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Technical Report Overview

Report: Grave and Harmer Creek Westslope Cutthroat Population Monitoring 2022

Overview: This report is the annual synopsis of status and trends data for the report on results of Grave/ Harmer Creeks 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, Branton Environmental Consulting Ltd., and Lotic Environmental Ltd.

For More Information

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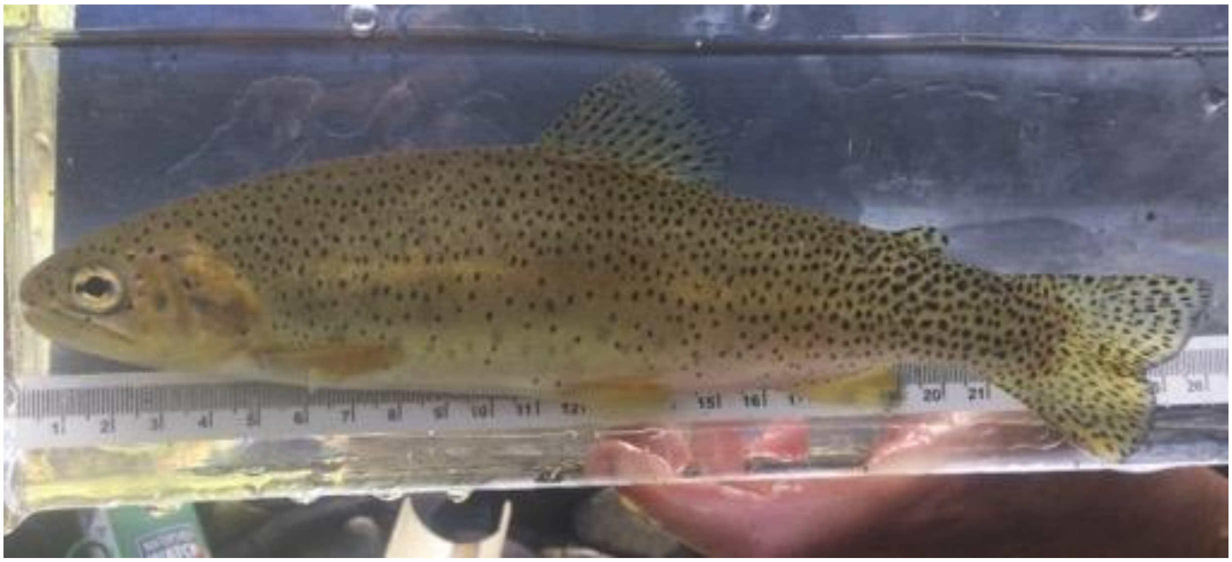
Grave and Harmer Creek Westslope Cutthroat Trout Population Monitoring 2022

FINAL REPORT

June 09, 2023



Prepared for: Teck Coal Ltd., Sparwood, BC

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The cover photo is of a Westslope Cutthroat Trout with fork length of 245 mm and weight of 201.2 g that was captured in Grave Creek GRA2 on the 9th of September 2022 by backpack electrofishing.

Executive Summary

The Grave Creek watershed is located in Southeastern British Columbia (BC), upstream of Sparwood, BC. The watershed includes Grave Creek and its tributary Harmer Creek which flow into the Elk River. The two creeks support isolated populations of genetically pure Westslope Cutthroat Trout (WCT; *Oncorhynchus clarkii lewisi*). The Harmer Creek population was separated from the Grave Creek population in 1971 by construction of the Harmer Creek Sediment Pond and Dam. In the Grave Creek watershed, disturbance from logging, roads and other development is relatively limited, except for an area in the southwest of the Harmer Creek subwatershed which is part of Teck Coal's Elkview Operations (EVO). These operations influence water quality and physical habitat in the Harmer Creek subwatershed and water quality in Grave Creek, below its confluence with Harmer Creek.

There is a WCT population monitoring program in Grave and Harmer Creeks. It was established to reduce uncertainties about the WCT populations, distribution, and habitat utilization. The monitoring program has evolved over time to collect and analyze data in a way that addresses 10 specific questions (Table E-1). These questions provide a foundation for understanding the status and trends in the populations' vital rates of growth, survival, reproduction, and movement which drive changes in the abundance of the populations.

Based on the fish monitoring data collected from 2017 to 2022, the estimated abundance of adults in both the Grave and Harmer Creek populations was lowest in 2019 and highest in 2022. The average length of all adults in both populations was highest in 2020 before decreasing in 2021 and 2022. This suggests that there is a new cohort(s) of fish being recruited into the adult life-stage which results in a lower average length of adults relative to previous years.

The abundance of age-1 fish was estimated to be higher in the Harmer Creek population in 2022 than in previous years and relatively high in the Grave Creek population compared to previous years. This was the second year in a row with high estimated age-1 abundance in both populations and a correspondingly high estimated egg to age-1 survival. An increase in the estimated survival rate for age-1 and older fish was also observed during this time-period.

In 2022, age-0 fish from both the Grave and Harmer Creek populations were estimated to be substantially shorter in length on October 1, near the end of the growing season, than in previous years. In addition, the body condition of age-2 + fish (90 to 169 mm) in 2022 was substantially lower than from 2017 to 2021. Together these results suggest that age-0 fish may have had lower than usual energy status going into the winter of 2022. Energy status of age-0 fish and the amount of energy necessary to survive winter, based on its duration and severity, affect overwintering survival and recruitment for the cohort of fish.

Increased sampling in 2022 indicates there are some productive tributary streams contributing to both populations. To date, tributaries have not been included in the population estimates, but in the future with the increased sampling effort they are expected to provide additional insight into the dynamics of the populations.

Recommendations for future sampling include a continued focus on increasing electrofishing coverage, including into the tributaries, ongoing aging of fish, and the assessment of age-0 body condition.

Table ES1 Answers to the ten questions considered in the current report which inform population carrying capacity, productivity and viability

Question	Subcategory	Grave Creek	Harmer Creek
Population Characteristics: Questions about the fish population that are relatively constant across years			
1. What is the geographic range of the fish population(s)?	Mainstem (accessible)	Mainstem from river kilometre (rkm) 2.1 to 12.5 and Harmer Creek below the Harmer Sediment Pond.	Mainstem from 0.8 to 10.0 rkm
	Tributaries (accessible)	429235 Creek (3.46 km) It may also extend into the lower parts of several other tributaries.	Lower 1.8 km of EVO Dry Creek and 0.8 km of South Tributary, the lower parts of Balzy and Sawmill creeks.
2. What is the genetic diversity and effective genetic population size of the fish population(s)?	Alleles/Loci	1.6	1.4
	Effective genetic population size	43	23
3. What are the life-history strategies within the fish population(s)?		Small (< 300 mm) fluvial residents.	
4. What is the timing of life-history events?	Spawning	Spawning by late May until mid-July.	
	Incubation	Fry emerge after 575 to 600 degree days.	
	Rearing	Growing season ends in October depending on stream temperatures.	
5. What are the sizes of the key life-stages?	Age-0	~ 38 mm on October 1	~ 32 mm on October 1
	Age-1	50 – 89 mm in September	50 – 89 mm in September
	Adult	Females that were mature in May are likely ≥ 170 mm in September.	
Vital Rates and Associated Endpoints: Questions about the fish population that can vary by year			
6. What is the growth rate of key life-stages?	Adult	Fish mature (reach 170 mm in September) between age-3 and age-6.	
7. What is the spatial distribution of key life-stages?	Nests	Highest densities from 3 to 8.5 km and in Harmer Creek below the Harmer Sediment Pond	Primarily in mainstem below EVO Dry Creek
	Age-1	Highest densities at top of mainstem, between the culverts and in Harmer Creek below the Harmer Sediment Pond	Primarily in mainstem below EVO Dry Creek
	Adult	Highest densities around culverts and in Harmer Creek below the Harmer Sediment Pond	Highest densities in mainstem immediately below confluence with and into EVO Dry Creek

Question	Subcategory	Grave Creek	Harmer Creek
8. What is the abundance of key life-stages?	Age-1	~800 in 2019 to ~1,700 in 2022	~14 in 2019 to ~1,800 in 2022
	Adult	~400 in 2021 to ~600 in 2022	~280 in 2017 to ~360 in 2022
9. What is the total number of eggs deposited?	Eggs	~26,000 in 2017 to ~39,000 in 2022	~16,000 in 2017 to ~23,000 in 2022
10. What is the survival of key life-stages?	Egg to age-1*	~2.1% in 2018 to ~7% in 2022	~0.08% in 2018 to ~9% in 2022
	≥ Age-1	>80%	

**The estimated survival rate required for population replacement is 1-5%.*

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1 INTRODUCTION

The Grave Creek watershed flows into the Elk River upstream of Sparwood in southwestern British Columbia. The watershed includes Grave Creek and its tributary Harmer Creek which support isolated populations of genetically pure (Cope and Cope 2018) Westslope Cutthroat Trout (WCT; *Oncorhynchus clarkii lewisi*).

Westslope Cutthroat Trout are of special concern to the Ktunaxa Nation and are also of special concern under federal and provincial legislation and policy. 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 Grave Creek watershed include poaching and broad scale landscape factors related to forestry, recreation, and transport corridors. Recreational angling has been prohibited in the Grave Creek watershed since 2020 (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 (2007b) documented how poor age-1 recruitment can occur due to a short growing season and 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).

Population Dynamics *- the changes in abundance of fish over time*

Carrying Capacity *– the number of fish the habitat can support*

Intrinsic Productivity *- the average number of adults that each adult would produce over its lifetime when the amount of habitat is not limiting (at very low population density)*

Viability *– the probability of the population persisting in the long term given chance events and environmental variation*

In the Grave Creek watershed, disturbance from logging, roads and other development is relatively limited, except for an area in the southwest of the Harmer Creek subwatershed which is part of Teck Coal's Elkview Operations (EVO) and is influenced by waste rock deposits in two of its headwater tributaries – EVO Dry Creek and, to a lesser degree, South Tributary. These operations influence downstream water quality in Harmer Creek and in Grave Creek, below its confluence with Harmer Creek as well as physical habitat in EVO Dry Creek through calcite formation. In addition, as part of mine operations, the Harmer Sediment Pond Dam was built in 1971. Until that time, the Harmer Creek and Grave Creek fish populations were a single population. When the dam was constructed, it effectively created separate populations in Harmer Creek and Grave Creek by restricting the upstream movement of fish.

The WCT population monitoring program in Grave and Harmer Creeks, which is in its sixth consecutive year, was established to address the requirement of the Environmental Assessment Certificate (EAC #M16-01) for the extension of mining at EVO; to undertake additional fish and fish habitat assessments in the Harmer-Grave Creek system (Condition #14). The goal of the program was to reduce uncertainties in the WCT population abundance, distribution, and habitat utilization in Grave and Harmer Creeks. The monitoring conducted between 2017 and 2019 indicated that there was low abundance of juvenile fish in the Harmer Creek population (Cope and Cope 2020a). An evaluation of the environmental stressors (natural and anthropogenic) contributing to what was identified as low recruitment in those years was undertaken by a multi-disciplinary group of subject matter experts. The findings of that Evaluation of Cause are summarized in the Text Box below and have been published (Harmer Creek Evaluation of Cause Team 2023).

Harmer Creek Evaluation of Cause

An Evaluation of Cause (EoC) investigated what might have caused reduced recruitment in the Harmer Creek population for the 2017 to 2019 spawn years (Harmer Creek Evaluation of Cause Team 2023). The findings are briefly summarized below.

Data suggests low recruitment was caused primarily by few fish surviving their first winter. Small fish may not have enough stored energy to survive winter and may be more likely to be stressed by other environmental factors than if they had enough fat reserves. The findings suggested that the small size of fish before winter was likely related to natural conditions, specifically the short growing season and naturally low water temperatures and, to a lesser extent, reduced growth that resulted from the young fish being exposed to selenium. Recruitment may also have been higher if habitat conditions in Dry Creek, a mine-influenced tributary, were not impaired. As well, winter conditions from late 2018 to spring 2019 were unusually cool regionally and may have further contributed to challenging conditions that could have required more energy for young fish to survive or caused direct mortality from ice. Survival of age-1 fish was low enough that year to be considered "recruitment failure".

The potential for low adult abundance to contribute to the reduced recruitment was investigated but found to be unlikely as patterns in relevant metrics (number of adults, body condition, fecundity and presence of definitive nests) were similar in the Harmer and Grave Creek population areas and the pattern of low recruitment over those years was not observed in the Grave Creek population.

In addition to meeting its original goals, the monitoring program has evolved to address additional uncertainties. A framework for predicting the effects of management actions on the dynamics (carrying capacity, intrinsic productivity and viability) of fish populations is under development. The framework identifies how actions influence fish population dynamics through the effects of habitat changes on the populations' vital rates (growth, survival, reproduction, and movement).

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)

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 will enable the consequences of alternative management actions on the long-term dynamics of the fish populations to be estimated. The intrinsic productivity and viability of the WCT populations in the Grave watershed will be estimated in 2023 using the population model of ESSA Technologies Ltd. and Ecofish Research Ltd. (Lodmell et al. 2017; Ma and Thompson 2021).

2 STUDY AREA AND WCT POPULATIONS

The study area for the WCT population monitoring program consists of the fish habitat upstream of the barrier falls at river kilometer (rkm) 2.1 on Grave Creek (Figure 1). Consistent with Fisheries and Oceans Canada (DFO) we use the term fish habitat to refer to any environmental variables that directly or indirectly influence the dynamics of the population including, for example, benthic invertebrate drift from non-fish bearing tributaries. Based on our current knowledge, we subdivide the physical habitat available into that which is accessible to fish, that which is occupied by fish, and that which contains sufficient fish densities to effectively contribute to the population. It is important to note that the fish in Harmer Creek below the Harmer Creek Sedimentation Pond Dam are part of the Grave Creek population[1].

Throughout this document we follow Wells and Richmond (1995) in using the term subpopulation to refer to an arbitrary spatially-delimited subset of individuals from with a population The subpopulations are defined with respect to sections of creek. The sections are chosen to represent groups of fish that for modeling purposes can reasonably be assumed to have the same growth, survival, reproduction and/or movement based on our current understanding of the habitat (physical, chemical, and biological). As such the subpopulation groupings reflect the life-stage(s) and vital rate(s) under consideration as well as the presence of fish barriers and the available data for the analysis in question. Subpopulation groupings do not necessarily correspond to reach breaks which represent substantive changes in gradient, channel confinement, or major tributaries (Johnston and Slaney 1996). For the purposes of this report, the Grave Creek mainstem (above the barrier falls) is divided into three subpopulation areas (Grave Lower: GL,

[1] The stream network and river kilometres are derived from the Teck stream network and all spatial coordinates are for UTM Zone 11N (NAD83). All fish lengths are fork lengths unless otherwise stated.

Grave Middle: GM, Grave Upper: GU) and the Harmer Creek mainstem is divided into four subpopulations (Harmer Lower: HL, Harmer Pond: HP, Harmer Middle: HM, and Harmer Upper: HU). Each tributary is considered its own subpopulation (Figure 1).

For the purposes of this 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 remains age-0 until the end of the calendar year whereupon it becomes an age-1 individual. Fish that are too big to be age-1 and too small to be adults are categorized as age-2+ and therefore include multiple spawning cohorts. Fish are assumed to become adults (mature) when they reach a length of ≥ 170 mm in September at an average age of 4 years (Thorley et al. 2022c).

3 FIELD METHODS

Since its initiation in 2017 the Grave and Harmer WCT Population Monitoring program has included redd surveys in the spawning season and electrofishing in the fall. In addition, in 2022 a survey of barriers in the mainstem and tributaries of both Grave and Harmer Creeks was conducted to determine the upstream extent of accessible habitat. A summary of methods used in 2022 is provided below (also see Table 1) and the full study design and methods are provided in Thorley et al. (2022a).

3.1 BARRIER SURVEY

To reduce the uncertainty in the upstream extent of accessible habitat, a natural barriers survey was conducted. The survey followed the BC Resource Inventory Committee (RIC) standards for a Reconnaissance (1:20,000) Fish and Fish Habitat Inventory to identify barriers to upstream fish passage. Surveys were conducted between June 1 and August 10, 2022, with crews beginning at a point of known fish distribution and surveying upstream for features that may limit upstream fish passage, specifically vertical drops (i.e., falls), steep gradient, or lack of channel. Photographs of the barrier and measurements of barrier heights and widths, and plunge pool depths were recorded into the Teck Collector App (Brooks and Robinson, 2022).

In addition to a physical barrier survey, the distribution and relative abundance of WCT throughout the Grave and Harmer Creek watersheds was investigated using environmental DNA (eDNA) (Kim and Hocking 2023). eDNA sampling included known fish bearing reaches as control sites. eDNA sampling was conducted from September 14 to October 1, 2022, in Harmer Creek, Dry Creek, Balzy Creek, Sawmill Creek, Grave Creek mainstem, Harriet Lake Creek, 429235 Creek, upper Grave Creek, Grave Creek East Tributary, and Grave Lake. The full report including details on methods and the full analysis is available in Kim and Hocking (2023).

