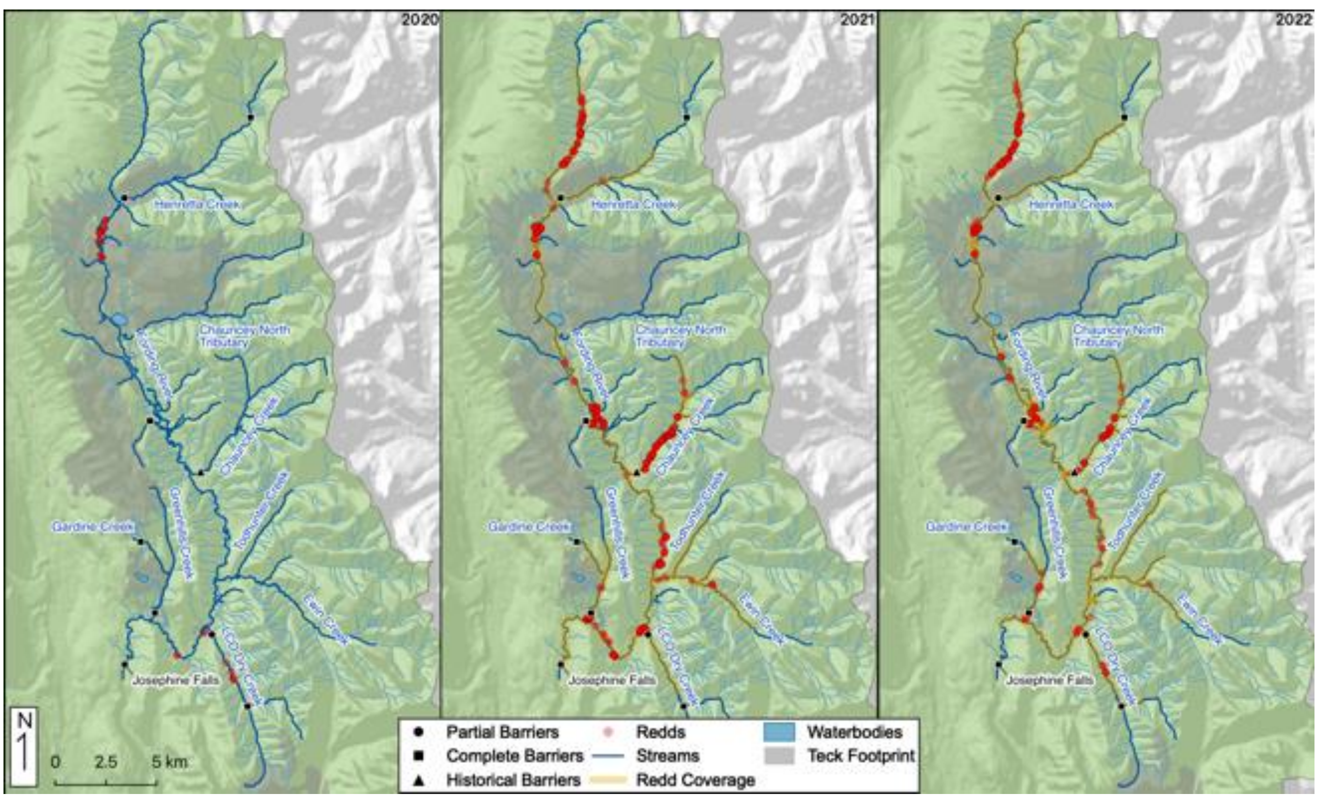

Figure 4. The recorded definitive redds by year with redd survey coverage. Redds are indicated as transparent points so that more intense color indicates higher densities.

In 2022 the estimated total unique nest counts in most subpopulations were lower than those in 2021, and markedly so for Chauncey and Fish Pond Creeks (Figure 5). The estimated total unique nest count for all the mainstem and tributaries sections considered together was 118 redds (95% CI 75-174), about half of the estimate for 2021 of 240 nests (95% CI 172-338; Figure 6).

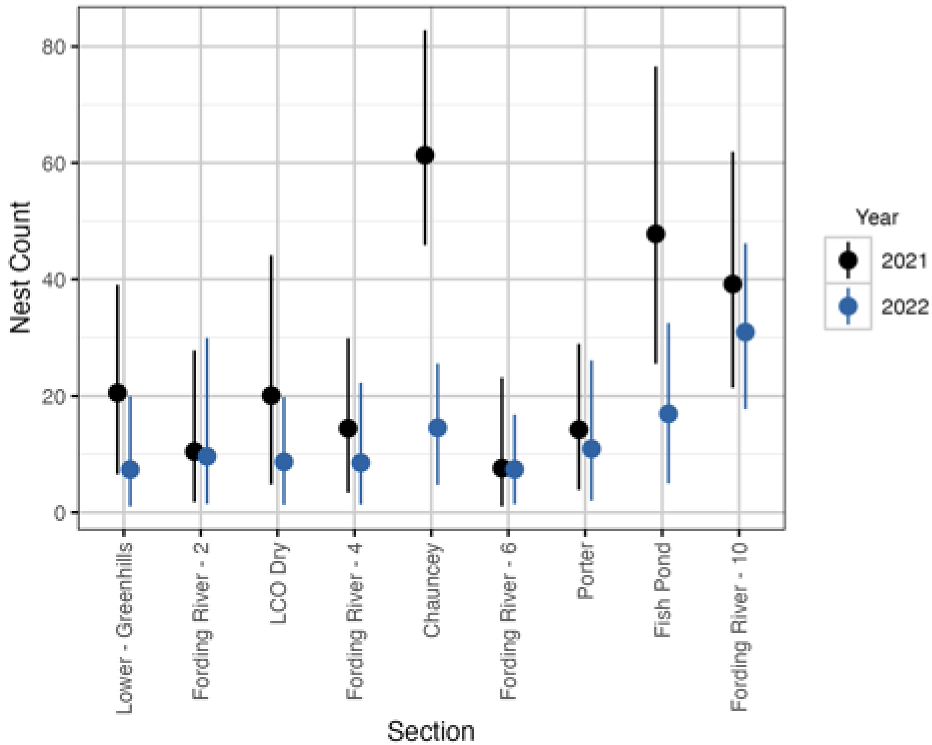

Figure 5.The estimated total unique nest count in 2022 by stream (with 95% CIs).

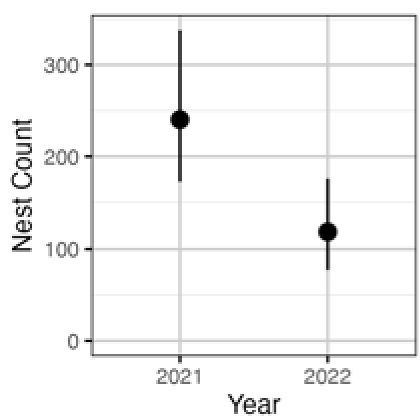

Figure 6. The estimated total unique nest count for the modelled sections by year (with 95% CIs).

LENGTH

FORK LENGTH

As detailed in the methods, fish were categorized into life stages according to length thresholds (**Error! Reference source not found.**; Table 7). Age-1 length thresholds varied by stream. The length range for age-1 fish was as low as 40 to 74 mm in Chauncey Creek and Ewin Creek and as high as 75 to 114 mm in lower Greenhills Creeks.

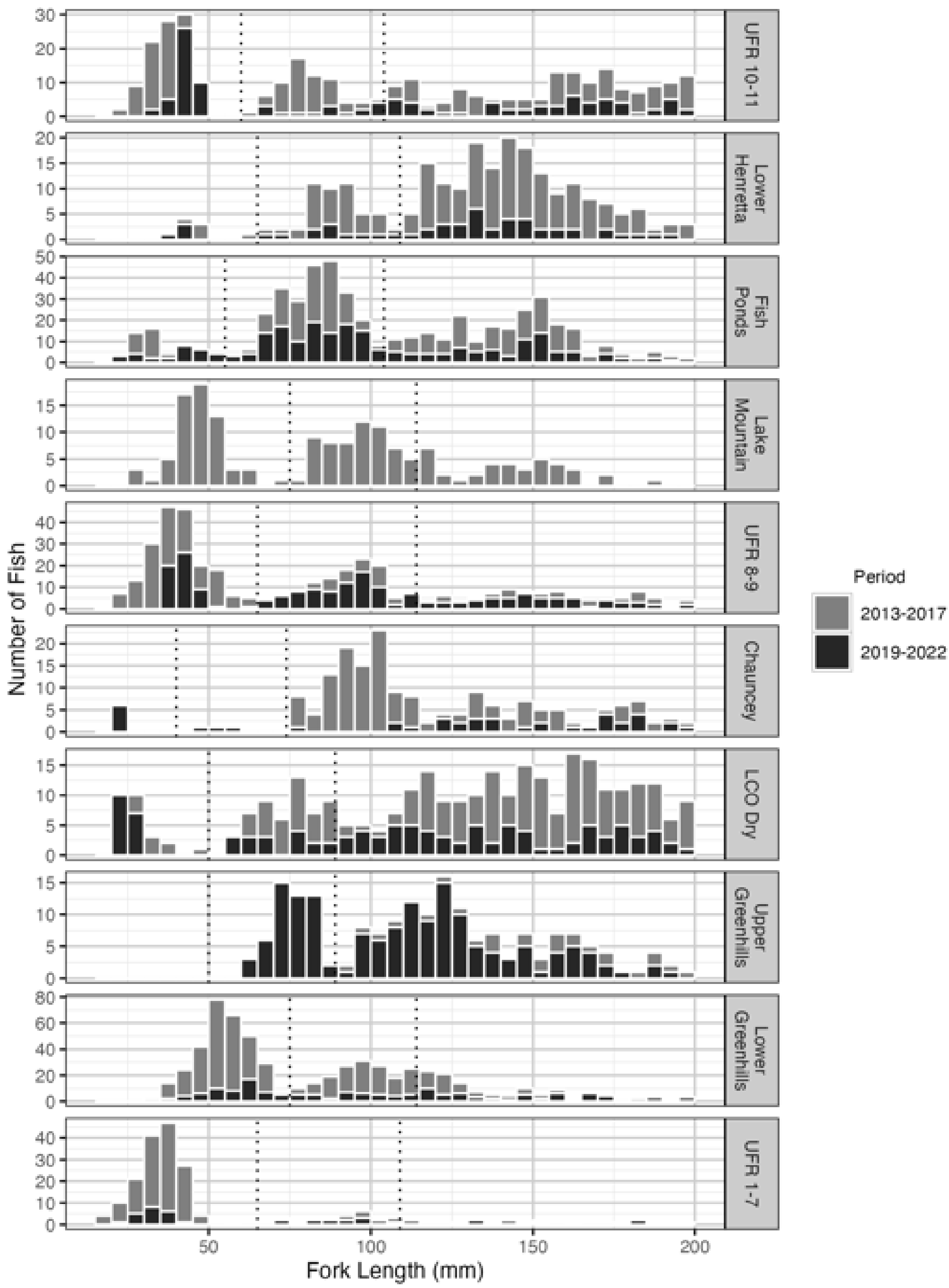

Figure 7. Electrofishing WCT captures for the upper Fording population by fork length, subpopulation and period.

