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Technical Report Overview

Report: Grave – Harmer Westslope Cutthroat Population Monitoring and Assessment 2021

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

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

For More Information

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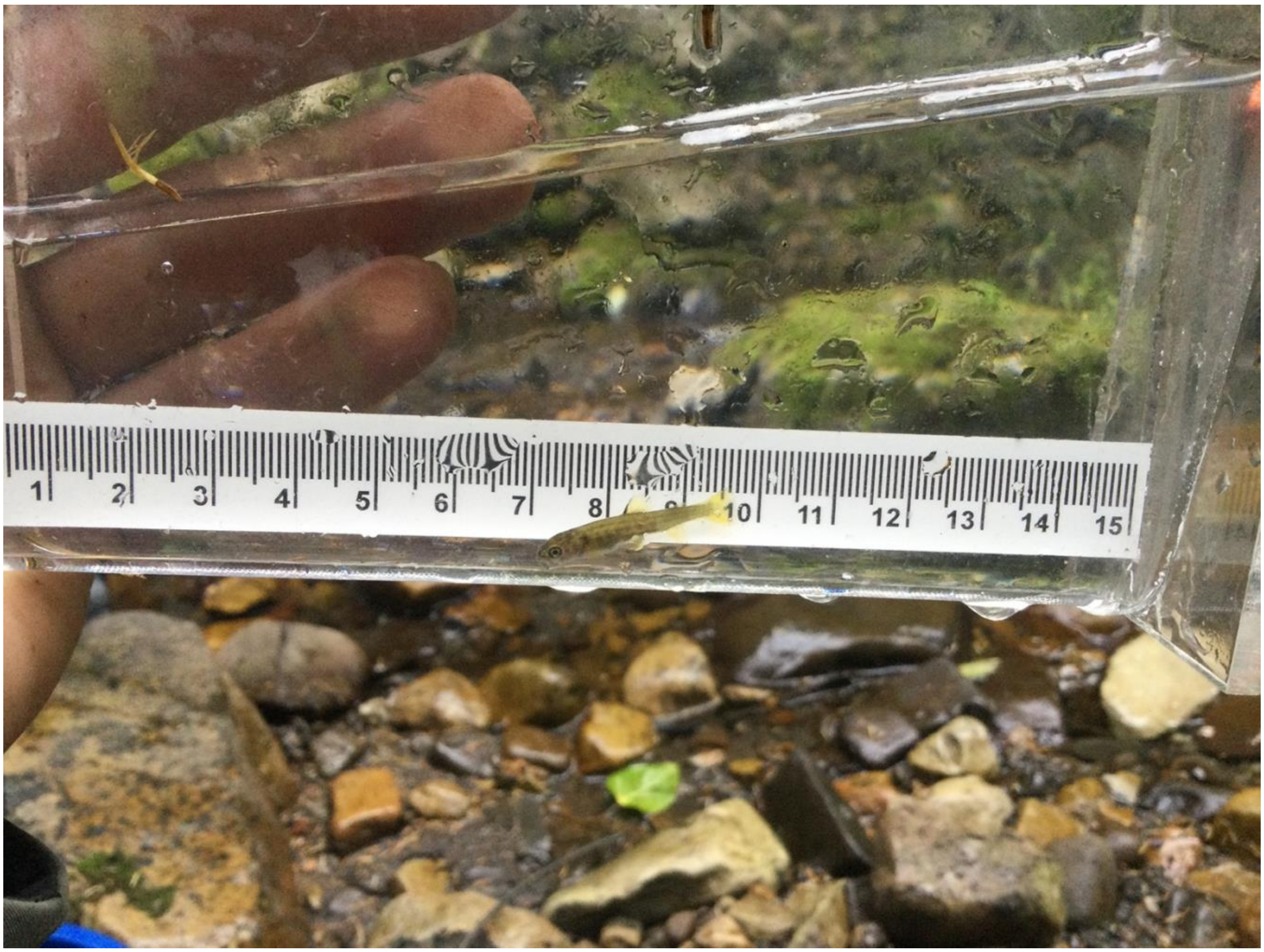
Grave and Harmer Creek Westslope Cutthroat Trout Population Monitoring 2021