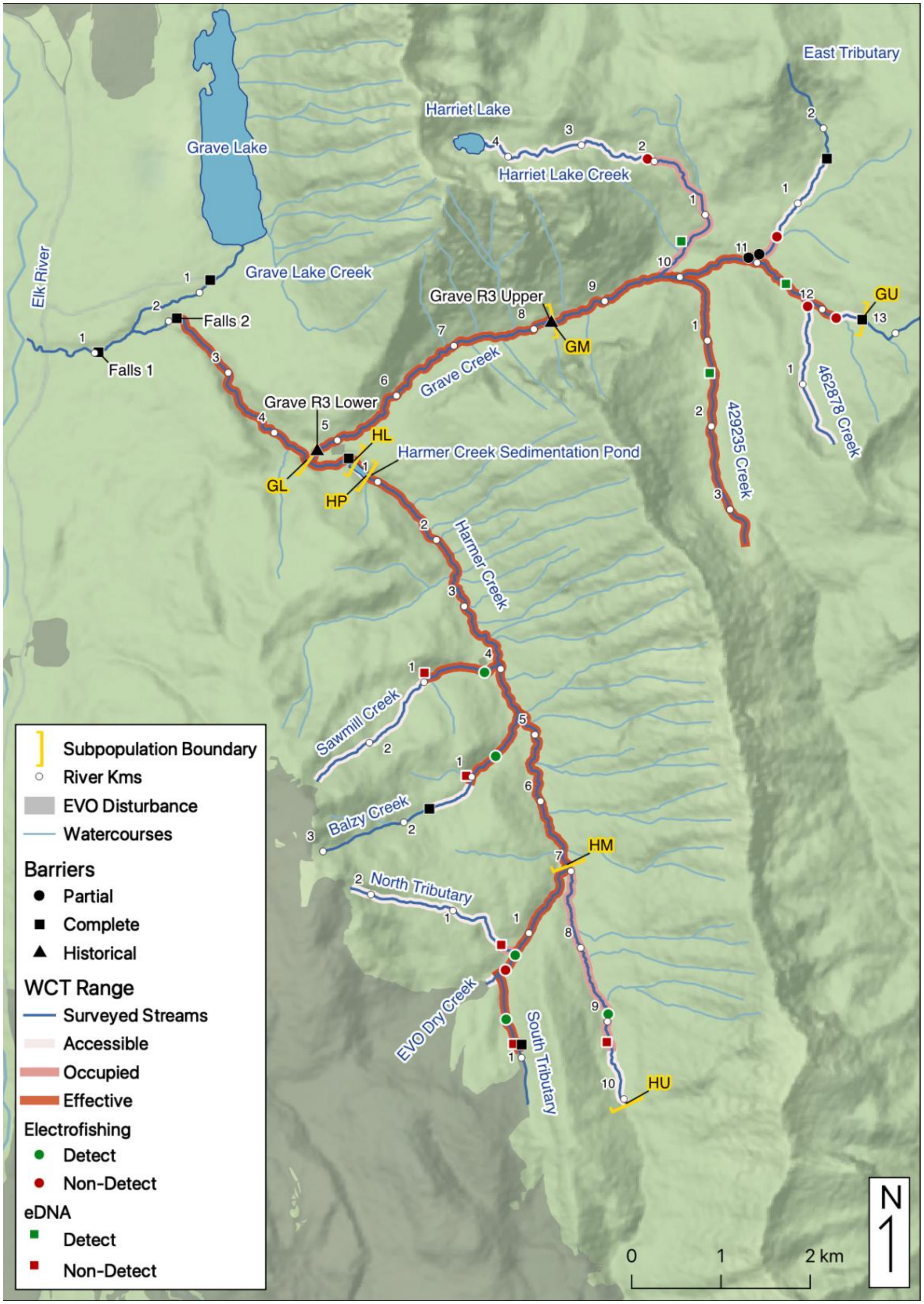

Figure 1. Grave and Harmer Creek Westslope Cutthroat Trout population geographic range with mining disturbance, barriers, and the most upstream documented fish detections and downstream non-detections.

Table 1. Summary of Methods and Analysis.

Question	Data Source	Analytic Method
Population Characteristics		
1. What is the geographic range of the fish population?	Electrofishing Redd Surveys GIS Barrier Surveys eDNA	Professional judgement based on fish observations and barriers, stream size and stream gradient; presence and absence
2. What is the genetic diversity and effective genetic population size of the fish populations (s)?	Fin clips	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 Redd Surveys	Professional judgement based on fish size, spawning behaviour and available habitat
4. What is the timing of life history events?	Redd Surveys Stream temperatures	Water temperature and nest fading and area-under-the-curve (AUC) nest count models
5. What are the sizes of the life stages?	Electrofishing Bank walks	Professional judgment based on length frequency plots and length-at-age models
Vital Rates and Associated Endpoints		
6. What is the growth rate of key life stages?	Electrofishing	Growth model parameterized using inter-annual PIT tag recaptures and professional judgment for mean maximum fish length.
7. What is the spatial distribution of key life stages?	Electrofishing Redd Surveys	Estimated using the lifecycle and nest count models
8. What is the abundance of key life stages?	Electrofishing	Estimated using the lifecycle model
9. What is the total number of eggs deposited?	Electrofishing	Literature-based length-fecundity relationship parameterized using adult abundance and adult size
10. What is the survival of key life stages?	Electrofishing	Estimated using the lifecycle model

3.2 REDD SURVEYS

Once nests were observed in late June, redd surveys were conducted bi-weekly, as visibility permitted, in core spawning areas until late-July. The core areas correspond to the HM subpopulation area, which is further subdivided into HMa and HMb for redd surveys, and the four subpopulation groupings in the Grave Creek population area (see also Section 2, Figure 2).

Around peak spawning, the surveys were extended to include the following potential spawning areas:

- The lower 1.6 km of EVO Dry Creek downstream from the confluence with South Tributary
- The lower 0.6 km of South Tributary
- The 1.7 km of Harmer Creek above the confluence with EVO Dry Creek (i.e., HU)
- East Tributary, 429235 Creek and Grave Creek upstream of East Tributary (up to the end of fish distribution or suitable habitat)
- Sawmill and Balzy Creeks (up to the end of fish distribution or suitable habitat)

Redd surveys followed the standard protocol developed for monitoring spawning near Teck sites (Smit et al. 2022). During the surveys 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. However, prior to 2021, the 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 (2020b). For the purposes of this report, it is assumed that prior to 2021 each redd corresponds to one definitive nest. In 2022, the crew marked the location of each redd in the Teck Collector App (which records the spatial coordinates) and recorded the number of potential and definitive nests within the redd, and the number of adult fish associated with the redd.

3.3 ELECTROFISHING SURVEYS

Electrofishing surveys were conducted between August 26 and September 22, 2022 (Table 2). Sampling included two types of sites: small closed, and large open sites. A single electrofishing pass was conducted at all sites/sections, with additional passes conducted at a subset of sites to allow estimates of capture efficiency and therefore absolute abundance. For small closed sites, capture efficiency was estimated using removal-depletion methods. For large open sites, information about capture efficiency was gathered using mark-recapture with Passive Integrated Transponder (PIT) tags (Section 3.3.3). This combination of electrofishing methods follows the recommendations of the standard protocol for electrofishing at Teck sites (Thorley et al. 2022d) and facilitates comparison to previous years when only small closed sites were surveyed. The following sections provide details regarding electrofishing using the two methods.

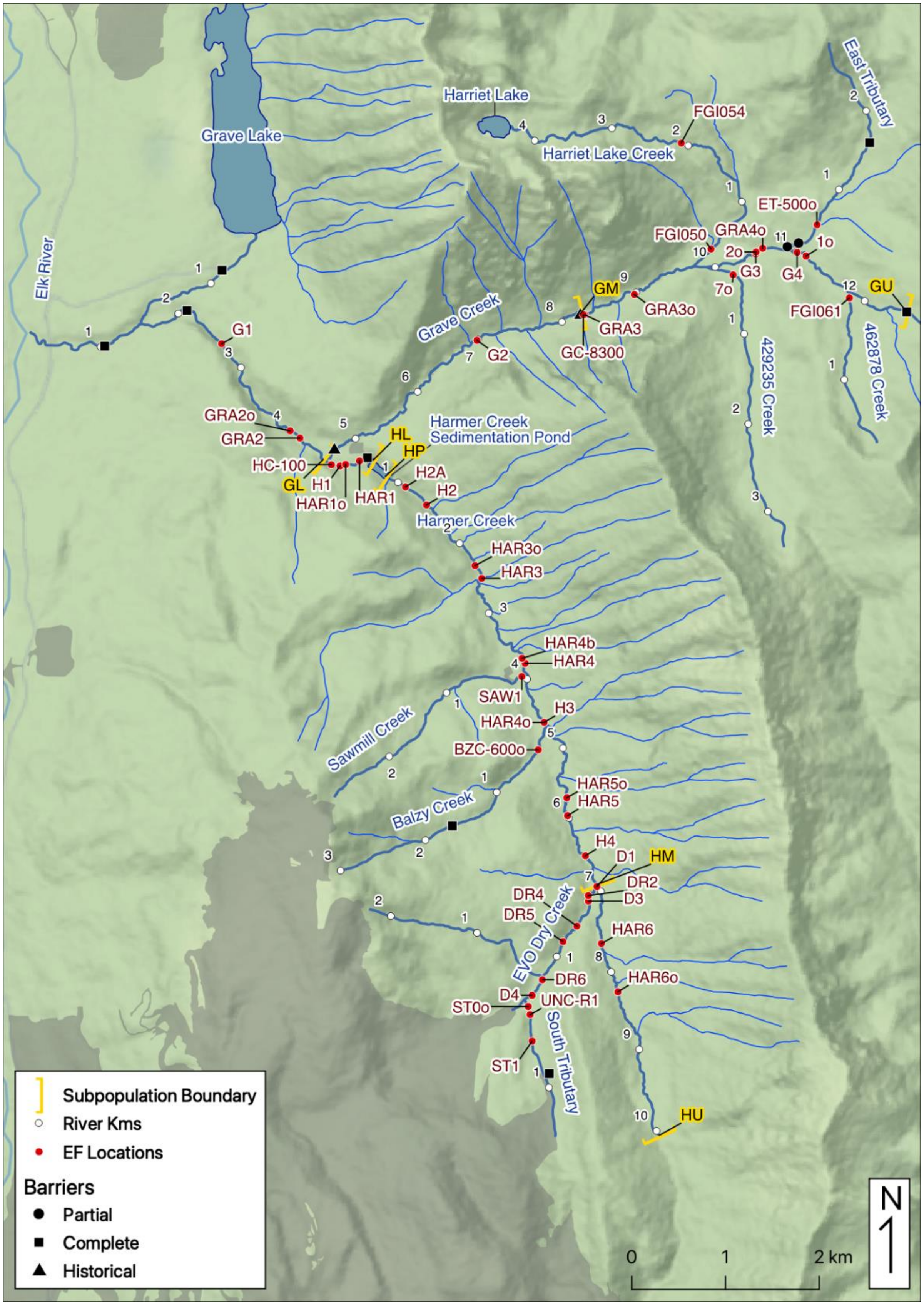

Figure 2. The backpack electrofishing locations visited in at least one year.

Table 2. The backpack electrofishing start and end dates by population and year.

Population	Year	Start Date	End Date
Grave	1996	04-Sep	26-Sep
Grave	2008	14-Aug	14-Aug
Grave	2013	15-Aug	21-Aug
Grave	2017	18-Sep	29-Sep
Grave	2018	18-Sep	24-Sep
Grave	2019	25-Sep	02-Oct
Grave	2020	18-Sep	01-Oct
Grave	2021	22-Sep	01-Oct
Grave	2022	6-Sep	22-Sep
Harmer	1996	04-Sep	15-Sep
Harmer	2008	15-Aug	19-Aug
Harmer	2013	04-Jul	30-Aug
Harmer	2017	08-Aug	30-Sep
Harmer	2018	07-Sep	14-Sep
Harmer	2019	16-Sep	03-Oct
Harmer	2020	22-Sep	01-Oct
Harmer	2021	17-Sep	28-Sep
Harmer	2022	26-Aug	22-Sep

3.3.1 SMALL CLOSED SITES AND REMOVAL-DEPLETION

Electrofishing at small, closed sites followed the methods used in 2021 and earlier years in the study area. In 2022, 12 of the 16 index locations established in previous years were sampled. Of the 12 index locations sampled, five locations (D3, H1, HAR1, H2, and GRA2) are positioned near sedimentation ponds that may be removed in the future. The remaining seven index locations were selected from among the remaining 16 index locations using a stratified random approach (three sites from Grave Creek and four sites from Harmer Creek) (Error! Reference source not found.). At each of the 12 locations, three single m esohabitat (pool, riffle, glide or cascade) sites of about 10 to 35 m in length (approximately 100 m² in wetted area) were sampled. Sites were isolated (closed) using stop nets at the upstream and downstream boundaries.

An initial electrofishing pass was conducted at all 36 of the mesohabitat sites (three per location). An additional second pass was conducted at 18 of the mesohabitat sites and a third pass at nine of those. The number of passes at each site was randomly assigned prior to fieldwork.

All habitat within a selected site was sampled. Upstream and downstream stop nets which typically spanned the entire wetted width of the stream channel provided closed site conditions. Electrofishing effort (seconds) was recorded at the end of each pass.

3.3.2 LARGE OPEN SECTIONS AND MARK-RECAPTURE

Electrofishing of large, open sites was used to increase the proportion of the accessible habitat sampled by electrofishing. The method consisted of a single open (without stop nets) pass at long (~300 m) sites. Sites were selected using stratified random sampling. The following strata were used to ensure all subpopulations of interest were sampled:

- Grave Creek population area:
  - Grave Mainstem: GL, GM and GU (4 strata)
  - Harmer Mainstem: HL 1(1 strata)
  - Tributaries: East Tributary and 429235 Creek were each a stratum (2 strata)
- Harmer Creek population area:
  - Mainstem: HMa (1 strata), HMb (2 strata), HU (1 strata)
  - Tributaries: Balzy Creek, Sawmill Creek, South Tributary EVO Dry Creek downstream of the Harmer Creek Sedimentation Pond (DRY-R1) and EVO Dry Creek upstream of the Harmer Creek Sedimentation Pond to the beaver ponds (DRY-R3) were each a stratum (5 strata)

The location of one long site within each of these 16 strata was randomly selected. The exception was EVO Dry Creek downstream of the EVO Dry Creek Sedimentation Pond, which is short enough that the whole section could be sampled. For strata without an existing bound on the accessible habitat, the upstream boundary of the potential sample selection area was based on the recommended barrier survey. Randomly located sections that incorporated a barrier were rejected and replaced with the next suitable, randomly selected section.

3.3.3 FISH PROCESSING

Fish processing followed the detailed methods provided in the standard protocol (Thorley et al. 2022d) with additional detail in the 2022 Study Design (Thorley et al. 2022a). In summary, all captured fish were measured (to mm), weighed (to 0.1 g), scanned for a PIT tag (if ≥ 100 mm) and photographed. A PIT tag was inserted into all healthy fish ≥ 100 mm (Thorley et al. 2022d). Processed fish were allowed to recover before being released as close to their capture location as possible, preferably near cover and in slow moving water.

3.4 NIGHT TIME DIP-NET SURVEY

Due to their small size and patchy distribution, age-0 WCT are infrequently caught during the fall backpack electrofishing. The size of age-0s is important because it has been linked to overwintering survival, particularly in cold, headwater streams (Coleman and Fausch 2007a, 2007b). Age-0 fish (and the occasional age-1 individual) in the stream margins were captured using hand nets during the dip-net surveys, to gather information on the size of the young-of-the-year. The surveys also provide limited information on the spatial distribution (occupancy but not relative density).

The dip-net surveys were conducted from October 3 to 30, 2022. The location, and estimated body length were recorded for all observed WCT. Fish ~ 100 mm or less were captured using a hand net where possible and were measured (to 1 mm) before being released at the location of capture.

In each of the sampling sessions two sites were sampled per night, for a total of eight sites with one site selected from each of the following areas:

- Grave Upper (GU)
- Grave Middle (GM)
- Grave Lower (GL)
- Harmer Lower (HL)
- Bottom half of Harmer Middle (HMa)
- Top half of Harmer Middle (HMb)
- 429235 Creek in the upper Grave Creek watershed

The lengths of the observed and captured age-0s were used in the length-at-age analyses. Brooks et al (in prep) will report separately on the relationship between water temperature and length of age-0 fry.