The vertical dotted lines indicate the selected age-1 life-stage boundaries. These length frequencies are cumulative, do not include capture effort, and should not be misinterpreted as reflecting abundance.

GROWTH

With a growth rate parameter (k) of 0.15 (95% CI 0.11-0.20), WCT in the UFR were estimated to become subadults between age-3 and age-6 (Figure 8).

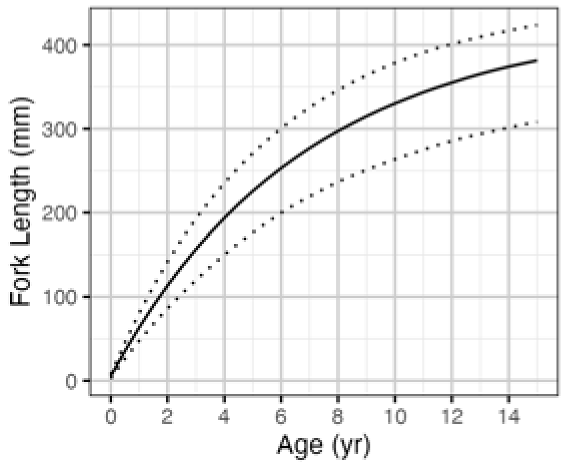

Figure 8.The length at age assumed by the population model of Ma et al. (2022) based on the Von Bertalanffy growth parameters estimated by Cope et al. (2016).

LENGTH-AT-AGE

AGE-0

Age-0 fish were captured during bank walks in areas with spawning activity (Table 10). The estimated average length of an age-0 fish in the mainstem UFR on October 1st varied between a low of 40 mm (95% CI 32-53) in 2022 and a high of a 46 mm (95% CI 36-65) in 2019 (Figure 9).

Table 10. The number of age-0 fish captured and observed during bank walks by subpopulation, stream, survey date and stream distance. These are not systematic surveys and should not be misinterpreted as indicating abundance. rm = river meter.

subpopulation	stream name	survey date	lower rm	upper rm	observed	captured
UFR 1-7	Fording River Oxbow	2022-10-13	585	665	0	20
Lower Greenhills	Greenhills Creek	2022-10-13	230	270	0	3
LCO Dry	LCO Dry Creek	2022-10-12	3800	4125	0	0
LCO Dry	LCO Dry Creek	2022-10-13	275	610	2	9
LCO Dry	LCO Dry Creek	2022-10-14	610	645	6	0
Chauncey	Chauncey Creek	2022-10-13	835	850	1	1
Chauncey	Chauncey Creek	2022-10-14	850	855	3	0
UFR 8-9	Fording River	2022-10-11	60405	60445	32	7
Fish Ponds	Fish Pond Creek	2022-10-12	40	165	15	5
Lower Henretta	Henretta Creek	2022-10-11	175	375	1	3
UFR 10-11	Fording River	2022-10-11	64585	64850	23	16

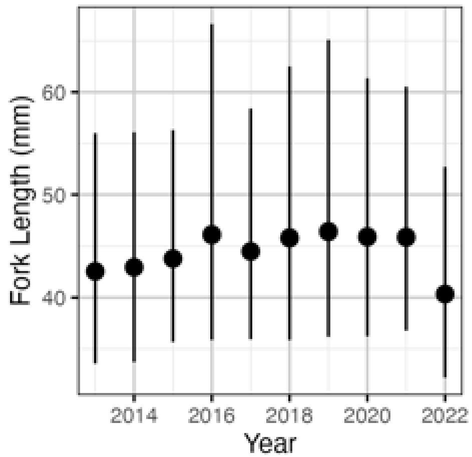

Figure 9. Estimated annual average fork length of age-0 fish in the mainstem upper Fording River, October 1st (with 95% CI).

The estimated fork lengths for age-0 fish in a typical year were longest in lower Greenhills Creek at 64 mm (95% CI 56-74; Figure 10) and Lake Mountain and lower Henretta all of which are pond (or lake influenced). Conversely the estimated fork lengths were shortest in LCO Dry after the main channel was bypassed around the sediment ponds in 2020 (LCO Dry Creek-Post Bypass), at 27 mm (95% CI 20-40) and Chauncey Creek, at 28 mm (95% CI 20-40). Prior to 2020 the estimated fork length for the age-0 fish in LCO Dry Creek in a typical year was 39 mm (95% CI 31-50). Age-0 fish are on average expected to increase in length by about 5 mm from Oct. 1 to Oct. 15 (Figure 11).

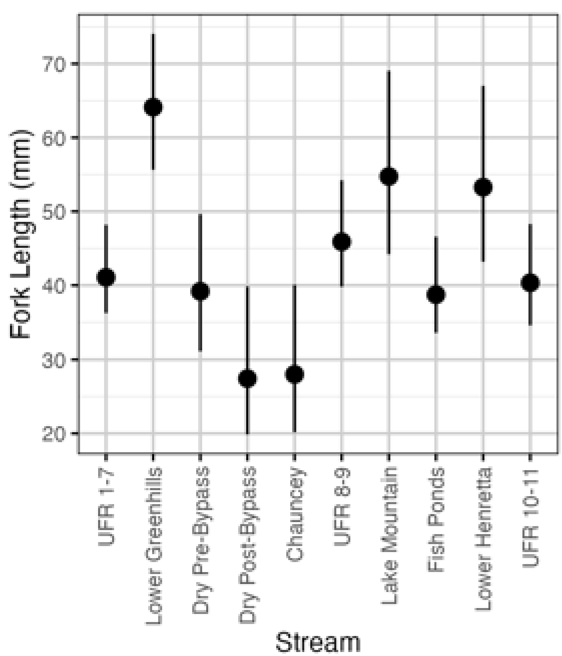

Figure 10. Estimated fork length for typical age-0 fish on October 1 in a typical year by subpopulation (with 95% CI).

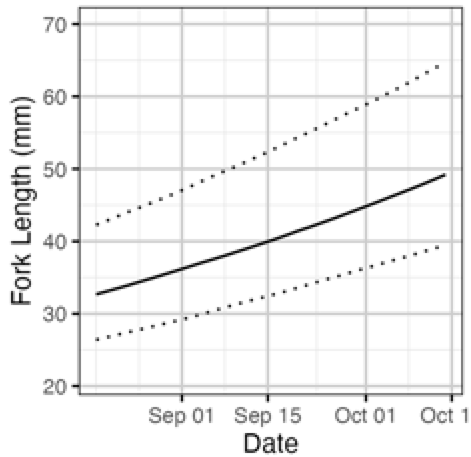

Figure 11. The expected fork length for an age-0 fish by date in a typical subpopulation in a typical year.

BODY CONDITION

Fish length and weight are used to calculate body condition, a proxy of a fishes' lipid reserves and an indicator of health (Figure 12; Figure 13).

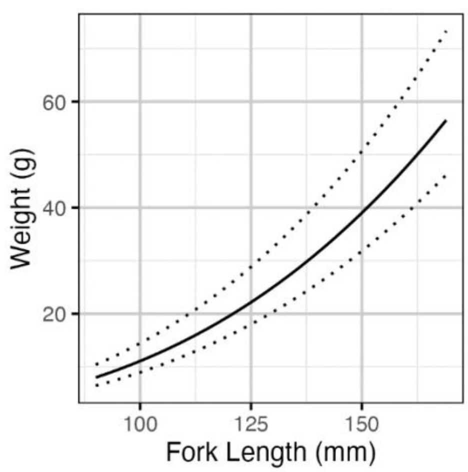

Figure 12. The estimated weight by fork length in a typical subpopulation in a typical year (with 95% CIs).

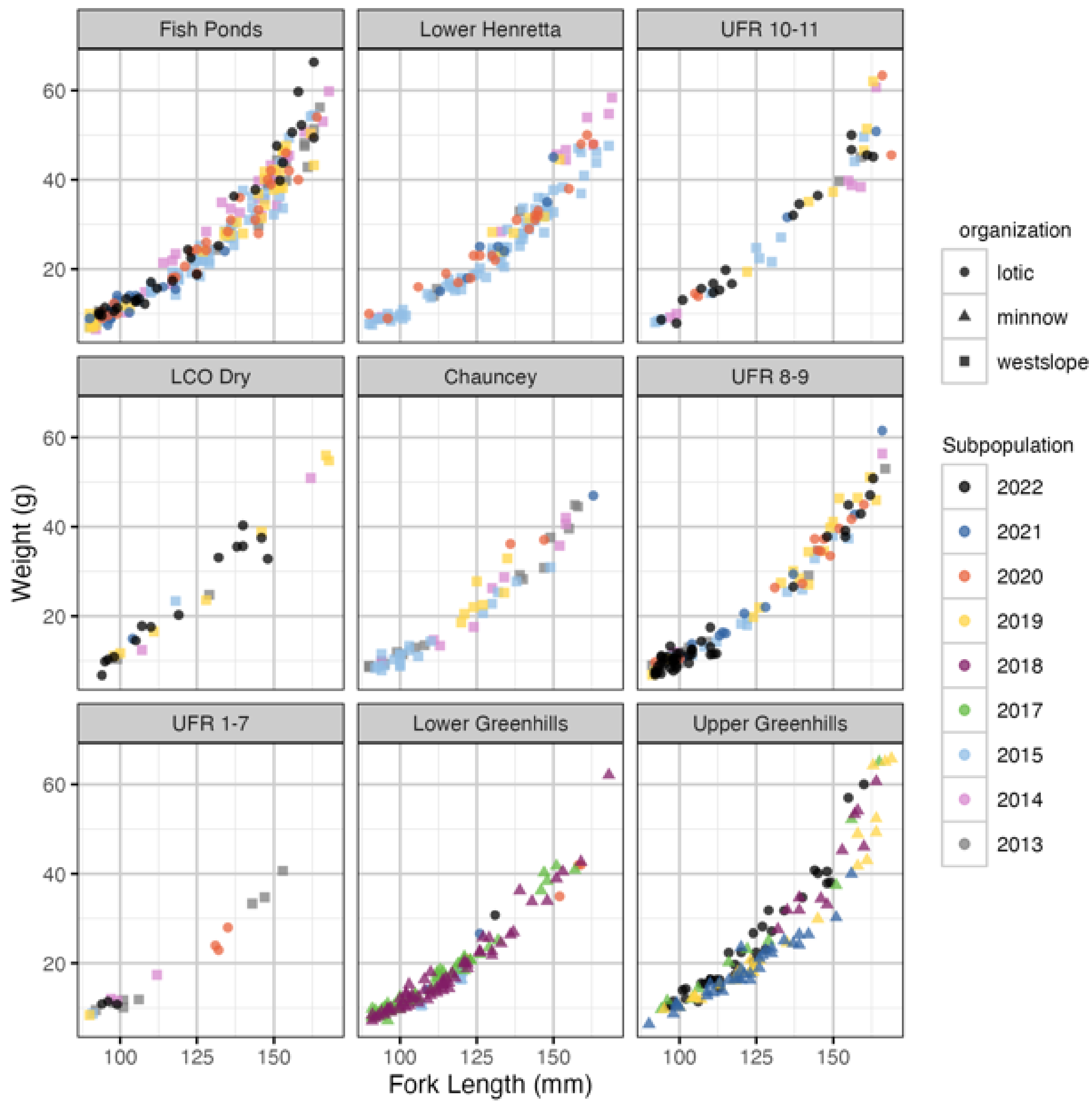

Figure 13. Length-weight relationships for WCT in the upper Fording River.