FINAL REPORT

June 19, 2022



Prepared for: Teck Coal Ltd., Sparwood, BC

Prepared by: Thorley, J.L.[1], Kortello, A.K.[1], Brooks, J.L.[2] & Robinson, M.[2]

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The **suggested citation** for this interpretive report is:

Thorley, J.L., Kortello, A.K., Brooks, J.L. & M. Robinson. (2022) Grave and Harmer Creek Westslope Cutthroat Trout Population Monitoring 2021. A Poisson Consulting and Lotic Environmental report prepared for Teck Coal Ltd., Sparwood, BC.

The cover photo is of a Westslope Cutthroat Trout with fork length of 26 mm and weight of 0.54 g that was captured in Grave Creek GRA3R on the 22nd of September 2021 by backpack electrofishing.

EXECUTIVE SUMMARY

Harmer Creek is a tributary of Grave Creek, which flows into the Elk River in Southeastern British Columbia (BC). The two creeks support isolated populations of genetically pure Westslope Cutthroat Trout (WCT; *Oncorhynchus clarkii lewisi*). The Harmer population was separated from the Grave population in 1971 by construction of the Harmer Creek Sediment Pond and Dam. The Harmer Creek subwatershed is influenced mostly by waste rock deposits in two of its headwater tributaries – Dry Creek and South Tributary. A large decline in the catches of fish < 150 mm in Harmer Creek in 2019 initiated a detailed review of the effects of environmental stressors (natural and anthropogenic) on the abundance of the Grave and Harmer populations. The review, which is being conducted by the Harmer Creek Evaluation of Cause Team, should be available in 2022.

The current report recognises three primary fish population metrics: carrying capacity (long-term average expected adult population abundance); productivity (population replacement rate at extremely low density), and viability (probability of persistence for 40 generations). In order to estimate these metrics it is necessary to answer a series of secondary questions using data from redd surveys (2018-2021), electrofishing surveys (1996, 2008, 2013, 2017-2021) and age-0 bank walks (2021). The answers to these questions are summarized in the Executive Summary Table on the following page.

The results are consistent with

- *reduced recruitment* for the 2017, 2018 and 2019 spawn years in the Harmer Creek population and for the 2018 spawn year in the Grave Creek population,
- *recruitment failure* in the Harmer Creek population for the 2018 spawn year,
- *above replacement recruitment* for the 2020 spawn year in both Harmer and Grave creek populations
- a moderate decline in the number of adults in both populations since 2017.

The recruitment terms are defined in the conclusions.

Executive Summary Table. Answers to the nine secondary questions considered in the current report which inform population carrying capacity, productivity and viability.

Question	Subcategory	Grave	Harmer
1. What is the geographic range of the fish population(s)?	Mainstem	Mainstem from 2.1 to 10.5 km and below the Harmer Sediment Pond.	Mainstem from 0.8 to 8.6 km
	Tributaries	It may extend into the lower parts of several tributaries.	Lower 1.8 km of EVO Dry Creek and 0.8 km of South Tributary. It may extend into the lower parts of Balzy and Sawmill creeks.
2. What are the life-history strategies within the fish population(s)?		Small (< 300 mm) fluvial residents.	
3. 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.	
4. What are the sizes of the key life-stages?	Age-0	~ 40 mm on October 1	~ 34 mm on October 1
	Age-1	50 – 99 mm in September	45 – 94 mm in September
	Adult	Females that were mature in May are likely ≥ 170 mm in September.	
5. What is the growth rate of key life-stages?		Typical age-4 fish is ~ 174 mm in September	
6. What is the spatial distribution of key life-stages?	Redds	Highest densities from 3 to 8.5 km and below the Harmer Sediment Pond	Primarily in mainstem below EVO Dry Creek
	Age-1	Highest densities at top of mainstem, between the culverts and below the Harmer Sediment Pond	Primarily in mainstem below EVO Dry Creek
	Adult	Highest densities around culverts and below the Harmer Sediment Pond	Highest densities in mainstem immediately below confluence with and into EVO Dry Creek
7. What is the abundance of key life-stages?	Age-1	~290 in 2019 to ~1,200 in 2021	~19 in 2019 to ~640 in 2021
	Adult	~520 in 2017 to ~260 in 2021	~280 in 2017 to ~170 in 2021
8. What is the total number of eggs deposited?	Eggs	~23,000 in 2017 to ~12,000 in 2021	~13,000 in 2017 to ~9,500 in 2021
9. What is the survival of key life-stages?	Egg to Age-1	~3-7%	~0.1% for 2018 spawn year to ~5% for 2020 spawn year
	≥ Age-1	Typically ~57%	