4 DATA ANALYSIS

4.1 DATA PREPARATION

The data collected prior to fall 2020 were provided by Teck Coal Ltd. as an assortment of Excel spreadsheets and shape files. The 2020 electrofishing and 2021 field data were provided by Lotic Environmental Ltd. as Excel spreadsheets and gpx and kmz files. The 2022 field data were provided by Teck Coal Ltd. as layers in a geodatabase file. The streams, lake and manmade waterbody spatial objects were extracted from the geodatabase file. The data were cleaned and tidied (Wickham 2014) using R version 4.2.2 (R Core Team 2022) before being archived in a purpose built SQLite relational database.

4.2 STATISTICAL ANALYSIS

Model parameters were estimated using Bayesian methods. The estimates were produced using JAGS (Plummer 2003) and STAN (Carpenter et al. 2017; Thorley et al. 2022a). For additional information on Bayesian estimation the reader is referred to (McElreath 2020). 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 2011a). Model convergence was confirmed by ensuring that the potential scale reduction factor $\hat{R} \leq 1.05$ (Kery and Schaub 2011a) and the effective sample size (Brooks et al. 2011) $\text{ESS} \geq 150$ for each of the monitored parameters (Kery and Schaub 2011a).

The parameters are summarised in terms of the point estimate and the lower and upper 95% credible limits (CLs) which together constitute the 95% credible interval (CI). 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 individual variables and the response 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 average values (expected values of the underlying hyperdistributions) (Kery and Schaub 2011b). The analyses were implemented using R version 4.2.2 (R Core Team 2022) and the `mbr` family of packages. For additional information the reader is referred to https://poissonconsulting.ca/f/1835819364.

4.3 MODEL DESCRIPTIONS

4.3.1 NEST COUNT

The definitive nest counts were analysed using a hierarchical Bayesian Area-Under-the-Curve (AUC) model (Hilborn et al. 1999; Su et al. 2001) to estimate the expected annual definitive nest count. This is the total number of unique definitive nests that an average observer would be expected to count if they went out every day and marked every definitive nest to prevent double-counting.

Key assumptions of the nest count model include:

- Lineal definitive nest density varies by survey section.
- Lineal definitive nest density varies randomly by survey section within year.
- The expected definitive nest count varies by the percent lineal coverage.
- Spawning activity is normally distributed through the season.
- Nests are definitive for approximately 18 days (Thorley et al. 2022b).
- The variation about the expected definitive nest count is normally distributed.
- Redd counts prior to 2021 are cumulative, correspond to individual definitive nests, and occur with sufficient frequency to avoid missing nests due to nest fading.

4.3.2 LENGTH-AT-AGE

The length of a fish provides information about its likely age, maturity and, for females, fecundity. Length is also an important predictor of overwintering survival for age-0 Cutthroat Trout (Coleman and Fausch 2007a, 2007b). A common measure of the length of a trout is its fork length (used here), which is the length from the snout to the fork in the tail.

The average length of the age-0 and adult fish in each population in each year was estimated using a generalized linear mixed effects length-at-age model. The length of age-0 fish is an important predictor of overwintering survival while the length of adults provides an indication of fecundity. The lengths of 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 age-0 length-at-age model include:

- Fork length varies among populations.
- Fork length varies randomly among years within populations.
- Fork length varies by day of the year of capture.
- Fork length varies by observation vs capture.
- The residual variation in the fork lengths is as described by student’s t distribution truncated at 18 mm.
- The standard deviation of the normal component of the residual variation varies by observation vs capture.

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

- Fork length varies randomly among years within populations.
- The residual variation in the fork lengths is log-normally distributed.

4.3.3 BODY CONDITION

Body condition compares an individual's mass relative to its length, and is a measure of health and growth potential (Bentley and Schindler 2013). All else being equal, fish with higher body condition would be expected to have more energy stores for growth, reproduction and metabolic processes than fish of a similar length but lower body condition.

The electrofishing length and weight data for fish from the Grave and Harmer Creek populations were analysed using an allometric mass-length model (He et al. 2008) to evaluate body condition of age-2+ (fish ≥ 90 and < 169 mm) and adults (≥170 mm). Fish <90 mm (ie., age-0 and age-1) were excluded from the current analyses as the error in their weight measurements is 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 expected weight of a 1 mm fish, β is the exponent scaling term and L is the length[2]. In order to estimate the body condition (C) the actual weight was divided by the expected weight.

$$C = {}^{W}\!/_{\alpha L^{\beta}}$$

Key assumptions of the age-2+ condition model include:

- α can vary randomly by year, subpopulation within year and population within year.
- The residual variation in weight is log-normally distributed.

Key assumptions of the adult condition model include:

- α can vary randomly by year, and population within year.
- The residual variation in weight is log-normally distributed.

Preliminary analysis indicated little variation in α by day of the year.

The body condition was estimated by dividing the expected weight for a particular subpopulation and/or year by the expected weight for a typical subpopulation in a typical year based on the estimated α and β terms.

[2] If the shape (and density) doesn't change with length then β will be 3. If, however, fish depth or width increases disproportionately with length, as is often the case, then $\beta > 3$. Fulton's K was not used because it assumes $\beta = 3$ (Cone 1989).

4.3.4 FECUNDITY

Fecundity, the number of eggs per spawning female, is a key parameter informing population models. Following Ma and Thompson (2021) fecundity was calculated based on the average adult fork length (FL) for each population in each year using the following allometric relationship from Corsi et al. (2013), adjusted to convert fork lengths into total lengths.[3]

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

4.3.5 LIFECYCLE MODEL

The lifecycle model uses the electrofishing data collected in consecutive years to estimate capture efficiency, site densities and abundance as well as survival and recruitment rates for the individual life-stages.

The following five life-stages of WCT are recognized in this report: eggs, age-0, age-1, age-2+, and adults. However, the abundance of age-0 WCT in Grave and Harmer Creeks cannot be reliably estimated (due to their patchy distribution and extremely low capture efficiency associated with their small size). Consequently, the lifecycle model estimates the egg-to-age-1 survival (as opposed to the separate egg-to-fry and fry-to-age-1 survival).

To account for changes in the density of life-stages from one year to the next, a hierarchical Bayesian removal stage-based lifecycle model (Figure 3; Schaub and Kery 2022), was fitted to all the single- and multipass-electrofishing data simultaneously. The number of fish in each life-stage is linked from one year to the next by survival and recruitment. Abundance estimates are improved, and uncertainty decreased, when consecutive years of data are available for modelling, particularly for age-1s which have relatively low capture efficiency and, as a result, noisy density estimates. For instance, if few age-1s are captured one year and the following year there are more age-2+ than would be expected based on the age-1 counts, the model back-casts to re-estimate the number of age-1s that were likely there the previous year.

The model recognises three life stages (age-1, age-2+ and adult) (Section 4.3.2). To allow for individual differences in the number of years required to reach the maturity threshold, the lifecycle model estimates a transition probability from age-2+ to adulthood. Key parameters include annual survival from age-1 and older (Φ), which varies by population (p) within year (t), the probability of an age-2+ fish transitioning to an adult (T), the probability of an adult being a female (α), the probability of an adult female spawning (ρ), the fecundity (F) and the egg-to-age-1 survival (S) from spawn year t to study year $t + 1$. The egg to age-1 survival required for population replacement was estimated as the multiplicative inverse of the average number of eggs each age-1 fish would be expected to deposit over its lifetime assuming typical rates of annual survival and fecundity based on the lifecycle model.

[3] In Thorley et al 2021 the equation $\mathrm{F} = \exp_{10}(-4.265 + 2.876 \cdot \log_{10}(\frac{\mathrm{FL}-1.69}{1.040}))$ was erroneously used. As a consequence, the fecundity was underestimated and the egg to age-1 survival was overestimated in Thorley et al 2022. This did not affect the estimated recruitment rate as a percent of replacement.

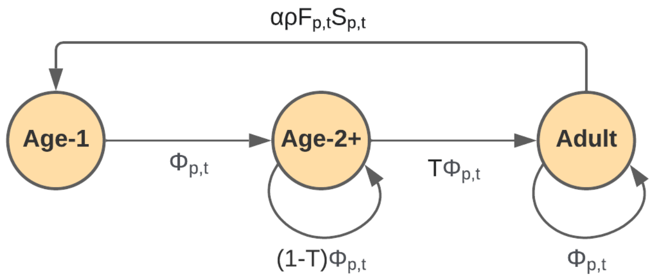

Figure 3. Life stages and parameters for the lifecycle model.

Key assumptions of the lifecycle model include:

- Lineal density in the initial year varies randomly by population and life-stage.
- The sex ratio is 1:1 and the probability of an adult spawning is 50%.
- The adult female fecundity for each population in each year is as estimated above (Section 4.3.4).
- The egg to age-1 survival varies by population and year.
- The annual survival from age-1 and older varies randomly by population and year.
- Fish become adult at an average age of 4 (Thorley et al. 2022c).
- There is demographic variation in the egg to age-1, and age-1 and older survival and number of spawners and probability of becoming adult.
- The number of fish at each site in each year is described by an over-dispersed (gamma) Poisson distribution.
- The over-dispersion varies by life-stage.
- The capture efficiency varies by life-stage and by the electrofishing effort (s/m^2) by life-stage and by percent site closure.
- The catch on each pass is binomially distributed.

The analytic appendix which includes model templates, parameter descriptions and parameter coefficient tables is available from https://poissonconsulting.ca/f/*1835819364*.

5 RESULTS

5.1.1 BARRIER SURVEY AND ACCESSIBLE HABITAT

The extent of accessible habitat has been partly identified in past studies using provincial protocols (Berdusco and Robinson 2008; Lotic Environmental Ltd. 2015; Cope and Cope 2020b; Harmer Creek Evaluation of Cause Team 2023). The accessible limits were further resolved in 2022 based on additional surveys in the headwaters of Grave Creek as well as several tributaries. All known features within the study area with the potential to restrict upstream fish passage, in addition to the two falls on Grave Creek at km 1.0 and 2.1, are listed in Table 3.

Habitat Classifications

Accessible - *to the first confirmed barrier to upstream movement.*

Occupied – *all Accessible habitat to the most downstream non-detect (electrofishing or eDNA).*

Effective - *all Occupied stream is assumed to be Effective (non-negligible density) unless repeated sampling indicates very low densities.*

Habitat downstream of a confirmed barrier is considered accessible regardless of use. For the purposes of this report, we further subdivide the habitat into that which is occupied by fish, and that which contains sufficient densities of fish to effectively contribute to the fish population dynamics (see Text Box).

There are 11 km of accessible mainstem habitat, including the lower 0.6 km of Harmer Creek, available to the Grave Creek population, 10.7 of those km are considered to be effective (Figure 1,Table 4). In additional there are 11.6 km of tributary habitat accessible to the Grave Creek population with 3.5 km currently considered to be effective.

The Harmer Creek population is able to access 9.7 km of mainstem habitat of which 6.3 km is considered effective (Figure 1,Table 4).

A total of 2.4 km in the Harmer Creek mainstem is classified as ineffective because, despite extensive sampling, only one WCT has been captured in the Harmer Creek Sedimentation Pond (HP) as reported by Cope and Cope (2020b), and only one WCT has been captured in Harmer Creek above the confluence with EVO Dry Creek (HU). In addition, there are 9.3 km of accessible tributary habitat of which 4.4 km is currently considered to be effective including 1.6 km in EVO Dry Creek[4].

[4] The EVO Dry Creek habitat is considered effective for estimating population abundance but not for estimating egg deposition as spawning is largely precluded due to calcite concreted substrate.

Table 3. Known potential barriers to upstream fish movement.

Barrier	Stream	Stream Distance (m)	Type	Status
Grave Creek Population Area				
East 1	East Tributary	50	culvert	passable
East 2	East Tributary	215	culvert	passable
East Cascade	East Tributary	1640	cascade	impassable
Falls 1	Grave Creek	1045	falls	impassable
Falls 2	Grave Creek	2115	falls	impassable
Grave R3 Lower	Grave Creek	4715	bridge	passable
Grave R3 Upper	Grave Creek	8260	bridge	passable
Grave R4	Grave Creek	10745	bridge	passable
Grave Deck	Grave Creek	11070	wood	passable
Grave Cascade	Grave Creek	12510	cascade	impassable
Grave Lake 1	Grave Lake Creek	1195	culvert	impassable
Harriet 1	Harriet Lake Creek	50	culvert	passable
Harriet 2	Harriet Lake Creek	1145	culvert	unknown
Harmer Creek Population Area				
Balzy Crossing	Balzy Creek	50	ford	passable
Balzy Falls	Balzy Creek	1665	falls	impassable
EVO Dam	EVO Dry Creek	140	dam	passable
Harmer Dam	Harmer Creek	540	dam	impassable
Harmer R3	Harmer Creek	3490	bridge	passable
Sawmill Crossing	Sawmill Creek	195	culvert	impassable
Sawmill 1	Sawmill Creek	915	wood	impassable
South Falls	South Tributary	845	falls	impassable

Table 4. The lineal (m) accessible and effective habitat by population, stream and subpopulation grouping.

Subpopulation	Stream Length: Effective (m)	Stream Length: Accessible (m)
Grave Creek Population		
Mainstem		
GL	2410	2410
GM	3720	3720
GU	3935	4245
HL	610	610
Mainstem total	10675	10985
Tributaries		
429235 Creek	3460	3460
462878 Creek	0	1800
East Tributary	0	1635
Harriet Lake Creek	0	4725
Tributaries total	3460	11620
Harmer Creek Population		
Mainstem		
HP	0	235
HM	5995	6035
HU	0	3160
Mainstem total	5995	9430
Tributaries		
EVO Dry Creek	1625	1790
Balzy Creek	1040	1655
North Tributary	0	2230
Sawmill Creek	915	2760
South Tributary	840	840
Tributaries total	4420	9275

5.1.2 NEST COUNTS

Based on the definitive nest count model, spawning is estimated to begin by mid-May, peak in mid-June and end in mid-July in both Grave and Harmer Creek (Table 5, Figure 4).

Table 5. Estimated timing of spawning activity with lower and upper 95% CLs.

Event	Estimate	Lower	Upper
Start (2.5%)	17-May	04-May	26-May
Peak (50%)	15-Jun	11-Jun	20-Jun
End (97.5%)	14-Jul	02-Jul	31-Jul

The distribution of definitive nests within the creeks was relatively consistent between 2017 and 2022 with the notable exception of 2020 when no definitive nests were recorded for the Grave Creek population below km 5.8 in the mainstem or below the Harmer Creek Sediment Pond (Figure 5).

In those years (excluding 2020), most definitive nests from the Grave Creek population were recorded between the two culverts at 4.5 and 7.8 km (GM) and the 0.5 km of Harmer Creek below the sedimentation pond (HL). The first year that a definitive nest was recorded above 7.8 km in Grave Creek was 2021. For the Harmer Creek population, all definitive nests have been recorded between the Harmer Creek Sediment Pond and the confluence with EVO Dry Creek (HM) except for 2020 when three definitive nests were recorded in EVO Dry Creek.

In 2022 the estimated annual total nest count was 13 definitive nests (95% CI 4-28; Figure 7) for the Grave Creek population and 8 definitive nests (95% CI 1-20) for the Harmer Creek population. These were the lowest estimates for total definitive nests recorded between 2018 and 2022 for the Harmer Creek population and were similar to the lowest estimate recorded for the Grave Creek population in 2020. In the subpopulation areas, definitive nests counts were variable over the years 2018 to 2022 for the Grave Creek population and showed a year over year decline in the Harmer Creek subpopulation starting in 2019 (Figure 8).