Fish body condition, relative to the mean fish body condition, varied annually between a high of 3% (95% CI -1-8) in 2014 and a low of -3% (95% CI -8-1) in 2015. Reliable weight measurements were not available for 2016 (see Thorley et al. 2021a). Body condition overall was estimated to be slightly above average in 2022 at 1% (95% CI -6-6; Figure 14). Fish condition is estimated to be slightly higher for fish in UFR 1-7, Upper Greenhills Creek, LCO Dry Creek and Fish Pond Creek whereas condition is typically lower for fish in Lower Greenhills Creek, UFR sections 8-9, and Lower Henretta Creek although the differences are small relative to the uncertainty (Figure 15). However, the inter-annual variability with subpopulations is relatively high and somewhat discordant among subpopulations (Figure 16).

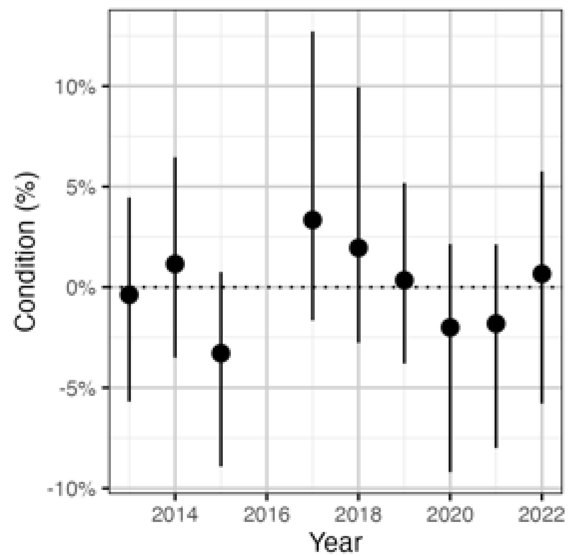

Figure 14. The percent change in the body condition of a 100 mm fish in a typical stream relative to a typical year by year (with 95% CIs).

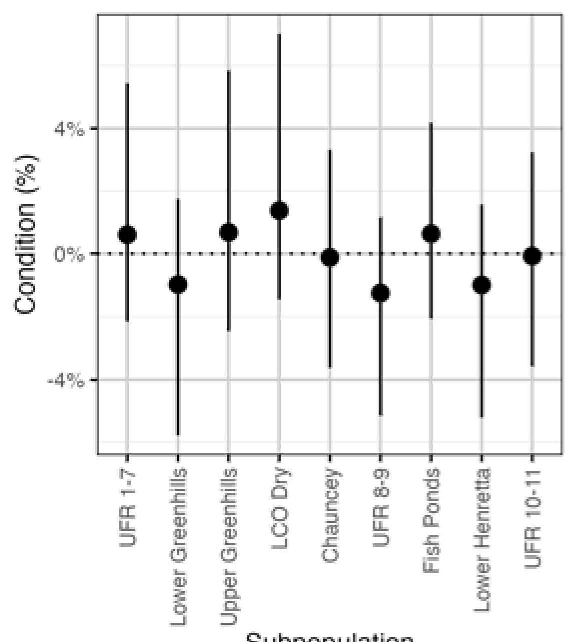

Figure 15. The percent change in the body weight of a 100 mm fish in a typical year relative to a typical stream by stream (with 95% CIs).

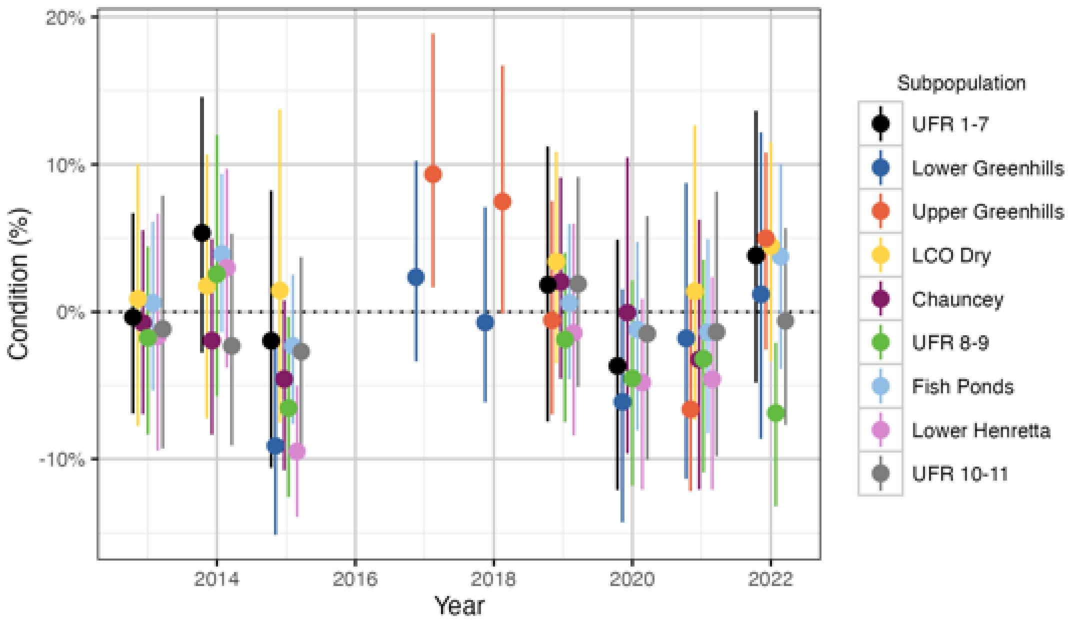

Figure 16.The percent change in the body weight of a 100 mm fish relative to a typical stream in a typical year by year and stream (with 95% CIs).

ELECTROFISHING

The use of large, open electrofishing sites and upstream night time snorkeling has allowed much more WCT habitat to be used in the calculation of the population abundance (Table 11).

Table 11. The length of habitat covered (m) by subpopulation, method and year.

subpopulation	method	2013	2014	2015	2017	2018	2019	2020	2021	2022
UFR 10-11	Electrofishing	153	169	137	139	0	137	127	375	450
Upper Henretta	Electrofishing	91	65	57	52	0	52	49	340	591
Upper Henretta	Snorkeling	0	0	0	0	0	0	0	0	322
Lower Henretta	Electrofishing	54	50	49	49	0	44	36	36	0
Fish Ponds	Electrofishing	97	94	83	83	0	132	174	77	198
Lake Mountain	Electrofishing	0	0	34	43	0	0	0	0	0
UFR 8-9	Electrofishing	68	49	89	93	0	375	227	503	906
UFR 8-9	Snorkeling	0	0	0	0	0	0	0	0	884
Porter	Electrofishing	0	0	0	0	0	0	0	0	275
Chauncey	Electrofishing	108	119	58	59	0	134	124	404	1881
Chauncey	Snorkeling	0	0	0	0	0	0	0	0	292
Ewin	Electrofishing	119	114	62	63	0	61	67	359	891
LCO Dry	Electrofishing	91	81	50	84	0	85	35	372	942
Upper Greenhills	Electrofishing	0	0	0	138	248	469	0	589	867
Lower Greenhills	Electrofishing	0	0	176.0	214	106	335	62	388	455
UFR 1-7	Electrofishing	201	155	171	152	0	172	120	1351	2343
UFR 1-7	Snorkeling	0	0	0	0	0	0	0	0	588

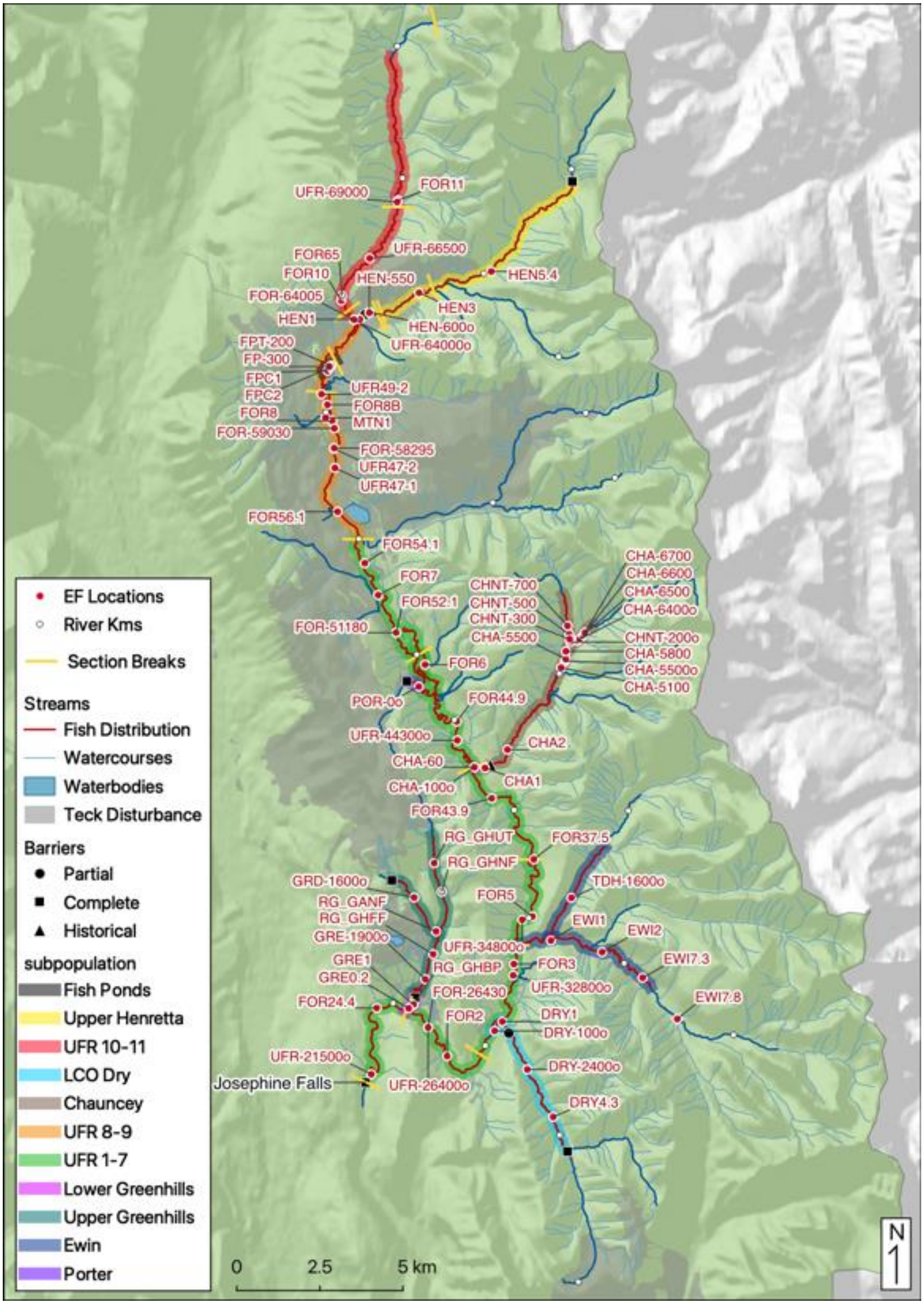

Figure 17. The backpack electrofishing locations visited in at least one year. The section breaks and river kms are labelled in the study area map.

CAPTURE DENSITIES

The electrofishing data indicate high annual variability in the distribution of electrofishing captures in the mainstem UFR and tributaries (**Error! Reference source not found.**, Figure 19). The most consistent capture densities for age-1 and age-2+ life stages on the mainstem UFR are in sections 8 to 11, with lower capture numbers in sections 1 to 7. In the tributaries, the most consistent capture densities occurred in Fish Ponds and lower Henretta Creek.

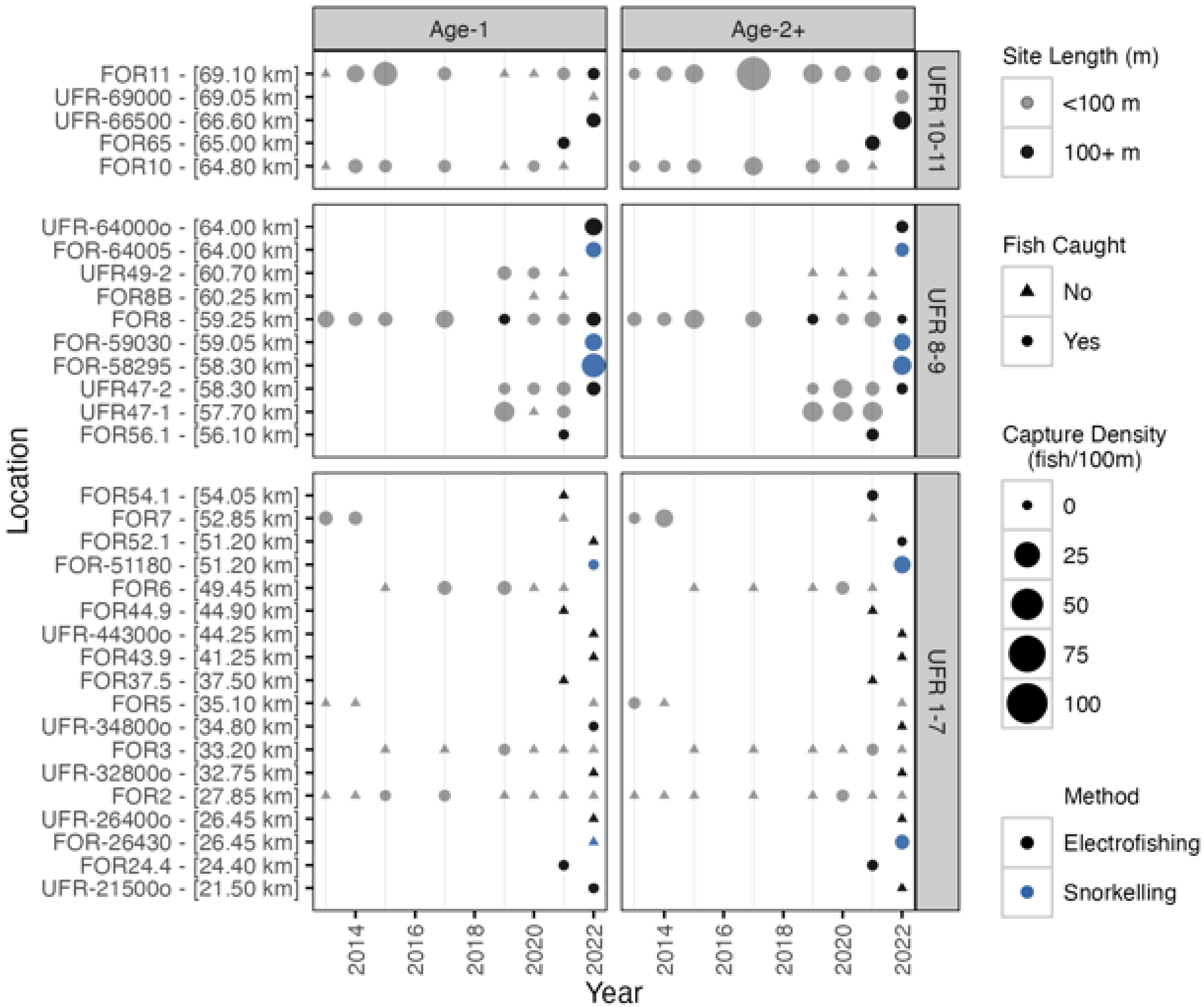

Figure 18. The electrofishing (and snorkeling) capture (and observational) density on the first pass by year, location and lifestage on the mainstem UFR.
Locations on the y axis are listed in an upstream direction as indicated by the stream distance (km) in square brackets (refer to Figure 1 for a map of the stream distances). Sections that were both electrofished and surveyed using upstream snorkeling are adjacent, for comparison. These plots represent raw data and do not account for capture efficiencies.

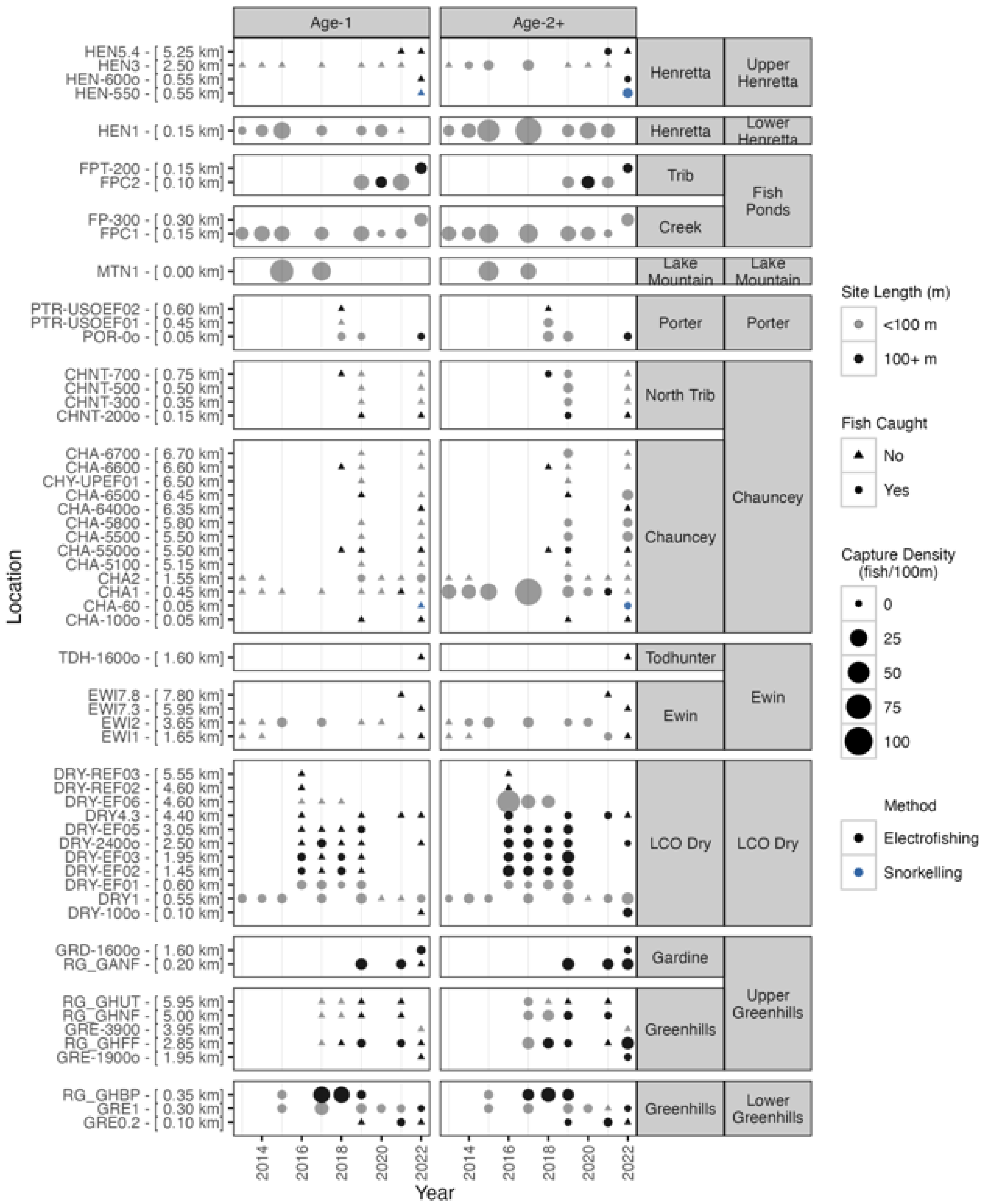

Figure 19.The electrofishing (and snorkeling) capture (and observational) density on the first pass by year, location and lifestage in tributaries to the UFR.
Sections that were both electrofished and surveyed using upstream snorkeling are adjacent, for comparison. These plots represent raw data and do not account for capture efficiencies.