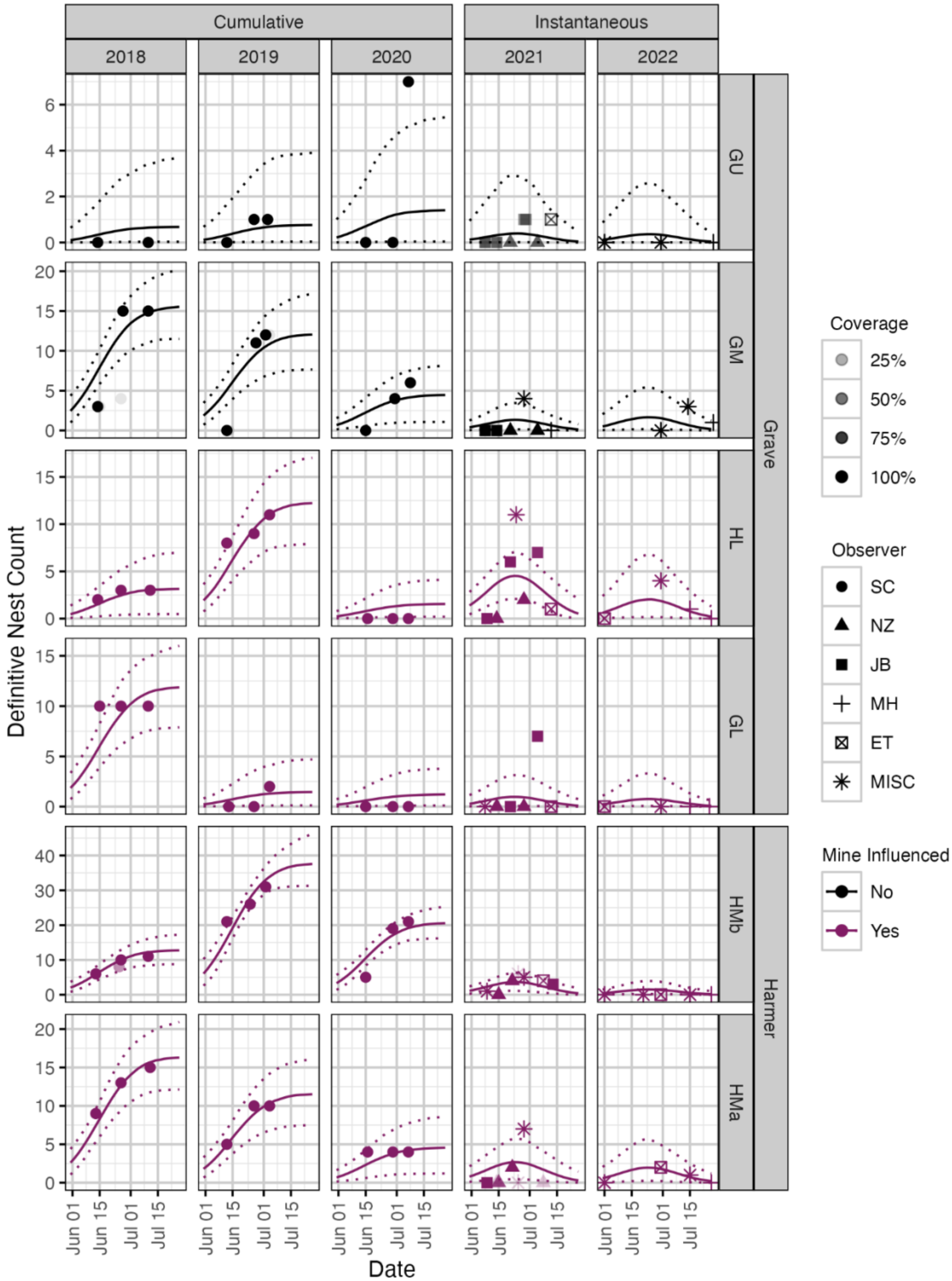

Figure 4. The estimated and observed definitive nest count by date, year, type (cumulative or instantaneous), section, subpopulation, population, mine-influence, lineal coverage, and observer (with 95% CIs).

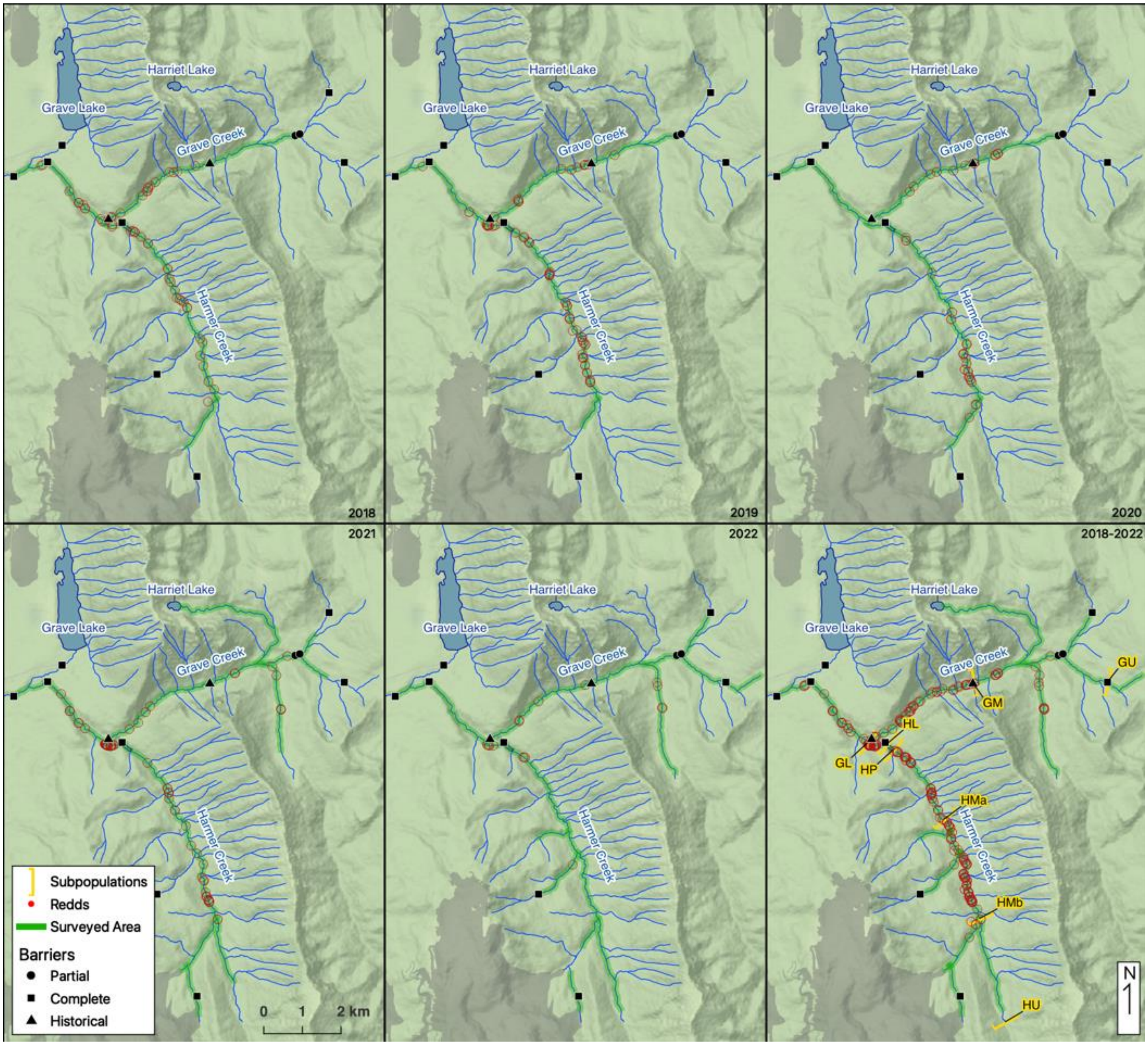

Figure 5. The spatial distribution of unique (2018-2020) and total (2021-2022) definitive nests by year. Nests are indicated as hollow circles.

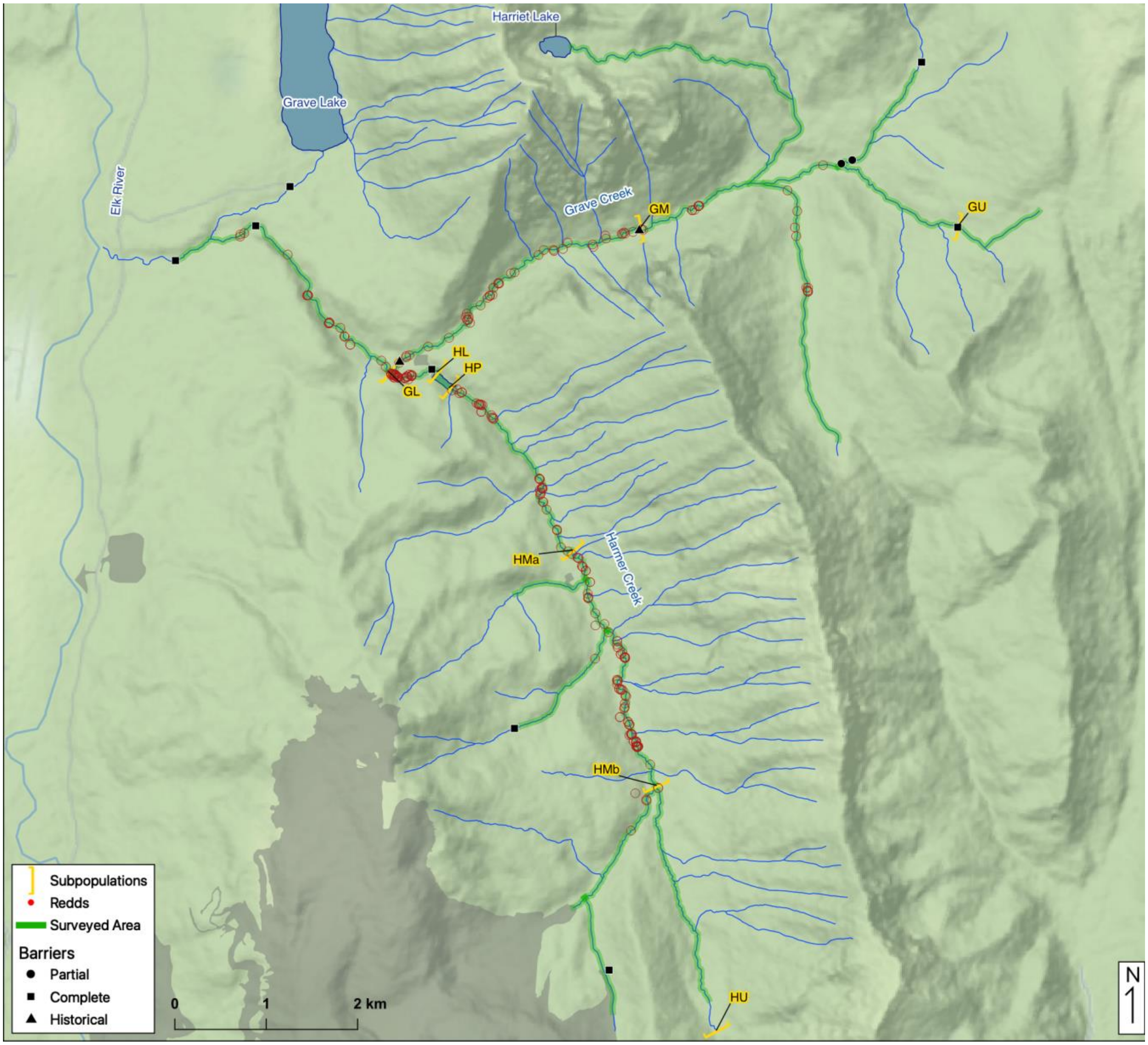

Figure 6. The spatial distribution of all recorded definitive nests from 2018 to 2022. Nests are indicated as hollow circles.

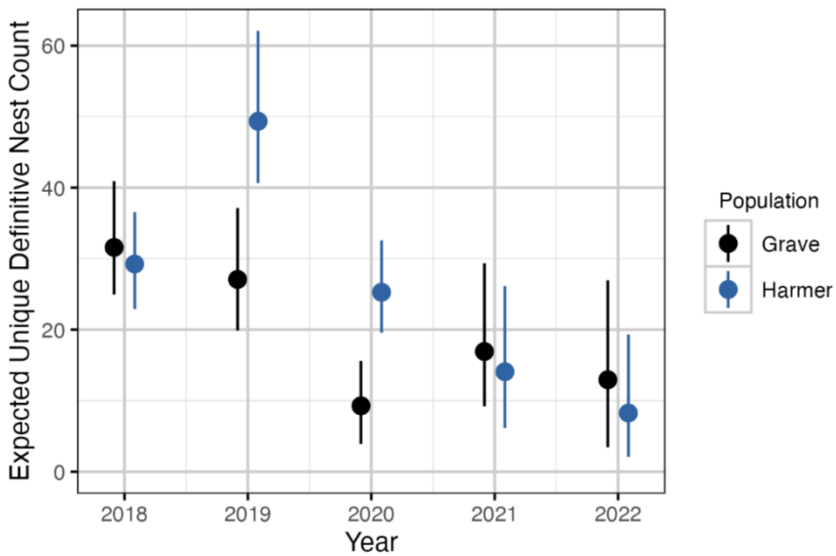

Figure 7. The expected total definitive nest count by year and population (with 95% CIs).

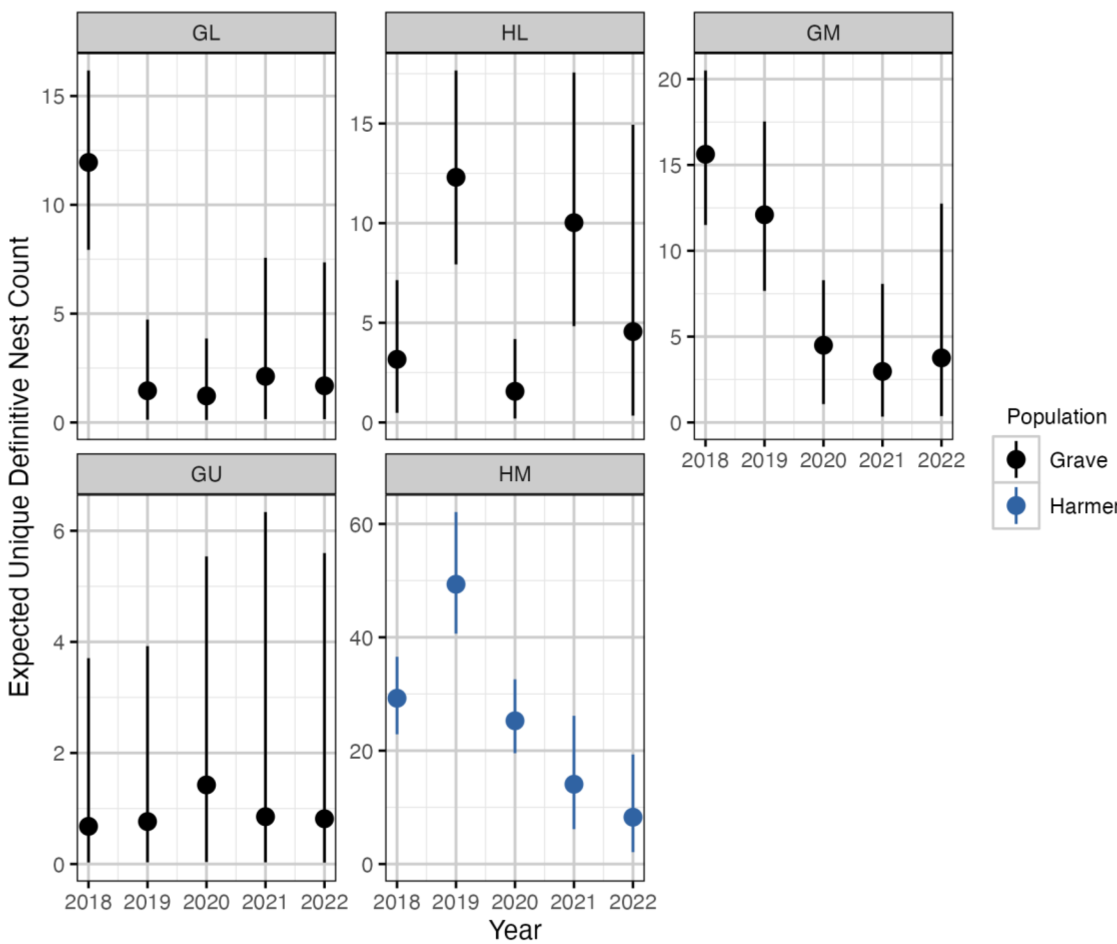

Figure 8. The expected total definitive nest count by year and subpopulation group (with 95% CIs).

5.1.3 LENGTH

Fish were categorized into life-stages based on length thresholds. Based on visual examination of length frequency plots of fish caught by backpack electrofishing and caught and observed during bank walks, fish were considered to be in the following life-stages based on the size parameters in parentheses: age-0 (<50 mm), age-1 (50 – 89 mm), age 2+ (90 – 169 mm) and adult (≥170 mm) (Figure 9).