CAPTURE EFFICIENCY

Estimates of capture efficiency allow absolute densities to be estimated from capture densities. As expected, the estimated capture efficiency was higher for age-2+ fish relative to age-1 fish but rapidly asymptoted with increasing effort. Tributaries, which were characterized by smaller fish, were estimated to have lower capture efficiencies for age-1's at lower effort (Figure 20). Capture efficiencies were higher for upstream night snorkel surveys than electrofishing (Figure 21), 75% (95% CI 24-99) versus 48% (95% CI 42-54) for age-1 and 90% (95% CI 52-99) versus 63% (95% CI 59-67) for age-2+. Credible intervals in night snorkel surveys are wide as they are based on relatively few sites.

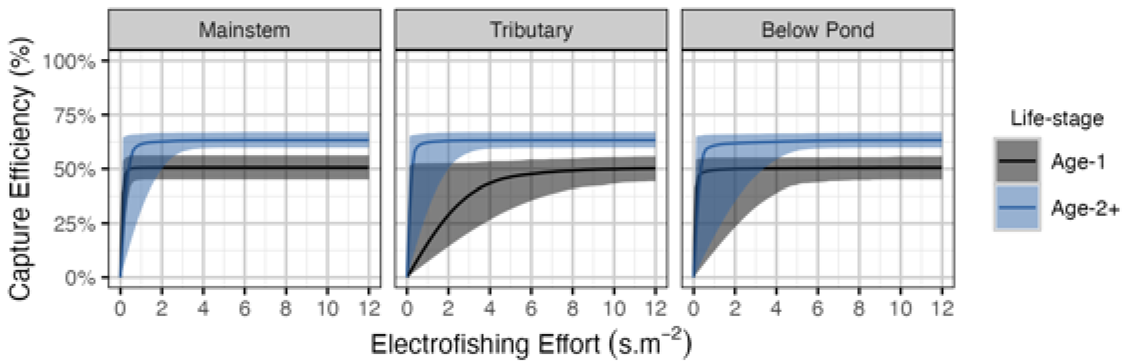

Figure 20. The capture efficiency by electrofishing effort and lifestage (with 95% CIs). Below Pond refers to a tributary that drains a pond, sediment pond or pit lake.

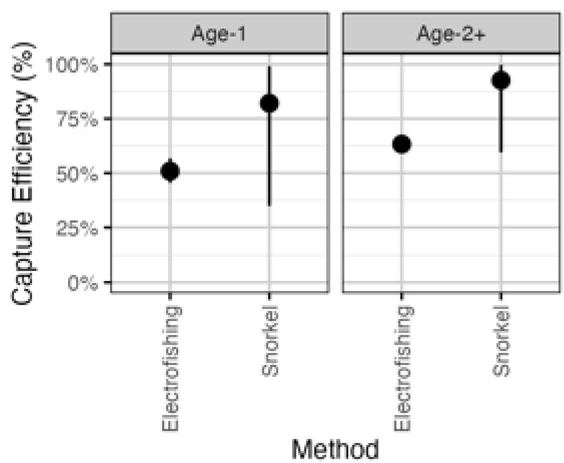

Figure 21. The estimated electrofishing capture efficiency by method and life-stage at average effort (with 95% CIs).

DENSITY

Age-1 and age-2+ WCT densities in the UFR showed substantial differences between different subpopulation groups. In particular, subpopulations in tributaries that were influenced by ponds (including sedimentation ponds and pit lakes) were estimated to have the highest overall densities of juveniles while subpopulations in tributaries that were not strongly influenced by ponds had the lowest overall estimated densities. The differences were greatest for age-1 fish with the density in the pond influenced tributaries estimated to be ~ 30 x higher than in the non-pond influenced tributaries (Figure 22). By subpopulation, the highest densities of age-1 fish were estimated for Fish Ponds at 81 fish/100m (95% CI 25-425; Figure 23, Figure 24). In contrast to the high number of redds recorded in Chauncey Creek in 2021, the estimated densities of age-1 fish were extremely low, at 0.6 fish/100m (95% CI 0.1-3). Only Upper Henretta Creek, at 0.4 fish/100m (95% CI 0-3), is lower.

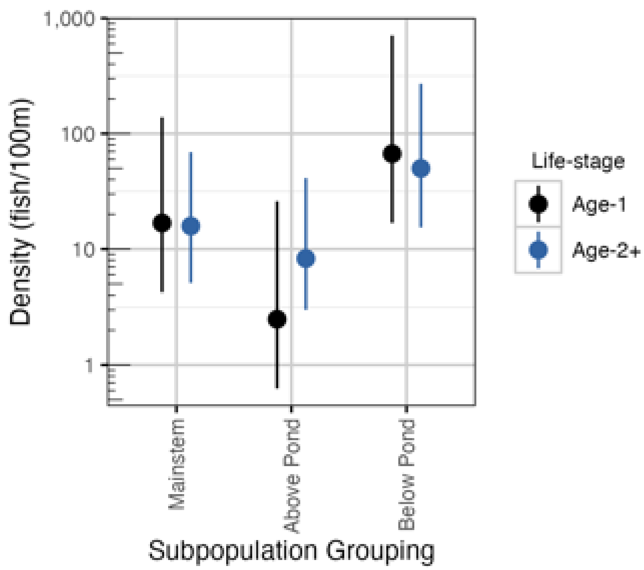

Figure 22. The estimated lineal density by grouping and life-stage in a typical subpopulation in a typical year (with 95% CIs).

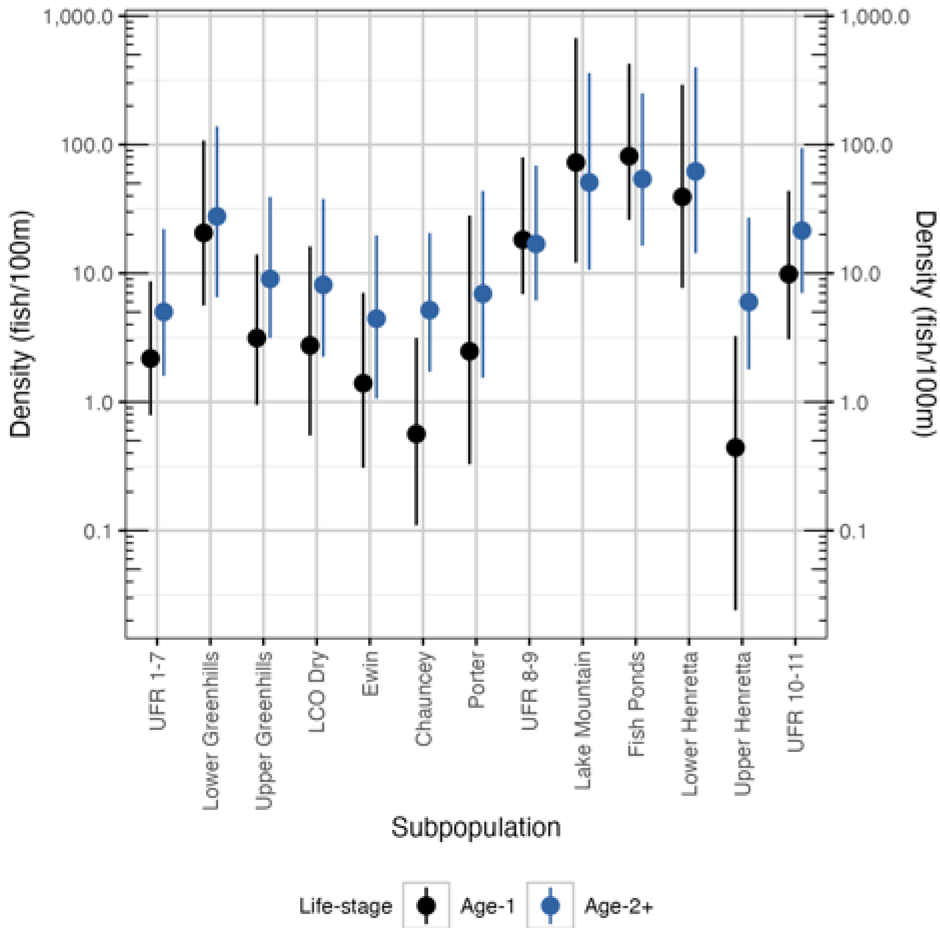

Figure 23. The estimated lineal density by subpopulation and life-stage in a typical year (with 95% CIs).

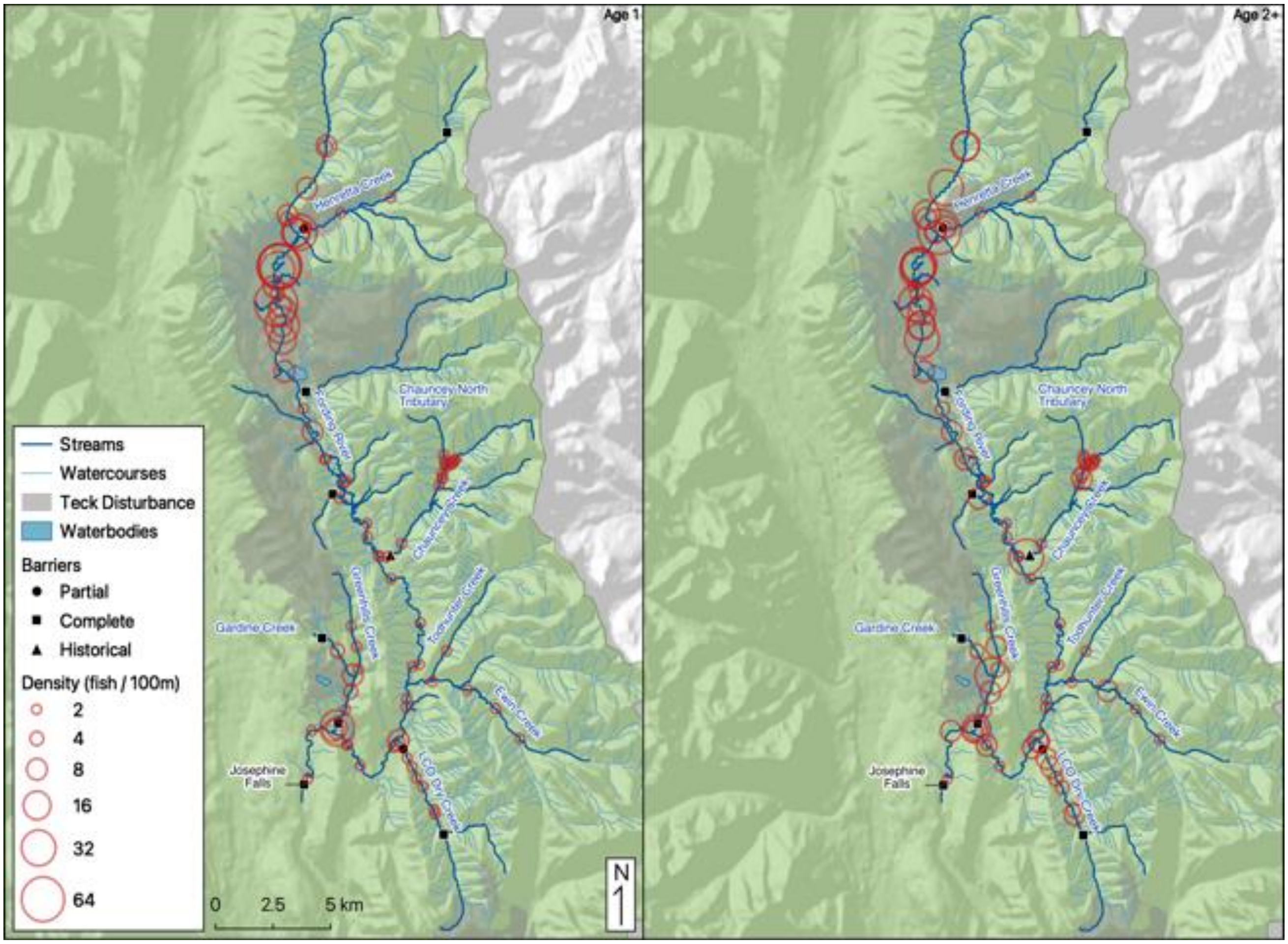

Figure 24. The spatial distribution of estimated density in a typical year by life-stage.

ABUNDANCE

When the length of habitat is taken into account the relative importance of tributaries with short but highly productive sections diminishes and upper, middle and lower sections of the mainstem UFR are estimated to provide habitat for more juvenile fish than any of the other subpopulations (Figure 25). In 2022, the total age-1 abundance of the population including upper Greenhills was estimated to be 2,300 fish (95% CI 1,300-5,400) and the age-2+ abundance was estimated to be 3,900 fish (95% CI 2,400-7,600). These values are similar to 2021 and within the historical range of variability (Figure 26). The highest estimated abundance for age-1 fish was in 2015 at 8,300 fish (95% CI 4,100-22,000) and in 2017 for age-2+ fish at 19,000 individuals (95% CI 11,000-35,000).

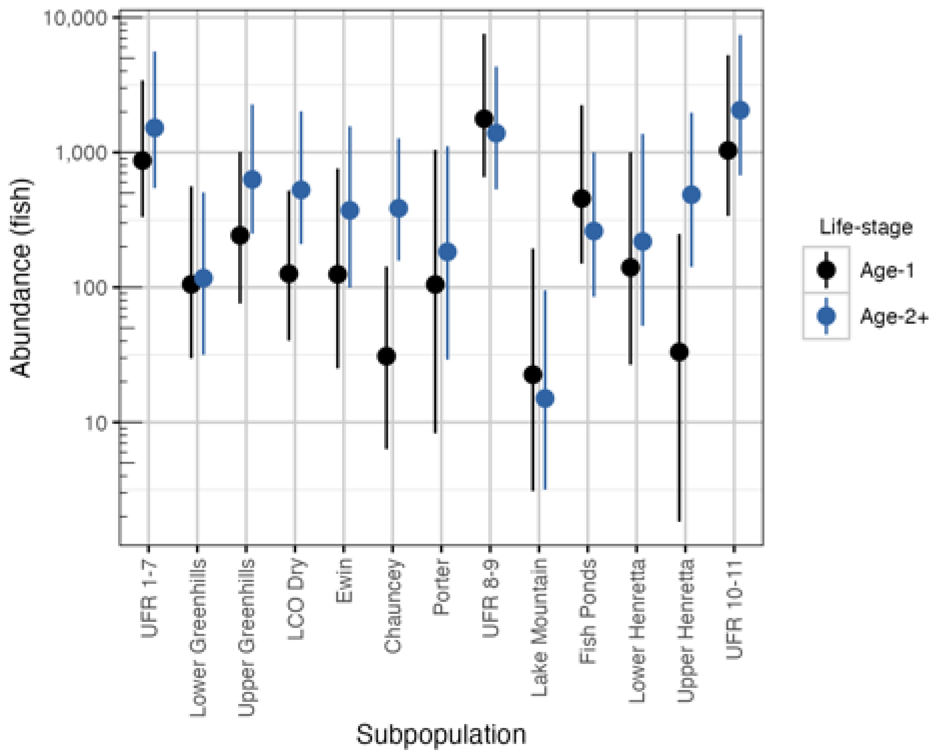

Figure 25. The estimated abundance of age-1 and age-2+ WCT by subpopulation and life-stage (with 95% CIs).

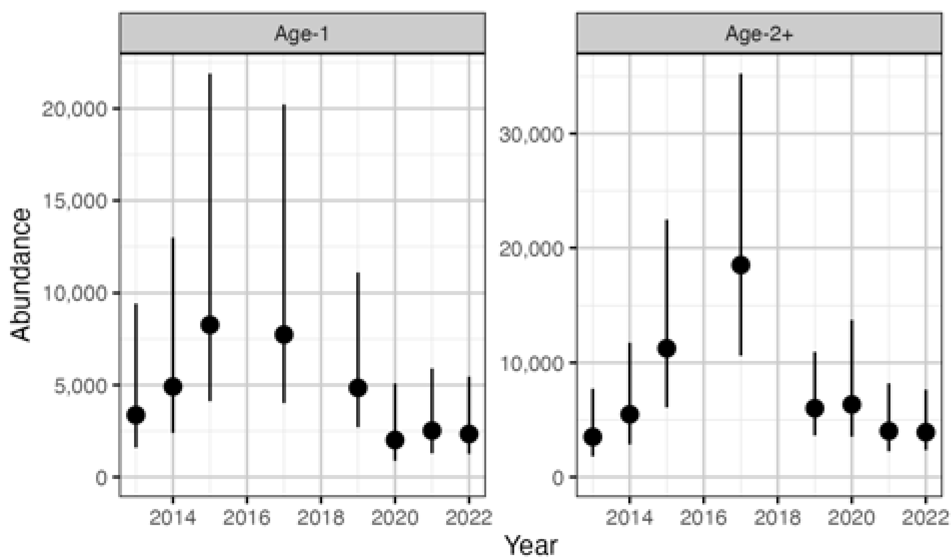

Figure 26. The estimated abundance age-1 and age-2+ WCT by year and life-stage (with 95% CIs).

SNORKEL SURVEYS

DISTRIBUTION

Juvenile (<200 mm; age-2+) and (sub)adult fish show similar changes in their pattern of distribution in snorkel surveys over time (Figure 27, Figure 28). Counts for both life stages were distributed relatively evenly throughout the mainstem UFR between 2012 and 2014. However, in 2017, counts increased substantially more in the mainstem UFR between sections S7 and S10 for both juveniles and (sub)adults. Then in 2021 following two years with very few fish observed anywhere in the system (2019 and 2020), the counts of WCT in the upper sections of the UFR increased relative to the rest of the mainstem. In 2022 there has been an increase in the counts of both (sub)adults and juveniles throughout the mainstem UFR. Fish Pond Creek had the highest count of juvenile WCT in 2022. The fork length distribution for fish counted in 2022 showed a marked shift towards more fish in the age-2+ size range, as well as more adults >300 mm, compared to 2021 data (Figure 29).

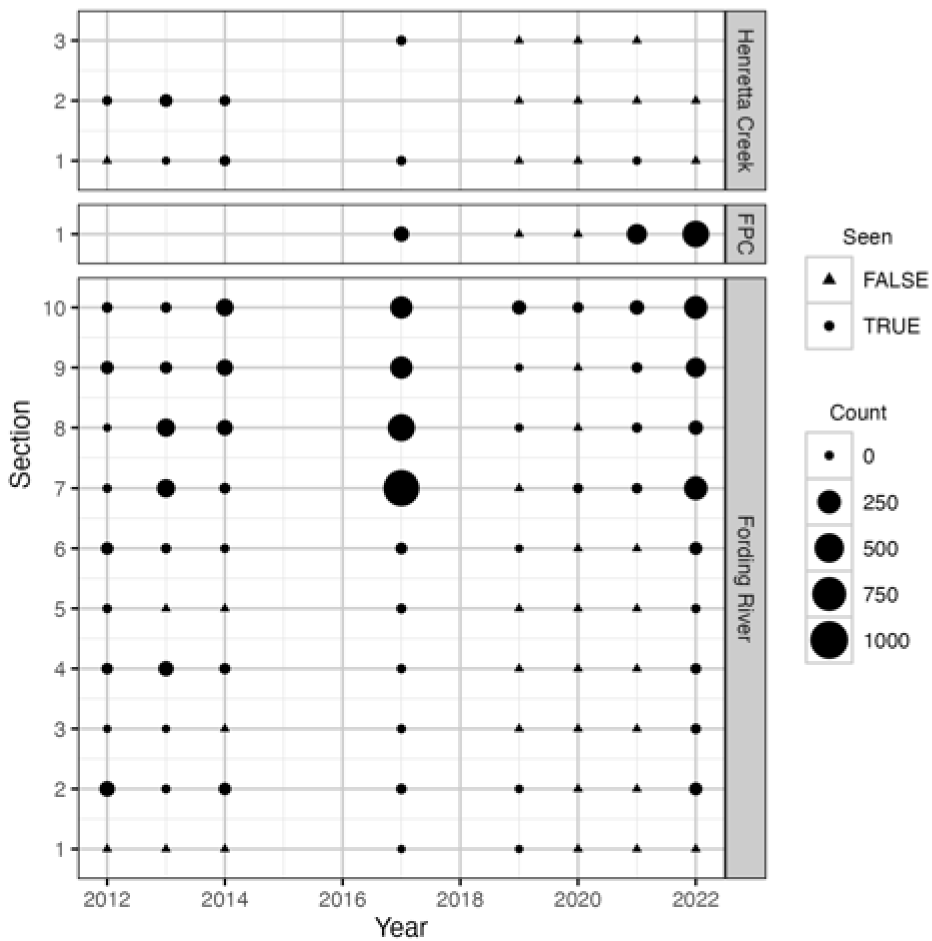

Figure 27. Raw total fall snorkel counts of juvenile (< 200 mm) WCT by year, section and stream. FPC is Fish Pond Creek.