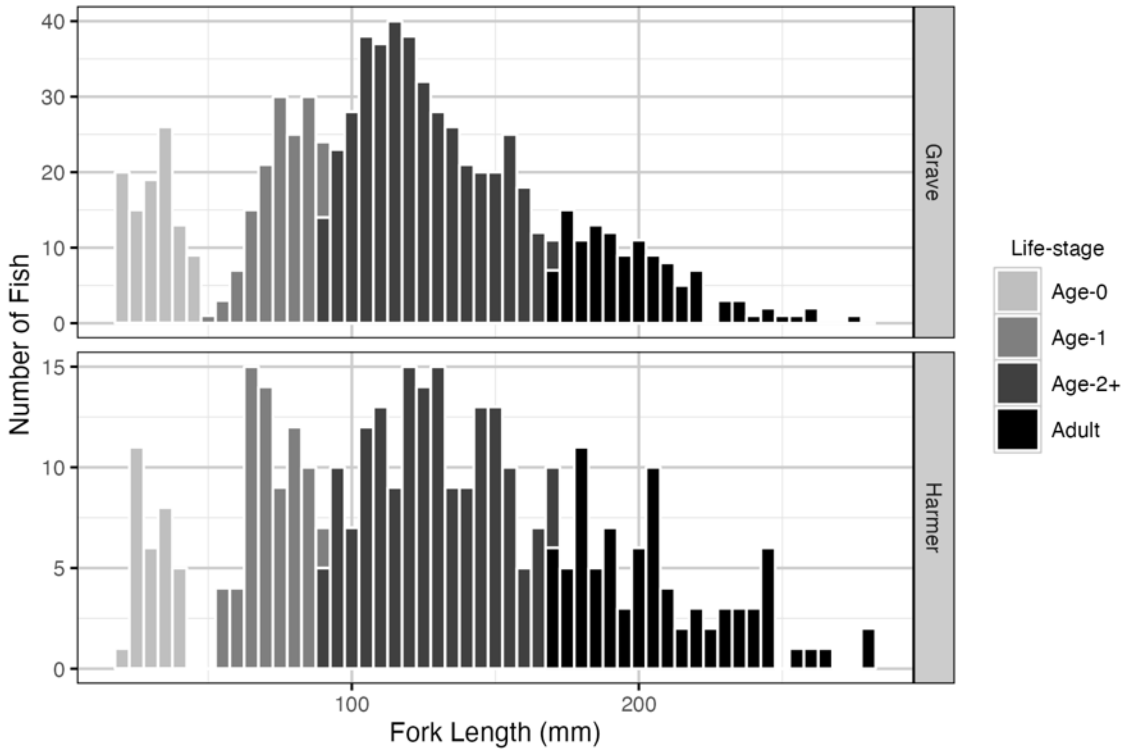

Figure 9. Fork lengths from electrofishing and bank walk fish captures and bank walk observations, by population and life stage (cumulative 2017 to 2022).

5.1.3.1 LENGTH-AT-AGE

The length-at–age analysis estimated that in a typical year, age-0 fish are 38 mm (95% CI 30-45 mm) at the end of the growing season in the Grave Creek population compared to 32 mm (95% CI 24-41 mm) for the Harmer Creek population (Figure 10).

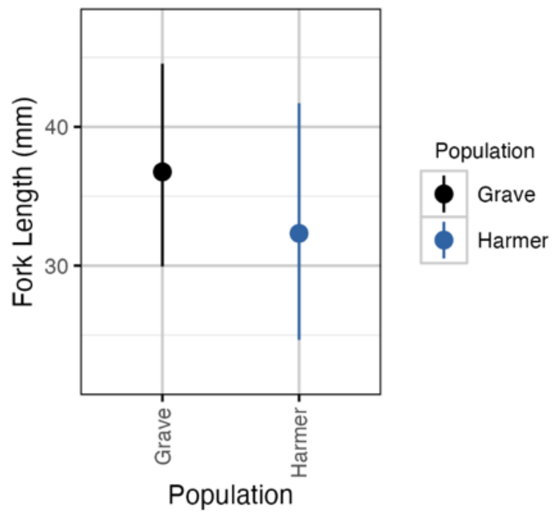

Figure 10. Estimated average fork length of age-0 fish on October 1 (end of growing season) in a typical year by population. Error bars represent 95% CIs.

Since 2017, average annual age-0 lengths have varied between 28 and 44 mm for the Grave Creek population and between 27 and 36 mm for the Harmer Creek population (Figure 11). In 2022 the age-0s in both populations were estimated to be shorter than in any other year for which data are available since this monitoring program began in 2017.

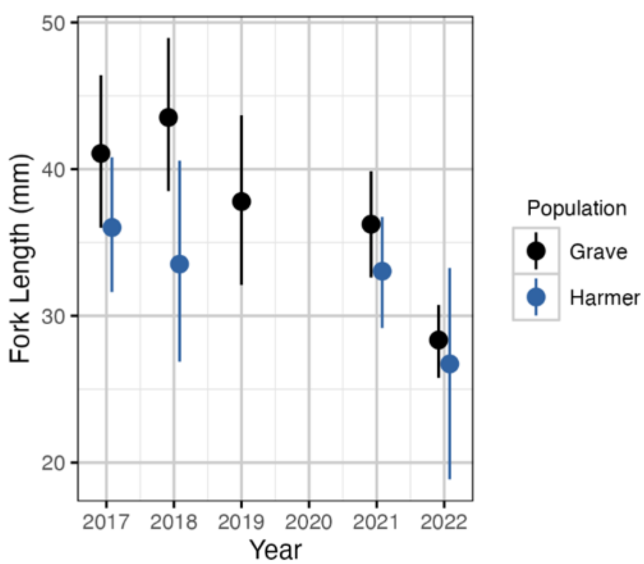

Figure 11. Estimated average fork length of age-0 fish on October 1 (end of growing season) by year and population. Error bars represent 95% CI.

Since 2017, average adult lengths varied between 192 and 205 mm for the Grave Creek population and between 194 and 218 mm for the Harmer Creek population (Figure 12). The estimated average length of the adults was highest in 2020 in both populations. The recent reduction in adult length may reflect recruitment of smaller, younger individuals into the adult population.

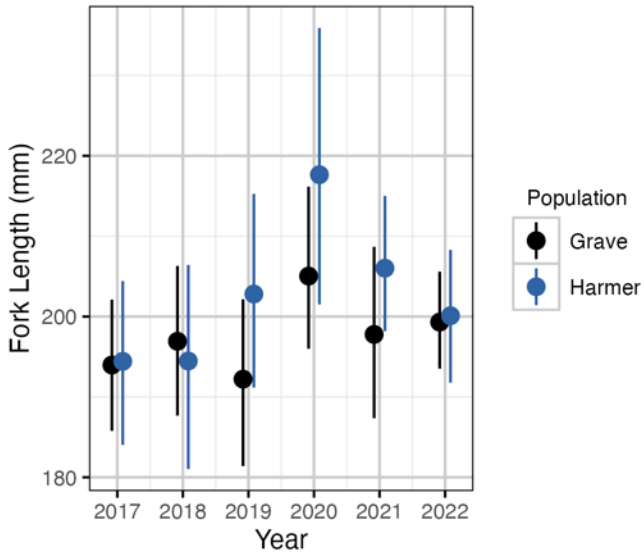

Figure 12. Estimated average fork length of adult fish on October 1 (end of growing season) by year and population. Error bars represent 95% CIs.

5.1.4 BODY CONDITION

The body condition of age-2+ fish (90 – 169 mm) in the Grave and Harmer Creek populations have been similar to each other through time (Figure 13). In 2022 the body condition (weight of a 100 mm fish relative to a typical year) was the lowest recorded for both populations at -3.5% (95% CI -9.1-1.1%) for the Grave Creek population and -2.8% (95% CI -9.1-2.3) for the Harmer Creek population (Figure 13). Body condition was highest in 2020.

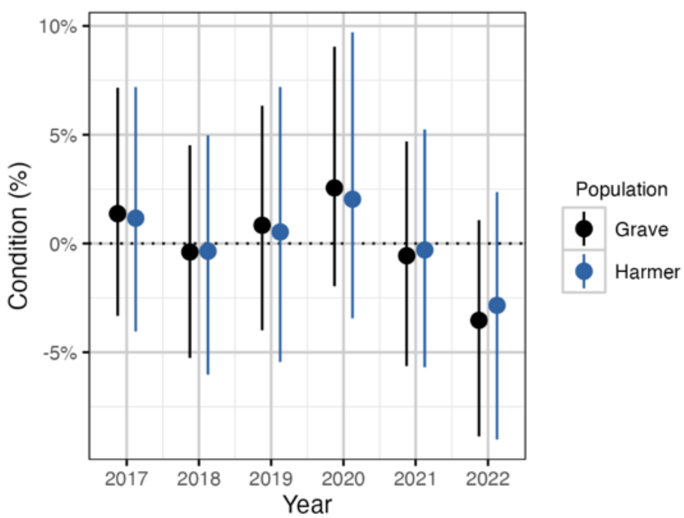

Figure 13. The percent change in the body condition (weight) for a 100 mm age-2+ fish relative to a typical year (0% change) by population and year. Error bars represent 95% CIs.

In addition to the annual variation in body condition, age-2+ fish in different subpopulations in Grave Creek show different patterns. For instance, in 2022, fish in GM had typical condition whereas fish in GU were almost 10% lower (Figure 14).

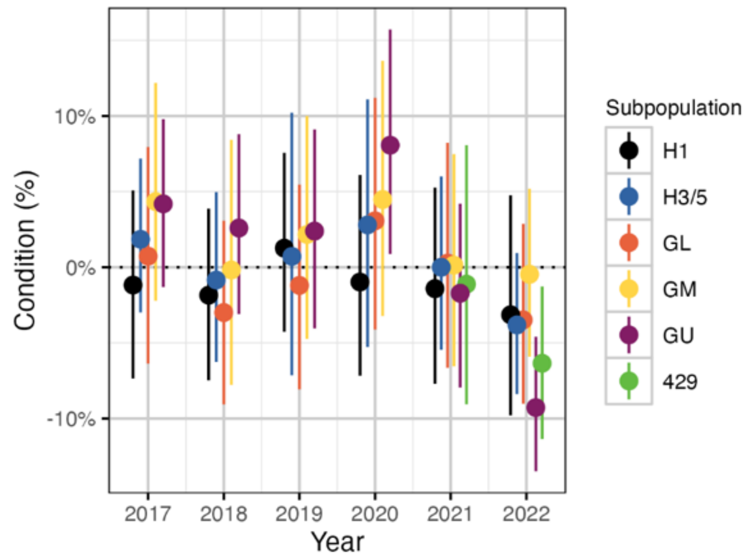

Figure 14. The percent change in the body weight of a 100 mm fish relative to a typical year by population and year (with 95% CIs).

The body condition of adult fish (≥170 mm) in the Grave and Harmer populations is generally similar from year to year, but was estimated to be higher in 2022 than for all other years than 2017 (Figure 15). Body condition in 2022 was estimated to be the highest since 2017 for both populations.

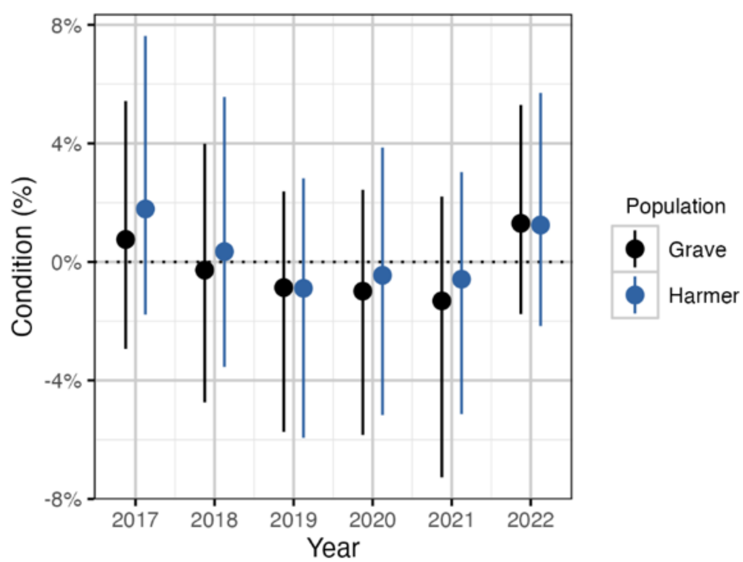

Figure 15. The percent change in the body condition (weight) for a 200 mm fish relative to a typical year (0% change) by population and year. Error bars represent 95% CIs.

5.1.5 FECUNDITY

The estimated annual fecundity based on the estimated adult mean fork lengths has varied between 237 and 278 eggs/female for the Grave Creek population and between 235 and 330 eggs/female for the Harmer Creek population (Figure 16). In 2022, the fecundity of 255 (95% CI 234 – 280) in the Grave Creek population and 258 (95% CI 229-291) in the Harmer Creek population were around the average value for the past 5 years.

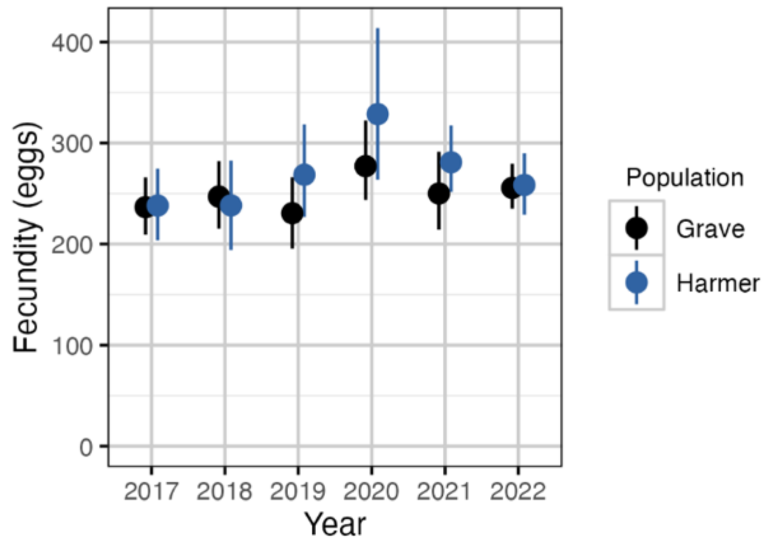

Figure 16. The calculated eggs per female by population and year. Error bars represent 95% CIs.

5.1.6 ELECTROFISHING CAPTURE DENSITIES

The electrofishing data indicate high annual variability in capture densities both among and within electrofishing locations over the years (Figure 17). The high capture densities of age-1 and age-2+ fish in Harmer Creek above the sediment pond in 2021 and 2022 is noteworthy as there were no age-1 captures in 2019 and 2020. This plot must be interpreted with caution since it represents raw data and does not account for capture efficiency.

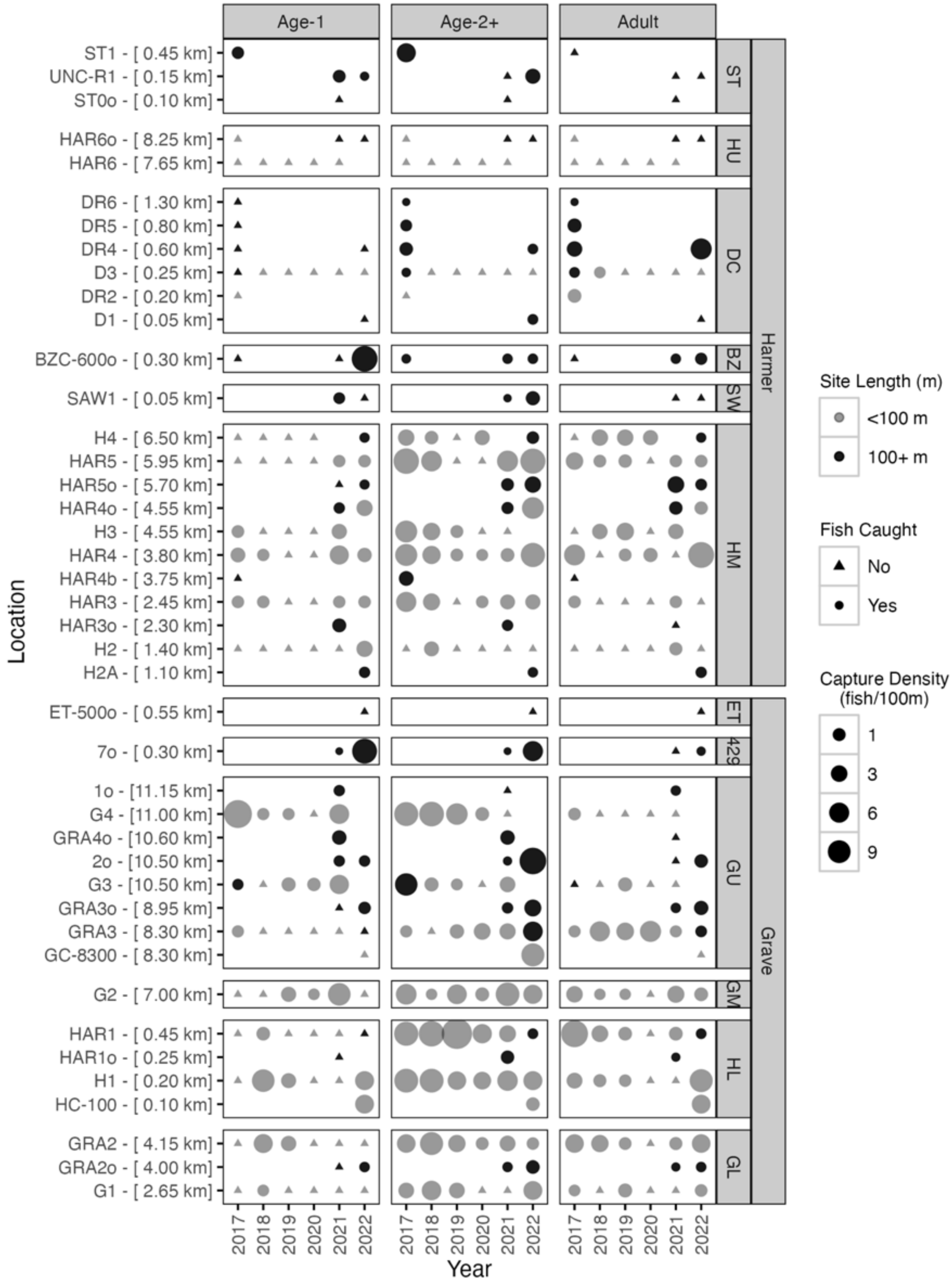

Figure 17. The mean electrofishing lineal capture density on the first pass by year, location, population, subpopulation and site length.
Locations on the y axis are listed in an upstream direction as indicated by the river km in square brackets (refer to Figure 1).

5.1.7 LIFECYCLE MODEL

The lifecycle model was developed to resolve inconsistencies between the density of age-1 fish and subsequent changes in the density of age-2+ fish. It does this by explicitly estimating egg deposition and survival rates (Figure 3). As a result, earlier estimates are updated with each additional year of data.

5.1.7.1 CAPTURE EFFICIENCY

The lifecycle model which estimated capture efficiency based on the decline in the number of captured fish with each removal pass allowed the capture efficiency to vary by life stage, electrofishing effort (by life stage) and closure. The results indicate that the estimated capture efficiency for age-1 WCT at a closed site with an electrofishing effort of 3 s/m^2 was just ~15%, but increased to ~50% with an effort of 12 s/m^2 (Figure 18). In contrast the capture efficiency for age-2+ fish was already 50% at 3 s/m^2 and increased to ~60% with an effort of 6 s/m^2. For adults, capture efficiency was ~65% at an effort of 3 s/m^2 and reached a maximum of ~ 88% with an effort of 7.5 s/m^2 (Figure 18). The model estimated that if 25% of the circumference site was open (equivalent to a square site without stop-nets) then the capture efficiency declined by ~22% (Figure 19). The density estimates account for the differences in capture efficiency.

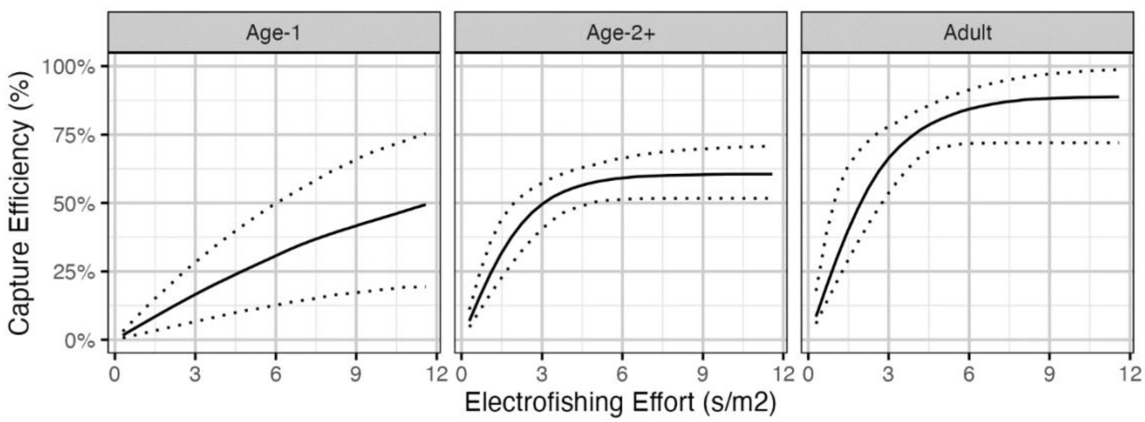

Figure 18. The estimated capture efficiency by electrofishing effort and life-stage (with 95% CIs).

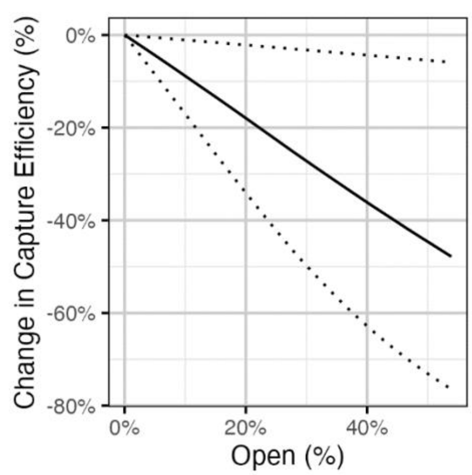

Figure 19. The estimated change in the electrofishing capture efficiency relative to 100% closure at an effort of 10 s/m2 (with 95% CIs).

5.1.7.2 DENSITIES BY SAMPLING LOCATION

The estimated densities (fish/100 m) for age-1, age-2 and adult fish were similar in the Grave and Harmer Creek populations for all years except 2018, 2019 and 2020 when they were lower for age-1 fish in the Harmer Creek population and for age-2+ fish for 2019 and 2020 (Figure 20). The estimated densities of age-1s were highest in 2021 and 2022 in both the Grave and Harmer Creek populations (Figure 20). The estimated age-2+ and adult densities were also both highest in 2022 for both populations. The proportional increase was greatest for age-1 and age-2+ fish in the Harmer Creek population.

The estimated lineal densities of age-1 fish averaged across all years are relatively high at the top of Grave Creek (GU), between the culverts on Grave Creek and below the Harmer Creek Sediment Pond (at the border of GL and HL) (Figure 21). For the Harmer Creek population age-1 densities are highest in the middle of Harmer Creek and subsequently decline upstream and downstream. Overall, the estimated densities of age-2+ fish show a roughly similar pattern to those for age-1 fish (Figure 22). For the adults the highest estimated densities are toward the top of Grave Creek (GU), in proximity to the culverts in Grave Creek (GL), below the Harmer Creek Sediment Pond (HL) and for the Harmer Creek population towards the upper end of Harmer Creek (HMb) and into EVO Dry Creek (Figure 23).

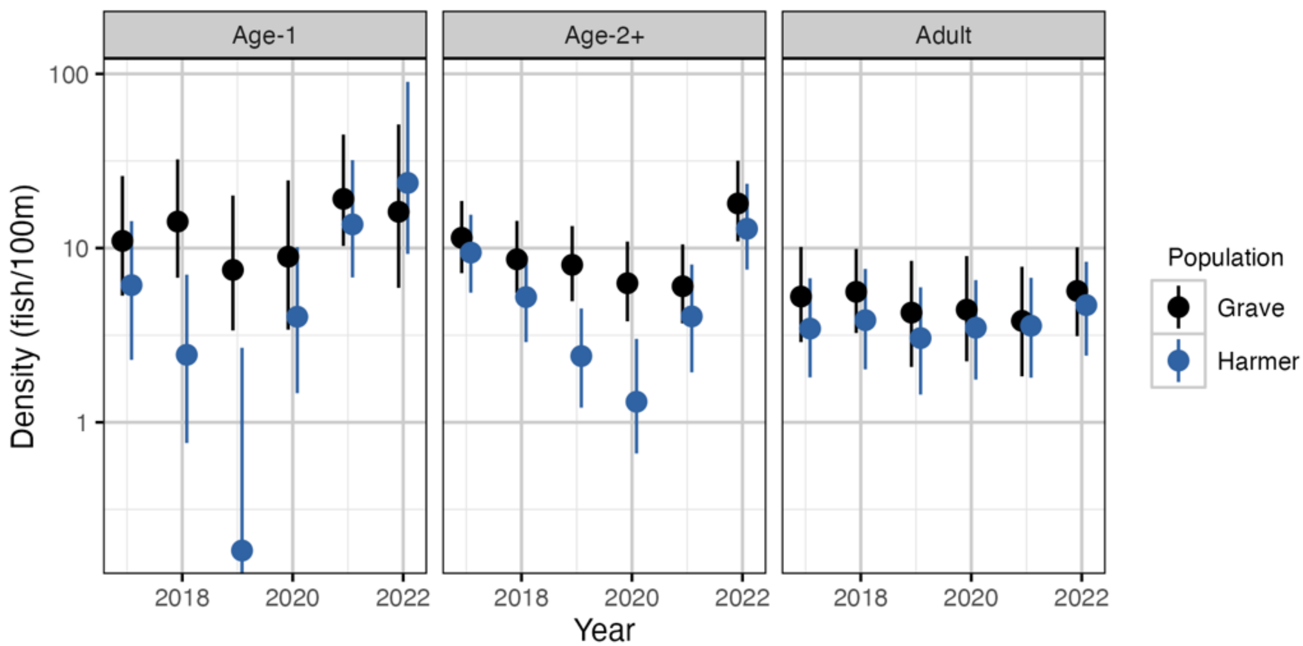

Figure 20. The estimated population density by year, life stage and population (with 95% CIs).

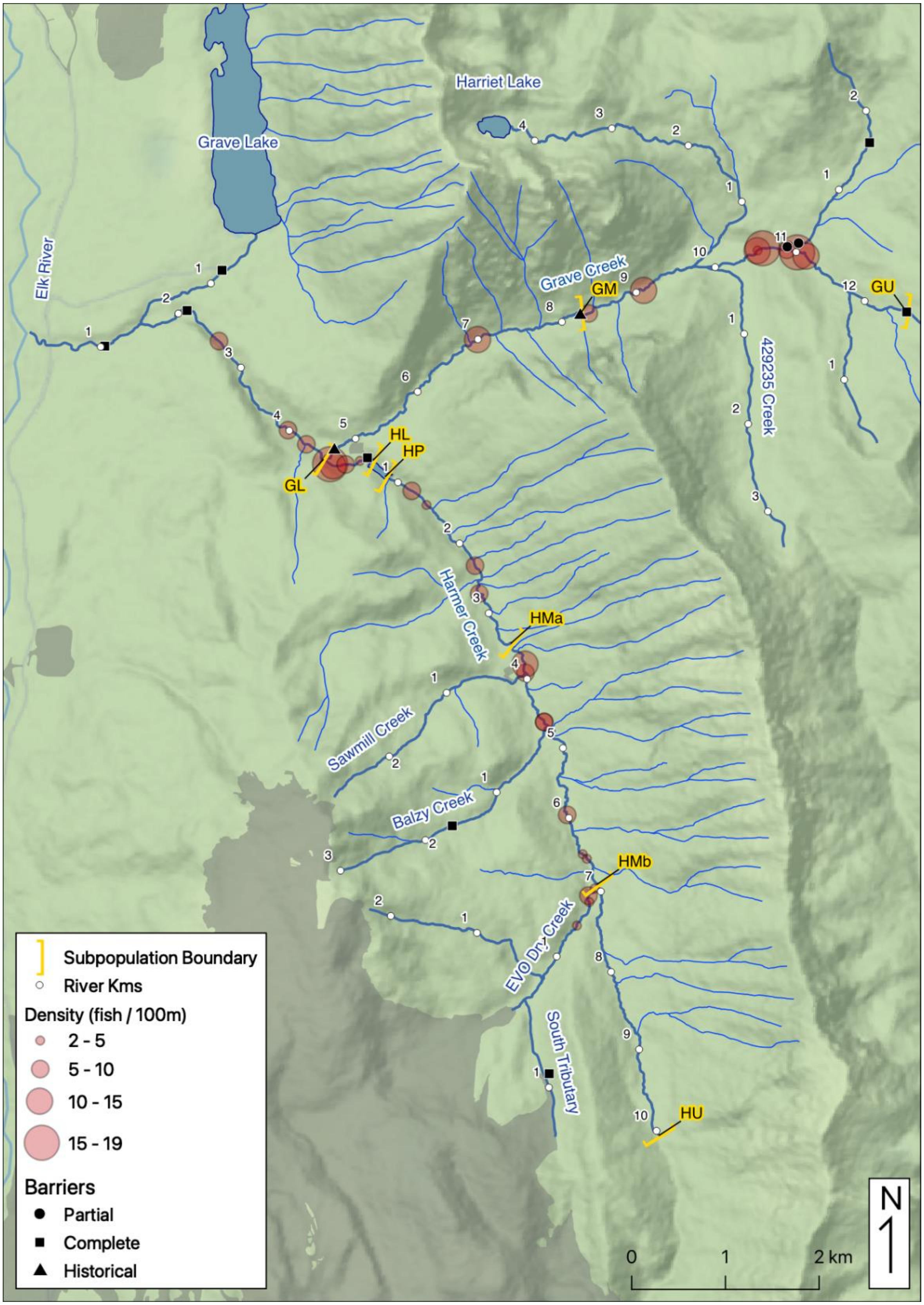

Figure 21. The estimated age-1 lineal density averaged across all years by location. Subpopulation boundary labels are at the upstream end of the area.

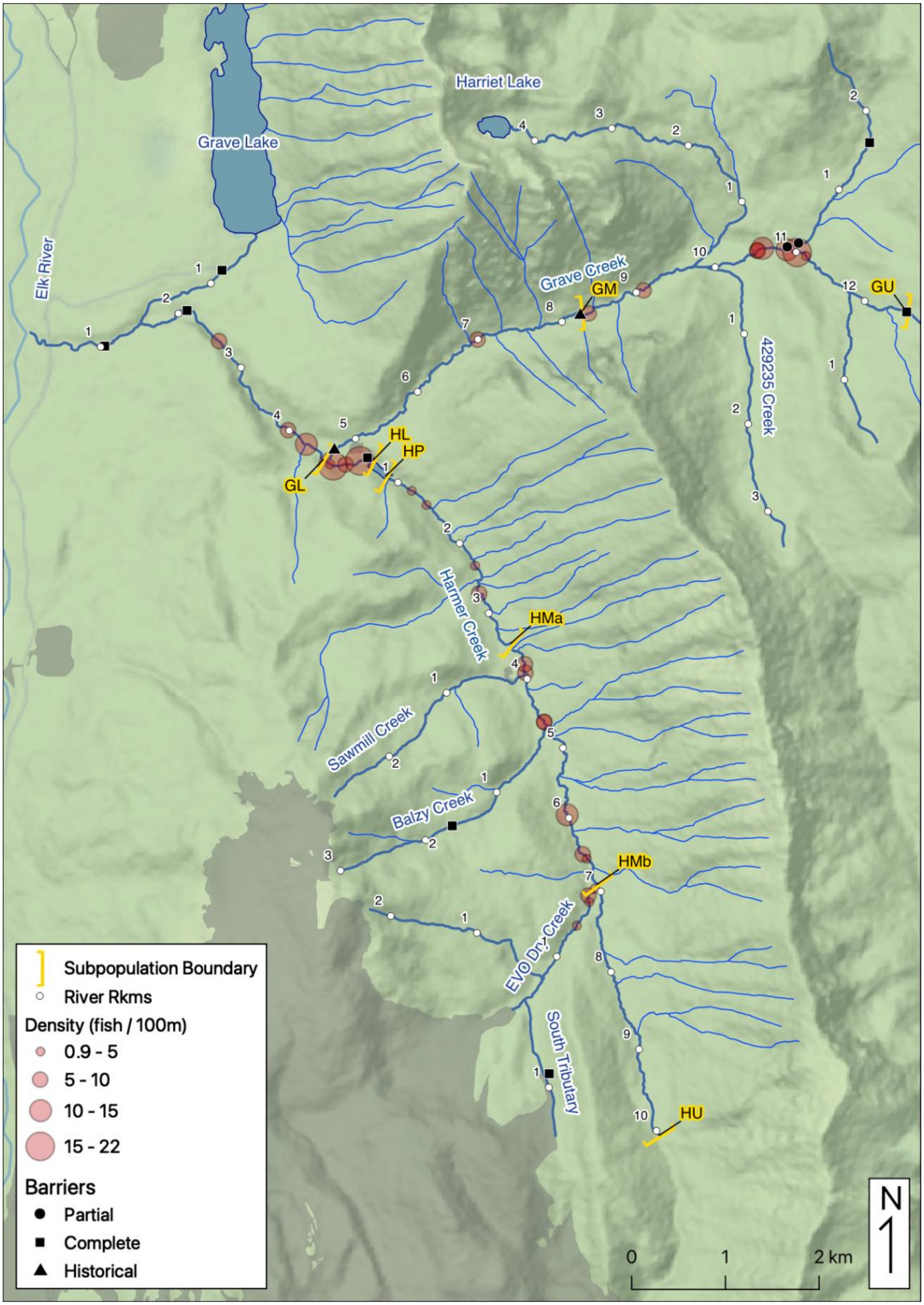

Figure 22. The estimated age-2+ lineal density averaged across all years by location. Subpopulation boundary labels are at the upstream end of the area.