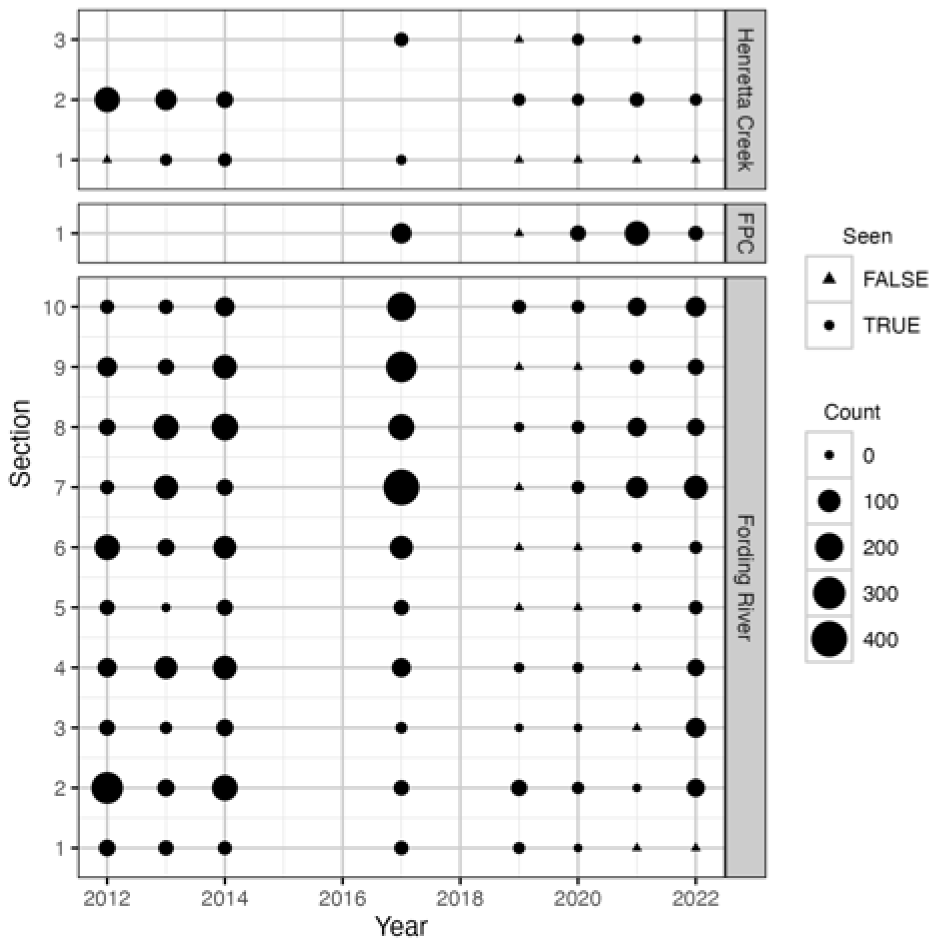

Figure 28. Raw total fall snorkel counts of (sub)adult (≥ 200 mm) WCT by year, section and stream. FPC is Fish Pond Creek.

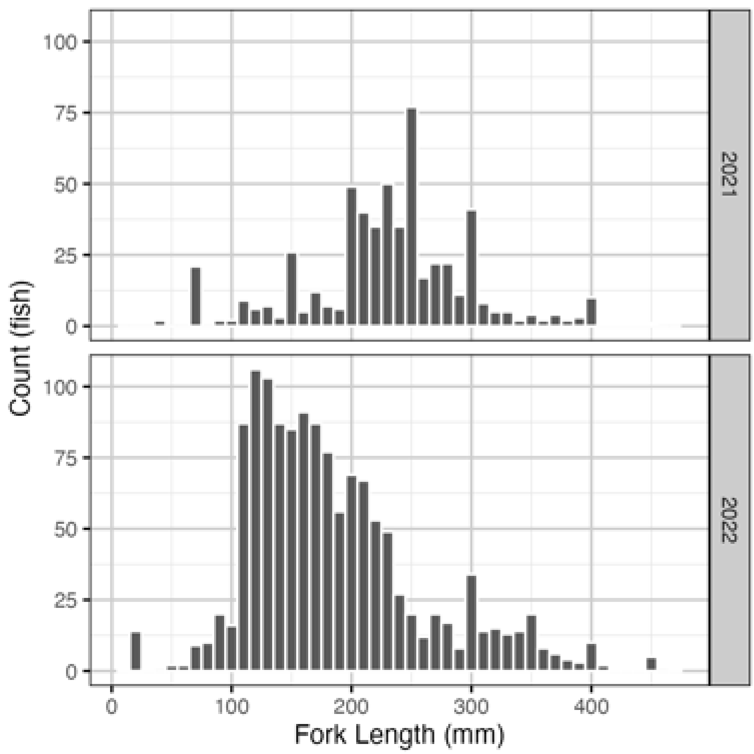

Figure 29. Fork length distribution for fish counted on the UFR in 2022.

(SUB)ADULT ABUNDANCE

(Sub)adult abundance followed a similar trend as age-1 and age-2+ fish and peaked in 2017, at 5,200 fish, before dropping by ~93% to 330 fish in 2019. The estimated (sub)adult abundance has increased over the past four years to 2,000 fish in 2022 (Figure 30).

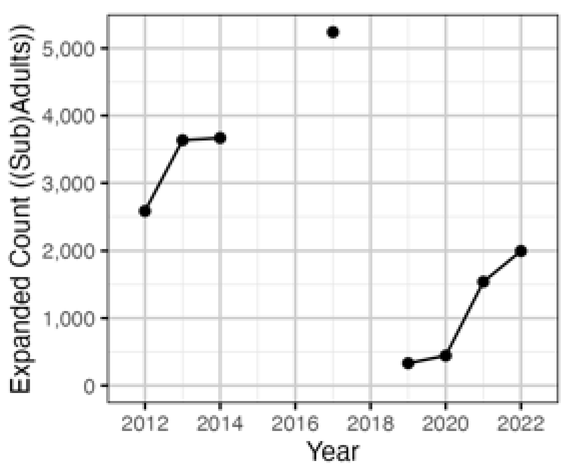

Figure 30. The estimated fall (sub)adult abundance by year assuming an efficiency of 42% for 2012, 23% for 2013 and 32% for 2014, 2017 and 2019-2022.

FECUNDITY

Based on the fecundity by fork length relationships from Corsi et al. (2013; Figure 31), the estimated annual fecundity is higher, at 860 eggs/female, in 2022 than the previous 4 years, and similar to values from 2013 and 2014 (Figure 32).

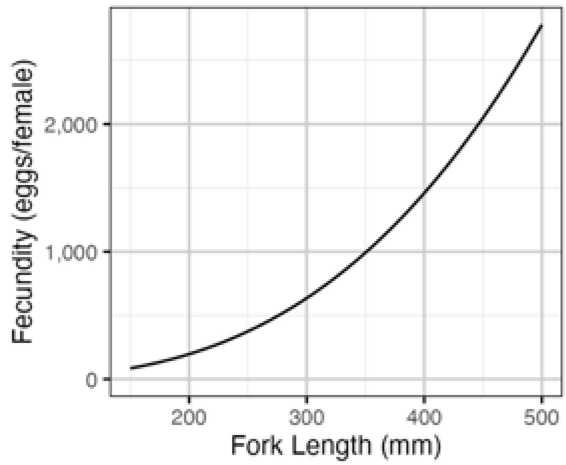

Figure 31. The assumed fecundity by fork length relationship from Corsi et al. (2013).

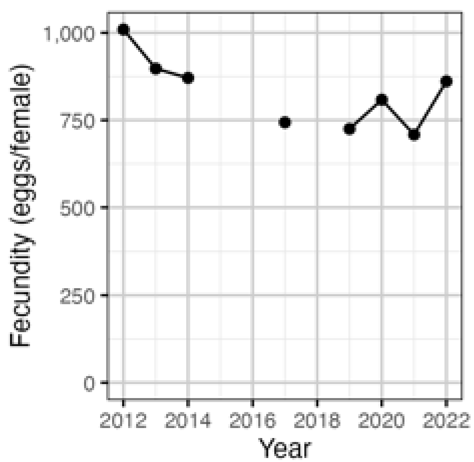

Figure 32.The estimated fecundity based on the snorkel data by year.

The estimated total egg deposition closely tracks (sub)adult abundance. Egg deposition peaked at 970,000 in 2017 and fell to just 60,000 in 2019 before rising steadily to 430,000 in 2022 (Figure 33).

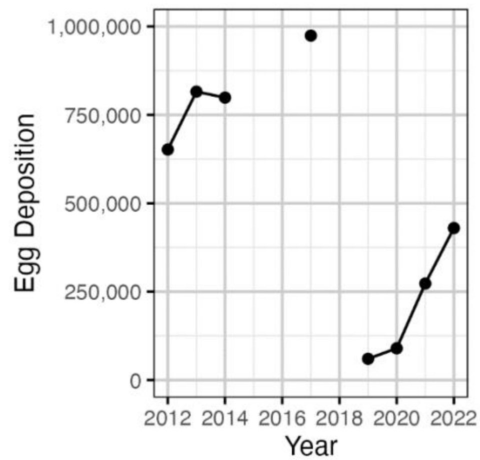

Figure 33.The estimated total egg deposition based on the snorkel data by year.

SURVIVAL

Egg to age-1 survival refers to the number of age-1 fish present in the fall of a given year, which were produced by spawning in the previous year (i.e., the spawn year). Survival was lower in 2021, at 1% (95% CI 1-2) than the previous two spawn years, but higher than 2012-2013. Egg to age-1 survival peaked in 2019 at 4% (95% CI 2-10; Figure 34), after the population decline. Survival trends show a density dependent relationship, with high survival rates in years of low egg deposition, and lower survival in years of high egg deposition.

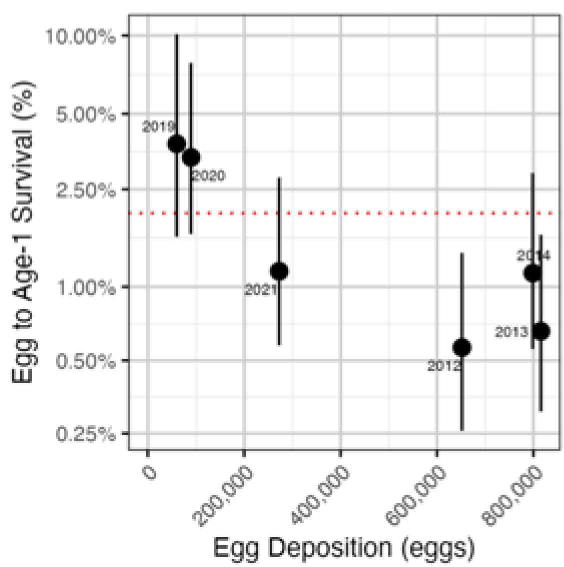

Figure 34. The egg to age-1 survival (on a logistic scale) by egg density and spawn year.
The dashed red line indicates the egg-to-fry survival required for replacement based on Ma and Thompson (2021). Error bars represent 95% CIs.

The analytic appendix which includes model templates, parameter descriptions and parameter coefficient tables is available from: *Thorley, J.L., Kortello, A.D., and Brooks J. (2023) UFR WCT Population Monitoring 2022. URL: https://www.poissonconsulting.ca/f/888366171*.