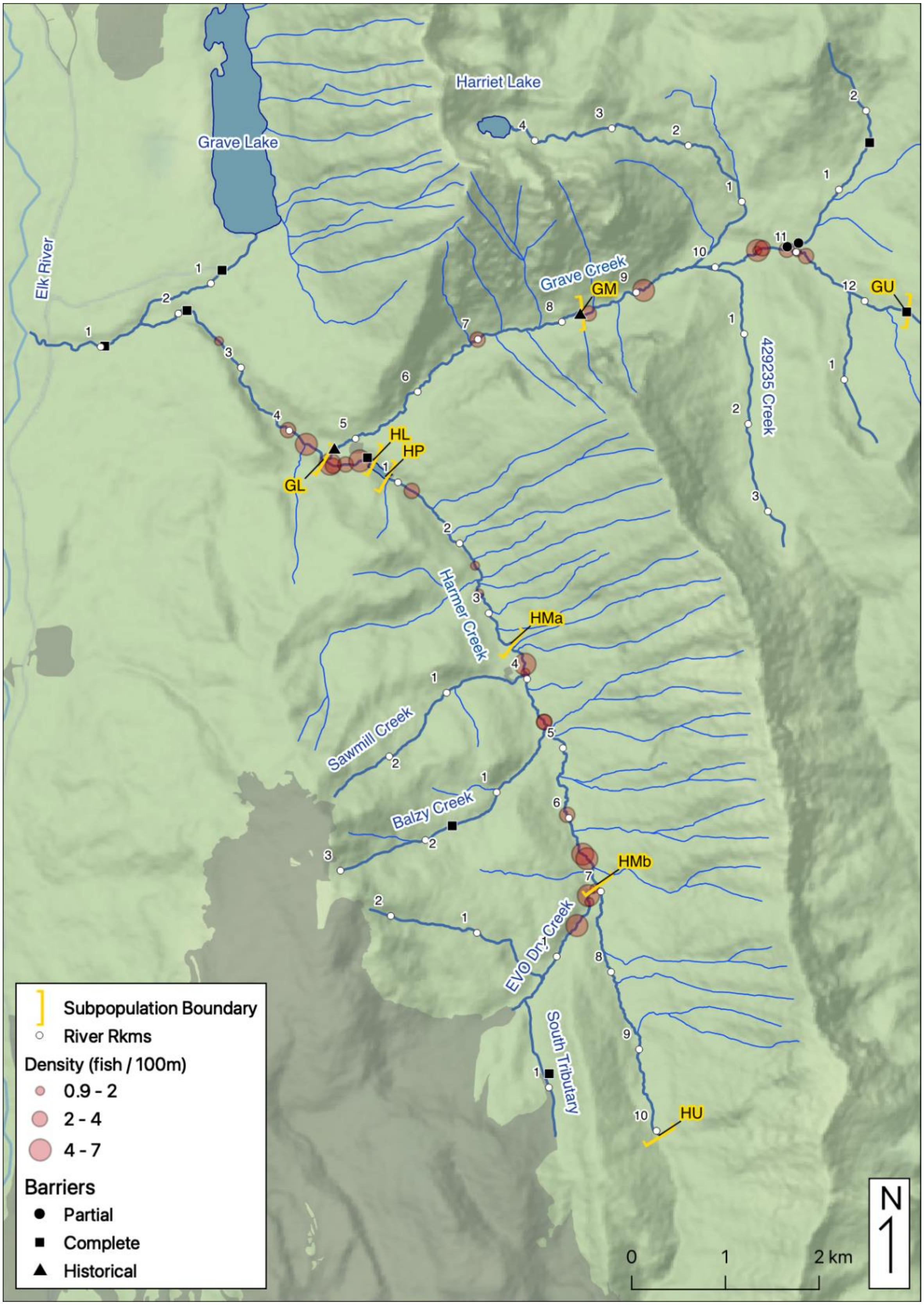

Figure 23. The estimated adult lineal density averaged across all years by location. Subpopulation boundary labels are at the upstream end of the area.

5.1.7.3 ABUNDANCE

The abundance estimates are calculated by multiplying the average population densities reported in Section 5.1.7.2 by the total amount of effective habitat. It is based on 10.7 km of effective mainstem habitat (GL, HL, GM, and GU) for the Grave Creek population and 7.6 km of effective habitat (HM and Dry Creek) for the Harmer Creek population. Estimated egg abundances are the product of the estimated adult abundance and the fecundity, under the assumptions of a 1:1 sex ratio and a 50% probability of an adult female spawning in any given year.

The lifecycle model estimated that all four life stages (age-1, age-2+, adult and eggs) were more abundant in the Grave Creek population than in the Harmer Creek population except in 2022 when the estimated abundance was similar for age-1s (Figure 24, Figure 25).

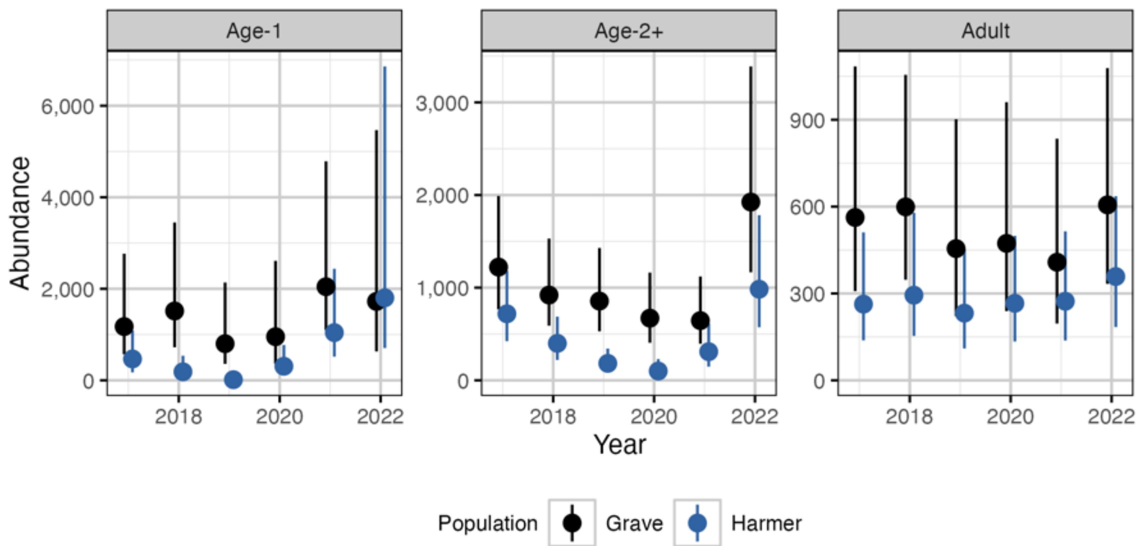

Figure 24. The estimated age-1, age-2+ and adult abundance by year and population. Error bars represent 95% CIs.

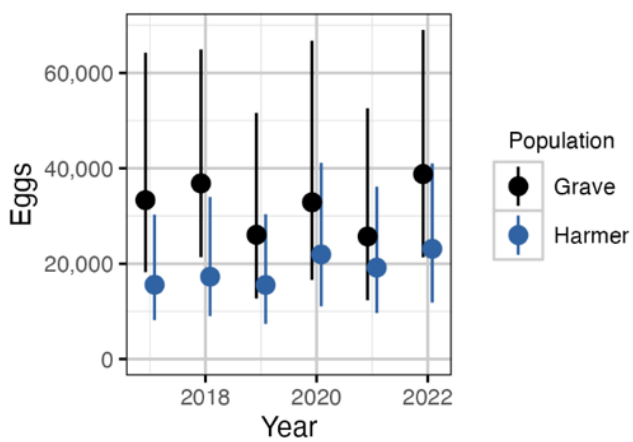

Figure 25. The estimated egg abundance by year and population (with 95% CIs).

Age-1

The estimated number of age-1 fish in the Grave Creek population area has ranged from a low of 800 (95% CI 360 – 2,100) in 2019 to a high of 2,000 (95% CI 1100-4,800) in 2021. In 2022 there were an estimated 1,700 (95% CI 630 – 5500) individuals. In the Harmer Creek population area, the number of age-1 fish for the Harmer population is estimated to have fallen from 470 (95% CI 170 – 1,100) to just 14 fish (95% CI 0-204) in 2019. Since then, the estimated number of fish has increased annually to a high of 1,800 fish (95% CI 710 – 6,900) in 2022.

Age-2+

The estimated abundance of age-2+ fish in the Grave Creek population declined from 1200 fish in 2017 (95% CI 570-2,800) to 640 fish (95% CI 400-1,100) in 2021, then further increased to 1,900 (95% CI 1200-3400) in 2022. The Harmer Creek population showed a steep decline from 720 fish (95% CI 420 – 1200) in 2017 to a low of 100 fish (95% CI 50-230) in 2020 followed by a substantial recovery to 980 (95% CI 570-1800) in 2022.

Adult

Estimated adult abundance in the Grave Creek population peaked at around 600 in 2018 and in 2022. The estimated number of adults in the Harmer Creek population ranged from 230 to 270 between 2017 to 2021 and peaked at 360 (95% CI 180-640) in 2022.

Eggs

For the Grave Creek population, the estimated egg deposition has fluctuated over the years from a low of 26,000 (95% CI 12000-53000) to a high of almost 39,000 (95% CI 21000-69000) in 2022. The Harmer Creek population also fluctuated from a low of around 16,000 (95% CI 7370-30390) to a high of 23,000 (95% CI 12000-41000) with the highest estimated egg deposition in 2022.

5.1.7.4 NESTS PER FEMALE SPAWNER

The estimated definitive nests from the nest count model were compared to the estimated number of female spawners from the lifecycle model. The results suggest that the estimated number of definitive nests is highly variable among years and should not be used to infer trends in adult abundance. The extent to which the annual variation reflects differences in observer efficiency vs spawning activity is currently uncertain (Figure 26).

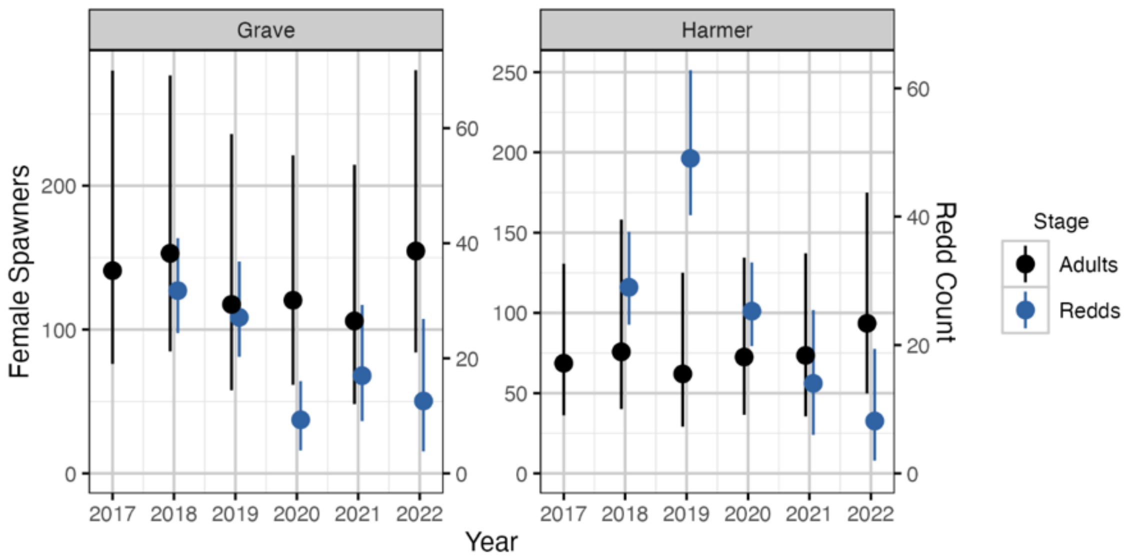

Figure 26. The estimated number of adults based on the lifecycle model and the estimated total definitive nest count by year and population (with 95% CIs).

5.1.7.5 ANNUAL SURVIVAL

The annual age-1 and older survival in both populations was estimated to be ~ 50% from 2017 to 2018 as well as in the from 2018 to 2019 (Figure 27). The annual survival in the Grave Creek population remained ~ 50% through the year 2020 to 2021 however the annual survival in the Harmer Creek population increased to ~ 80% beginning in the year 2020. The annual survival in the Grave Creek population increased to be similar to that in the Harmer Creek population at 84% (95% CI 51->99%) from 2021 to 2022. These latter survival estimates are higher than expected and may indicate that there is immigration to the mainstem habitats from tributaries that is not accounted for in the current lifecycle model.

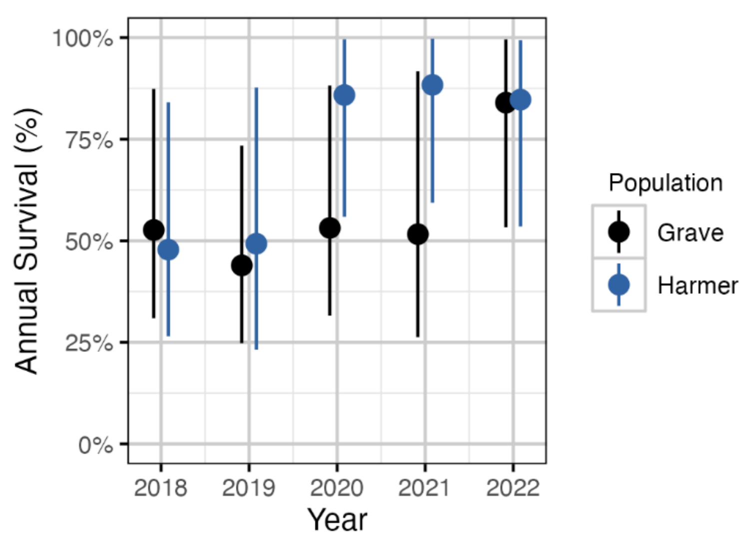

Figure 27. The estimated annual age-1 and older survival from year-1 to year by year by population (with 95% CIs).

5.1.7.6 EGG TO AGE-1 SURVIVAL

The estimated egg to age-1 survival rates are plotted in Figure 28. Although, total egg deposition is lower for the Harmer Creek population than the Grave Creek population (Section 5.1.7.3) the egg densities are similar for both populations because for the purposes of estimating egg densities the 1.8 km of EVO Dry Creek are excluded due to the lack of spawning habitat. Neither population demonstrates a clear density dependent relationship although this is not unexpected given the relatively narrow range of egg densities (Figure 28).

The estimated egg to age-1 survival has been relatively consistent in the Grave Creek population although survival was lower than in the other years for the 2018 spawn year. For the Harmer Creek population the average estimated egg to age-1 survival was at or just above the estimated replacement rate (see Text Box). However, for the 2018 spawn year the estimated egg-to-age-1 survival was low enough (< 0.1%) to indicate recruitment failure (here defined as a greater than 50% probability that recruitment is less than 10% of the 1% required for replacement). In contrast, for the 2021 spawn year, the egg to age-1 survival was ~7% in the Harmer Creek population and ~9% in the Grave Creek population.

Egg to Age-1 Recruitment

Egg to age-1 survival (or recruitment) 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).

The recruitment of age-1 fish is the product of the number of eggs deposited and egg to age-1 survival.

For a population to be stable over a long time period, each spawner must on average replace itself with another spawner over its lifetime. Rates of recruitment vary naturally.

The egg to age-1 survival rate allows conditions to be compared among populations and years, particularly when plotted by the egg density (eggs/100 m).

A literature review suggested that in a typical population an egg to age-1 survival rate of 5% is required for 100% population replacement (Ma & Thompson, 2021), while the life cycle model for the Harmer Creek and Grave Creek populations estimated the value to be 1% (95% CI; 0.3–5%) (Thorley et al., 2022).

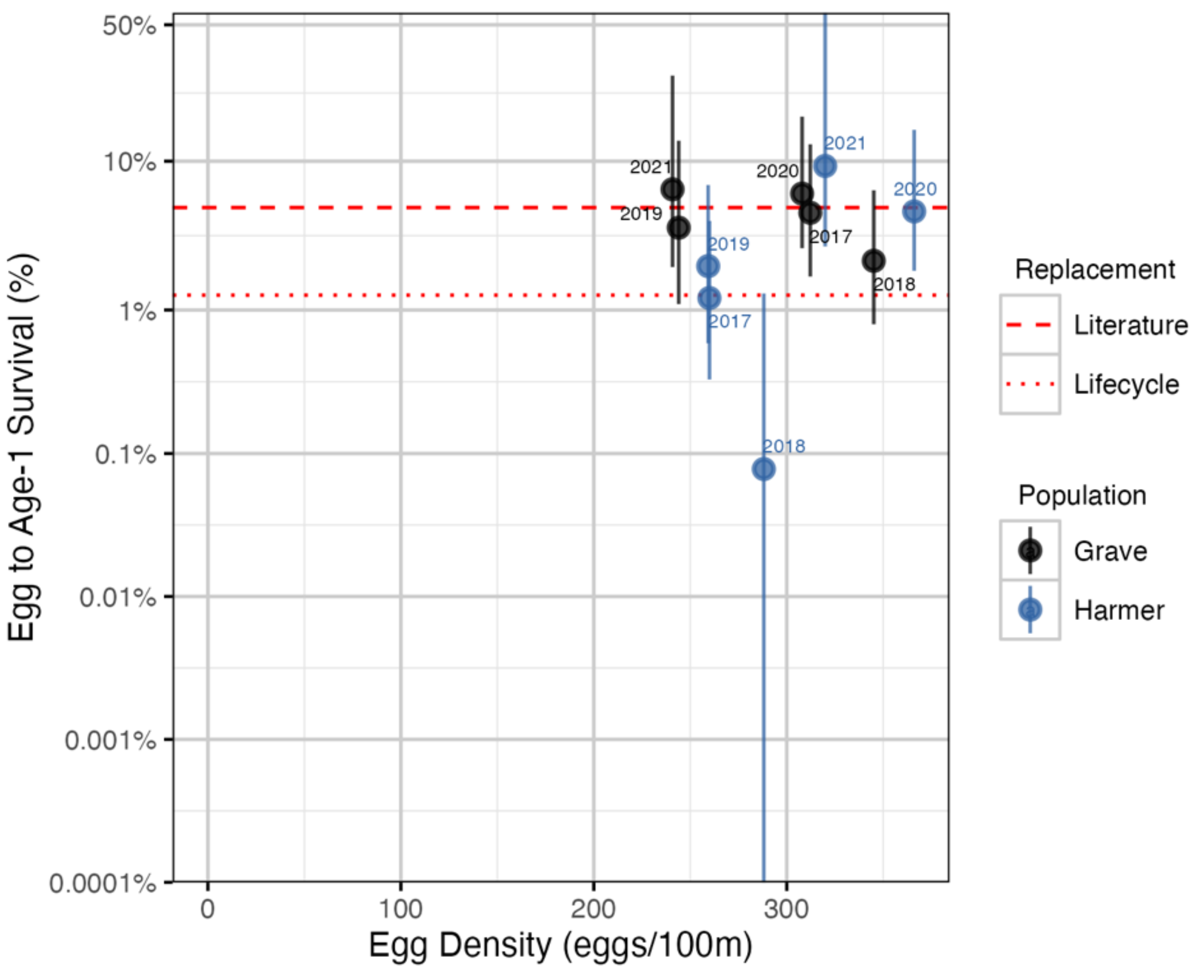

Figure 28. The egg to age-1 survival (on a logistic scale) by egg density, spawn year and population (with 95% CIs).

The red lines indicate the egg-to-fry survival required for replacement based on the literature (Ma and Thompson 2021) and the lifecycle model.

6 SUMMARY

As outlined in the Introduction, the population monitoring program has expanded to explicitly address 10 questions identified in a Framework (under development) related to 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.

6.1 POPULATION CHARACTERISTICS

In this section we describe the characteristics of the WCT populations in Grave and Harmer Creeks that provide context for understanding the dynamics of the population. These characteristics are not expected to change frequently, though the characterization will be updated as additional data are collected or if there are alterations to habitat, such as the installation or removal of barriers.

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

The geographic range of the Grave Creek population on the mainstem extends from the falls on Grave Creek at rkm 2.1 upstream to rkm 10.5. It also includes the lower 0.6 km of Harmer Creek below the Harmer Sediment Pond Dam as well the lower parts of East Tributary and 49235 Creek (Figure 1). The WCT that are stocked into Harriet Lake by the provincial stocking program likely constitute a distinct population although this is being confirmed by genetic analysis. In total there are 11 km of accessible mainstem habitat available to the Grave Creek population. Of these, 10.7 km are considered to be effective (Figure 1). There are 11.6 km of accessible tributaries available to the Grave Creek population, with 3.5 km considered to be effective.

The geographic range of the Harmer Creek population extends from the Harmer Creek Sedimentation Pond Dam to approximately rkm 8.6 where Harmer Creek originates as a groundwater spring. The main tributaries are the 1.8 km of EVO Dry Creek from the rock spoils to Harmer Creek and the 0.8 km of South Tributary although the lower parts of Balzy and Sawmill Creeks are also accessible. The Harmer Creek population area has 9.7 km of accessible mainstem habitat of which 6.3 km are considered to be effective (Figure 1). Of the 9.3 km of accessible tributary habitat, 4.4 km h are considered to be effective including 1.6 km in EVO Dry Creek.

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

In small, isolated populations, potential exists for inbreeding depression to occur (Soulé and Mills 1998; Taylor et al. 2003; Carim et al. 2016; Thorley et al. 2022b). Inbreeding depression is a decline in reproduction, growth, or survival due to the expression of recessive deleterious alleles. This can result in the loss of population fitness due to a lack of genetic diversity. Inbreeding depression can occur when low population numbers are combined with a lack of dispersal (i.e., where members of the population live in close proximity), which can result in closely related individuals breeding (Wang et al., 2002).

The effective genetic population size (NE) 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. However, see Frankham et al. (2014) who suggest that at 100/1000 rule is more appropriate.

An analysis of genetic data collected from the Grave and Harmer Creek populations in 2016 was used to quantify allelic richness, diversity and effective genetic population size (Thorley et al. 2022b). The genetic diversity was lower in the Harmer Creek population than in the Grave Creek population (allelic richness of 1.4 versus 1.6 alleles/loci and an expected heterozygosity of 0.09 versus 0.12). These differences are relatively minor and there is little to no genetic differentiation between the populations. The estimated effective genetic population size was estimated to be 43 for Grave and 23 for Harmer but these are uncertain. More genetic data has been collected and its analysis is pending.

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

All the fish in the Grave and Harmer Creek populations are considered to be fluvial residents (complete their life cycles within the streams) due to their small body size (< 300 mm), their isolation from the Elk River by the natural falls at rkm 1 and rkm 2.1 and because fish densities in the Harmer Sediment Pond appear to be negligible.

6.1.4 WHAT IS THE TIMING OF LIFE-HISTORY EVENTS?

Spawning commences by late May, it peaks around June 15 and continues to mid-July. 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 (2007b) estimate of 570 to 600 Accumulated Thermal Units (ATUs) for Colorado Cutthroat Trout (*Oncorhynchus clarkii pleuriticus*). Based on the spawning and temperature data collected by Cope and Cope (2020) and detailed in the Harmer Creek EoC (Harmer Creek EoC Team, 2023) it is estimated that fry emergence would begin in the warmest section of Grave Creek below the confluence with Harmer Creek around the end of July and continue in the coldest section of Harmer Creek above the confluence with EVO Dry Creek until approximately the middle of October. The growing season is assumed to end in late October but this is currently being evaluated further (Brooks et al in prep).

6.1.5 WHAT ARE THE SIZES OF THE KEY LIFE-STAGES?

Analysis of fish lengths suggests that age-0 fish from the Harmer Creek population are typically ~32 mm long by the onset of winter compared to ~38 mm for the Grave Creek population. This ~6 mm length difference is likely partly due to colder summer water temperatures in Harmer Creek (Bear et al. 2007; Cope and Cope 2020b). Studies on Colorado Cutthroat Trout suggest that fry with a total length below a threshold of 30-35 mm may lack sufficient energy reserves to survive the winter with consequences for subsequent recruitment (Coleman and Fausch 2007a, 2007b). Based on visual examination of fish length frequency plots, individuals between 50 and 89 mm are considered to be age-1, those between 90 and 169 are considered to be age-2+ and adults are ≥170 mm by October 1.

Vital Rates

The number of fish present in a population depends on four processes that occur during the life cycle of fish: reproduction, growth survival, and movement. The "vital rates" associated with these processes are defined below.

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

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

***Growth** - the rate of change in fish size (length and weight) over a defined period of time and it varies by life stage.*

***Movement** – the rate at which individuals 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.*

6.2 VITAL RATES

6.2.1 WHAT IS THE GROWTH RATE OF KEY LIFE STAGES?

The available evidence suggests that due to overall warmer water temperatures, WCT in the Grave Creek population emerge earlier and attain bigger size by the onset of winter than WCT in the Harmer Creek population. Subsequent growth and how it varies by year is currently poorly understood, but data suggest that a WCT at 4 years old will be ~174 mm. Increased PIT tagging of individuals to collect information on inter-annual growth is recommended.

Since 2017, average annual age-0 lengths have varied between 28 and 44 mm for the Grave Creek population and between 27 and 36 mm for the Harmer Creek population. In 2022 age-0s were shorter in both populations than in any other year since this monitoring program began. The average adult length has been higher in the Harmer Creek population than for the Grave Creek population over the years which may be indicative of an aging population. However, the average length of adults has been declining in the Harmer Creek population since 2020 which may reflect recruitment of younger, smaller individuals into the adult population.

Body condition of age-2+ and adults is generally similar in the Grave and Harmer Creek populations and in 2022 the body condition was the lowest recorded for age-2+ in both populations. In contrast the condition of adults in 2022 increased for both the Grave and Harmer Creek populations compared to the years 2018 to 2021 and was similar to that in 2017.

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

From 2018 to 2022, definitive nests were recorded throughout the mainstems of Grave and Harmer Creek, where suitable spawning habitat exists. However, over the same period, despite similar effort, only three definitive nests have been recorded in EVO Dry Creek, which is heavily calcified due to the influence of the rock spoils.

Analysis of the electrofishing capture data suggests that age-1 densities are highest in Harmer Creek below the sedimentation pond (HL) and in the upper part of Grave Creek (GU). In Harmer Creek the maximum densities are lower than in the Grave Creek population area, and are highest in Harmer Creek in the middle part of the river (HMa and HMb). An age-1 fish has never been caught in EVO Dry Creek despite extensive salvage in 2017 suggesting negligible recruitment in this tributary; a finding that is consistent with the almost complete lack of spawning in EVO Dry Creek. Age-2+ and adult densities follow a similar general pattern as age-1s with the exception that there are age-2+ and adult fish in EVO Dry Creek at similar densities to other parts of both the Grave and Harmer Creek populations areas.

Additional effort has been expended electrofishing in tributaries other than EVO Dry Creek since 2021. Relatively high densities of age-1 fish were recorded in Balzy Creek in the Harmer Creek population area and in Tributary 429235 Creek in the Grave Creek population area. To date the upstream extent of fish use has not been determined in 429235 Creek.

6.2.3 WHAT IS THE ABUNDANCE OF KEY LIFE-STAGES?

The lifecycle model estimated that all life stages (age-1, age-2+, adult and eggs) were more abundant in the Grave Creek population than in the Harmer Creek population in each year with the exception of 2022 for age-1s when they were similar for the two populations.

The estimated abundance of all age classes age-1 and above was higher, or similar to the highest recorded abundance, in both the Harmer and Grave Creek populations in 2022. Age-0 abundance is not estimated as capture efficiency is very low and uncertain for that age class.

The estimated abundance of eggs and age-1s has varied from year to year in the Grave Creek population since 2017. The age-2+ and adult abundance generally declined from 2017 to 2021, which was followed by approximately a threefold increase for age 2+ and a doubling for adults in 2022.

In the Harmer Creek population, the estimated abundance of age-1 and age-2+ fish declined from 2017 to 2019 for age-1s and to 2020 for the age-2+ after which the estimated abundance increased with the highest numbers of each age class recorded in 2022. The estimated abundance of adults has fluctuated over the years.

6.2.4 WHAT IS THE TOTAL NUMBER OF EGGS DEPOSITED?

The number of age-1 recruits in any given year is bounded by how many eggs are deposited. Egg deposition, in turn, depends on the number of spawning females, their fecundity, which is the number of eggs each spawner produces, and the presence of suitable spawning habitat.

In 2022, fecundity was similar in the Grave and Harmer Creek populations. For the Grave Creek population, the estimated egg deposition has fluctuated over the years from a low of 26000 (95% CI 12000-53000) in 2019 and 2021 to a high of almost 39000 (95% CI 21000-69000) in 2022. The Harmer Creek population also fluctuated from a low of around 16000 (95% CI 7370-30390) in 2017 and 2019 to a high of 23000 (95% CI 12000-41000) in 2022. This increased estimated egg deposition in 2022 reflects the higher abundance of adults in the populations.

> ***Populations Fluctuate***
>
> *Numbers of fish often fluctuate from year to year in response to changes in habitat. The changes in habitat can be driven by natural or anthropogenic factors. When numbers are lower, fish tend to have higher growth, survival and fecundity. In this way, given sufficient genetic diversity, fish populations can recover from several years of very low recruitment.*

6.2.5 WHAT IS THE SURVIVAL OF KEY LIFE-STAGES?

The annual survival rate of all life stages has increased in the past two years. The lifecycle model estimated that annual survival for age-1 and older fish in both populations was estimated to be ~ 50% from 2017 to 2018 and increased to ~80% beginning in 2020 to 2021 for the Harmer Creek population and in 2021 to 2022 for the Grave Creek population These survival estimates are higher than would be expected and may indicate that there is immigration to the mainstem habitats for tributaries that is not accounted for in the current lifecycle model.

The lifecycle model estimated egg to age-1 survival rates for the Grave Creek population of between 2 and 7%, for the spawn years 2017 to 2021, with the lowest estimated survival in 2018 and the highest in the 2021 spawn year. For the Harmer Creek population the estimated egg to age-1 survival rates for the 2017, 2018 and 2019 spawn years were just 1%, 0.1% and 2.0%, respectively. The egg to age-1 survival rate for the Harmer Creek population was 5% for the 2020 spawn year and 9% for the 2021 spawn year. These can be compared with the literature-based rate of 5% (Ma and Thompson 2021) and with the lifecycle model-based rate of 1% required for population replacement. Consequently, the egg to age-1 survival rates in 2021 suggest an increasing population in 2021.

7 DISCUSSION

The annual Grave and Harmer Creek population monitoring data provides insight into the status of the populations' vital rates and allow the evaluation of trends over time. Future analysis of these data can be used to study the causal effect relationships between habitat and the fish.

Our ability to study fish in their first year is limited. It is challenging to locate these small fish given their patchy distribution and they are too small to allow accurate weight measurements based on current methods. Our primary indicator for their status is length at the onset of winter, which is a key determinant of survival. Length, together with fish condition, contributes to the energetic status of the fish, where longer fish with higher condition (i.e., more lipids) have more energy available (Thorley and Branton 2023). In 2022 age-0 fish from both the Grave and Harmer Creek populations were estimated to be substantially shorter on October 1, near the end of the growing season, than in previous years. Ongoing work suggests that the condition of juvenile fish (age-1 and age-2+) may reflect the condition of fish in their first year and the condition of age-2+ in 2022[5] was also substantially below average for this system. Together this indicates that age-0 fish likely had lower than usual energy status going into winter. Energy status alone does not indicate how well fish may survive winter and how recruitment will be for that cohort of fish because it is the relationship between the amount of stored energy available and the amount of energy required to survive winter based on its duration and severity that affect survival. A separate study of the relationship between age-0 size and water temperature is underway and in the fall of 2022

[5] Weight data used to calculate the condition for age-1s will be undergoing reanalysis using models which account for the relatively high and variable measurement error.

preliminary results indicate that fish continued to put on length into the end of October (Brooks et al in prep).

For both the Harmer and Grave Creek populations the estimates suggest that in 2022

- *age-0s were shorter than from 2017-2021*
- *age-2+ were skinnier than from 2017-2021*
- *age-1 abundance was higher than from 2017-2020*
- *recruitment of age-1s from the 2021 spawn year was above that required for replacement and was higher than from 2017-2021*
- *adult abundance was higher than from 2017-2021*

The estimated abundance and egg to age-1 survival for age-1 fish in 2022 (i.e., spawned in 2021) was higher in both the Grave and Harmer Creek populations than in previous years and marks the second year in a row that this was the case. The estimated survival rate for age-1 and older fish also increased during this time period and the recruitment of age-1s was both above the level required for population replacement and was higher than it was from 2017 to 2021. The abundance of age-2+ fish was also higher than in previous years which is consistent with the relatively abundant age-1s from 2021 having an improved survival rate over previous years.

Based on the current data, the estimated abundance of adults in both the Grave and Harmer Creek populations was lowest in 2019 and highest in 2022. The estimated average length of the adults was highest in 2020 in both populations. The recent reduction in adult length may reflect recruitment of smaller, younger individuals into the adult population which may bode well for an increase in reproductive output.

Increased sampling in tributaries indicate that there are some productive streams contributing to both populations. To date tributaries have not been included in the population estimates, but in future they are expected to provide additional insight into the dynamics of the populations.

8 RECOMMENDATIONS

Given the improved recruitment status of the Harmer population it is recommended that the sampling program:

- continue to increase the coverage of both populations, including tributaries, using mark recapture at large open sites to account for the variability in densities at individual sites (Korman et al. 2016).
- continue PIT tagging to provide valuable information on capture efficiency, abundance, growth and movement.
- collect scale samples to allow the abundance of age-2 and age-3 to be estimated.
- continue to use bank walks to measure the lengths of age-0 fish.
- trial techniques to quantify the condition of age-0 fish.

Specific recommendations will be documented in the Grave and Harmer Creek Westslope Cutthroat 2023 Study Design.

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