DISCUSSION

As outlined in the Introduction, the population monitoring program has expanded to explicitly address 10 questions identified in the Fish and Fish Habitat Framework that characterize population characteristics and vital rates necessary for understanding the dynamics of fish populations. We answer the questions based on the findings of this and previous reports 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 57 km upstream, including side channels from Josephine Falls at 21 km to the upper limit of fish distribution around 75 km and also extends into an estimated 45 km of tributary habitat. The current report only considers the UFR population in the mainstem and connected tributary habitat. Key connected tributary habitat includes

- Lower Greenhills Creek to the sedimentation pond spillway at 0.5 km.
- LCO Dry Creek has access to the headpond at 5.5 km and into East Creek.
- Chauncey Creek.
- Ewin Creek to upper limit of fish distribution
- Porter Creek to fish barrier at sediment pond decant.
- Clode Creek to fish barrier at sediment pond decant.
- Fish Pond Creek and Fish pond Creek Tributary
- Henretta Creek to the gradient barrier at 9 km.

The fish in Chauncey Creek above 0.9 km were isolated from the main population by impassable culverts until 2020 (Robinson and Barnes 2021). In Greenhills and Gardine creeks an isolated population currently exists in the ~8 km of lotic habitat above the sedimentation pond spillway, which acts as a barrier to upstream movement. Based on hydraulic modelling (AJM Environmental Inc. and Higher Ground Consulting 2023) and a field survey by Lotic Environmental, the culvert at 1 km on LCO Dry Creek is classified as passable by (sub)adults at most stream flows. This classification is supported by the presence of redds above the culvert in 2020 and 2022. Consequently the fish in LCO Dry Creek are considered to be both demographically and genetically part of the UFR population.

2 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 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 2022 the estimate was 2,000 individuals. Given an increasing population trend, genetic diversity in the UFR population does not appear to be a concern in the short term. However, see Frankham et al. (2014) who suggest that a 100/1000 rule is more appropriate.

3 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).

4 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 2022, spawning was estimated based on the Area-Under-the-Curve model to begin around June 8 and continue until August 8. The observed onset of spawning activity in the mainstem UFR and most tributaries was delayed until early July, likely due to an unusually cold spring. However, spawning activity in Fish Pond Creek, Porter Creek and lower Greenhills Creek began in early June. Fish Pond Creek is groundwater influenced while Porter Creek and lower Greenhills Creek are downstream of sedimentation ponds. 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. An unusually warm fall may have extended the growing period into late October in 2022.

5 WHAT ARE THE SIZES OF KEY LIFE-STAGES?

The sizes of age-0 fish in the UFR population are variable by year and stream, with typical fork lengths for a fry from lower Greenhills Creek (65 mm) almost triple the length of fry from Chauncey Creek (22mm).

Age-0 size has implications for population dynamics, with WCT less than ~30 mm expected to have poor overwinter survival (Sogard 1997; Coleman and Fausch 2007a, 2007b). When the upstream sedimentation ponds were operational in LCO Dry Creek, age-0 fish were estimated to be approximately 40 mm. But after the main flow was diverted around the ponds, beginning in July 2020, there was an overall reduction in downstream temperatures (Whelan et al. 2022), and the fish are now estimated to be just 27 mm. An upstream spoil failure in February of 2021 may have also had an impact on age-0 size via its influence on turbidity, although there was no apparent effect on water temperatures (Whelan et al. 2022) and the fish data are from 2022.

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. As snorkel surveys prior to 2021 often simply recorded the length of fish as ≥ 200 mm, the current report includes subadults with adults inflating the total egg deposition and deflating the egg to age-1 survival.

6 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, with continued sampling and a longer data set (2012 to 2022), results are showing that the growth rate likely varies substantially by subpopulation 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, e.g., Chauncey Creek age-0 fish average 28 mm, and Greenhills Creek age-0 fish average 64 mm. This differs and expands the understanding detailed in Cope et al 2016. As discussed below, increased PIT tagging of individuals to collect information on inter-annual growth is recommended.

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

In 2022 the majority of the spawning activity occurred in sections 10 and 11 in the mainstem UFR, Fish Pond Creek, Chauncey Creek, and Porter Creek. Redds were also recorded in Greenhills, LCO Dry, and section S4 and S5 on the mainstem UFR. The distributions of age-0 and age-1 fish tend to be clumped and associated with spawning areas. However, densities of age-1 fish in different subpopulations in the UFR suggest rearing habitat is strongly temperature limited. The highest densities of age-1 occurred below or within lentic habitat in tributaries with ponds, sedimentation ponds or pit lakes, i.e., lower Henretta, lower Greenhills, Fish Ponds and Lake Mountain Creek (historically). Moderate densities occurred in the middle (UFR 8-9) and upper (UFR 10-11) sections of the mainstem UFR. The lowest densities occurred in subpopulations in tributaries that were not influence by lentic habitat, i.e., Ewin, Chauncey and upper Henretta. In the case of Chauncey Creek which is characterized by high redd densities, small age-0 fish, and low age-1 fish densities, the data suggests poor overwintering survival of the age-0 fish. Although the spatial distribution of age-2+ fish is similar to the age-1 fish suggesting some residency the differences are also less pronounced suggesting some redistribution of juveniles after their second fall.

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. However, the spatial pattern of (sub)adult WCT in 2022 was more similar to pre-2017 data, with a relatively even distribution throughout the mainstem.

8 WHAT IS THE ABUNDANCE OF KEY LIFE-STAGES?

AGE-1

The estimated abundance of age-1 fish increased from ~ 3,400 in 2013 to over ~8,400 in 2015 before dropping to ~1,900 in 2020 and remaining relatively stable at ~2,300 in 2022. It is important to note that the number of age-1 fish is determined by the number of eggs deposited the previous year and the overwinter survival of age-0 WCT. Consequently, interpretation of these numbers is conducted with respect to the egg deposition the previous year in the section on survival below.

The implementation of large, open mark-recapture sites for electrofishing has reduced uncertainty around fish population numbers in recent years, by increasing the proportion of habitat sampled. Previously, 95% CI's spanned almost an order of magnitude. An ongoing transition from small, closed sites to large, open sites for electrofishing is recommended. Additionally, the use of upstream night snorkeling, where appropriate, for surveying juvenile fish appears to be associated with a high observational efficiency while simultaneously reducing fish handling although it does not readily allow fish to be weighed, scaled or tagged.

AGE-2+

Age-2+ fish follow a similar, but time-lagged, trend when compared to age-1 abundances. The estimated abundance increased from ~ 3,500 in 2013 to over ~18,000 in 2017 before dropping to ~4,000 in 2021 and 2022. 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.

Downstream daytime snorkel surveys documented a large number of 100 to 200 mm fish many of which are expected to transition to (sub)adults in the coming year. This suggests a further increase in (sub)adult numbers in 2023. The reason why these fish were not detected in the electrofishing samples is uncertain but may be due to a low electrofishing capture efficiency of bigger age-2+ fish. Alternatively, bigger age-2+ fish may have a patchier distribution. Additional upstream night snorkel will allow these possibilities to be evaluated.

(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. Adult abundance has increased since 2019 to ~2000 fish and is now approaching 2012 estimates.

9 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 ~970,000 eggs in 2017 before falling to around 60,000 eggs in 2019, and then increasing by ~60% over 2021 numbers to ~430,000 eggs in 2022. As discussed above these estimates are likely inflated by the inclusion of immature subadult fish in the abundance estimates.

The increase in the estimated number of adults and eggs deposited in 2022, relative to 2021, contrasts with the 50% decline in the estimated nest count (Dunham et al. 2001; Gallagher and Gallagher 2005). However, redd observer efficiency may have been low in 2022 due to a later freshet; although Muhfeld et al. (2006) reports relatively low error rates in redd detection among experienced observers, turbid conditions during freshet can hamper visibility.

10 WHAT IS THE SURVIVAL OF KEY LIFE-STAGES?

Egg to age-1 survival dropped from about 3% in the 2019 and 2020 spawn years to 1% in 2021. Declines in egg to age-1 survival rates for the 2021 spawn year (corresponding to the survival to age-1 in 2022) suggest a density dependent response. For example, at higher fish densities, competition for stations with sufficient drift and lower predation risk would be expected to decrease recruitment. Density dependence tends to dampen the effect of environmental variation on a population's dynamics.

Calculations based on life-history parameters (Ma and Thompson 2021) from the population model suggest a survival rate of ~2% is required for population replacement. However, the rate of increase in the number of (sub)adults indicate that either the estimated population replacement rate is too low and/or the egg to age-1 survival has been underestimated. This discrepancy may be at least partly due to the inclusion of immature subadults in the adult population abundance estimates when calculating the total egg deposition. Adjusting for this inaccuracy will require distinguishing subadults from reproductive adults in the ≥ 200 mm size class.

Survival rates of radio tagged (sub)adult WCT in the UFR were 67% annually from 2012-2015 (Cope et al. 2016). Increases in abundance from 2019-2022 suggest similarly high (sub)adult survival in recent years.

CONCLUSIONS AND RECOMMENDATIONS

Overall, the available fish monitoring data, including the increasing number of adults, density dependent early life-stage survival, and levels of genetic heterozygosity are consistent with a relatively large, diverse, productive population of genetically pure WCT with a range that currently includes about 57 km of the mainstem upper Fording River and 45 km of connected tributaries. Following the large reduction in abundance in 2019 the (sub)adult population continues to rebound and is approaching pre-decline levels. In the absence of any extreme environmental conditions, a large number of 100 to 200 mm fish observed during the daytime snorkel surveys suggests further increases in (sub)adult abundance might be observed in 2023.

The environmental data as reviewed by the Evaluation of Cause Team (2021) indicates that the dramatic population decline in 2019 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. Environmental change is ongoing in the UFR watershed and a numerical, modelling approach is needed to reduce uncertainties about the effect of operations on fish populations. Temperature is a strong driver of the growth, survival and recruitment of WCT inhabiting cold headwater streams (Coleman and Fausch 2007a, 2007b). Streams in the UFR watershed are highly variable with respect to temperature regimes and observations of early life stage WCT size and distribution in UFR subpopulations are consistent with stream temperature as a primary driver. Therefore, understanding and predicting the impacts of anthropogenic changes to the watershed requires first accounting for temperature-related effects on population dynamics. Fish and habitat integration such as these will be documented in separate reports.

To further understand the drivers of the population dynamics the following actions are recommended:

- Understanding causal pathways for this system will require accounting for temperature differences in different subpopulations. Subpopulation estimates of growing season degrees by year are required.
- Analytic work to probabilistically separate historically combined counts of adults and subadults is necessary to generate more accurate estimation of survival and recruitment.
- Combining size-specific capture efficiencies from electrofishing, downstream snorkeling and upstream night snorkeling into an integrated population model will further reduce uncertainties in population estimates.

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