ACKNOWLEDGEMENTS

The organizations and individuals whose contributions have made this analysis report possible include Bronwen Lewis, Dorian Turner, Carla Fraser, Lindsay Watson, Warn Franklin, Dan Vasiga, Holly Hetherington, Cait Good and Mariah Arnold of Teck Coal Limited; Nicole Zathey, John Bransfield, Rick Smit, and Isabelle Larocque of Lotic Environmental Ltd.; Maggie Branton of Branton Environmental Consulting; Beth Power, Sarah Gutzmann and Ryan Hill of Azimuth Consulting Group Inc.; Jim Clarricoates, Heather McMahon and Kamila Baranowska of Ktunaxa Nation Council; Matt Neufeld, Josef MacLeod, Patrick Williston and Ron Ptolemy of the BC Ministry of Environment; Josh Korman of Ecometric Research; Brian Ma of ESSA Technologies Ltd.; Todd Hatfield, Jason Ammerlaan, Morgan Hocking and Eric Vogt of Ecofish Research Ltd.; Cynthia Russel and Amy Wiebe of Minnow Aquatic Environmental Services; Jesse Sinclair and Christopher Burns of LGL Ltd.; Nadine Hussein and Evan Amies-Galonski of Poisson Consulting Ltd.; Scott Cope and Angela Cope of Westslope Fisheries Ltd.; and Jeff Berdusco and Jon Bisset, among others.

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INTRODUCTION

Harmer Creek is a tributary of Grave Creek, which flows into the Elk River in Southeastern British Columbia (BC). The two creeks support isolated populations of genetically pure (Cope and Cope 2018a) Westslope Cutthroat Trout (WCT; *Oncorhynchus clarkii lewisi*). The WCT population in Grave Creek, which includes the lower 0.5 km of Harmer Creek, is separated from the Elk River system by natural bedrock falls that are 1.0 and 2.1 km upstream from the Elk River (labeled Falls 1 and 2 on Figure 1). The Harmer population was separated from the Grave population in 1971 by construction of the Harmer Creek Sediment Pond and Dam (Figure 1). Until October 2017 the Grave population was subdivided by a hanging culvert at river km 4.6, just above the confluence with Harmer Creek. This was likely installed during road building in the late 1960s. The creek was further subdivided between 2013 and October 2018 by a hanging culvert at 7.8 km (labelled Historical Barriers in Figure 1).

WCT are a species of Special Concern both provincially and federally. Identified threats include interbreeding with Rainbow Trout (*Oncorhynchus mykiss*), restricted fish passage due to culverts, mining, forestry and angling (Fisheries and Oceans Canada 2017). The current WCT population monitoring program was established by the Elk Valley Fish and Fish Habitat Committee in 2017 (Cope and Cope 2020).

The Harmer Creek sub-watershed is influenced by waste rock deposits in two of its headwater tributaries – Dry Creek and South Tributary. The waste rock deposits are from Elkview Operations (EVO), a Teck coal mine with a footprint that includes the upper part of the Harmer Creek sub-watershed (Figure 1). In contrast, there are no waste rock deposits in the Grave Creek watershed upstream of the confluence with Harmer Creek, although some exploratory mining has occurred. There has been logging in the watersheds of both creeks. Following the recommendations of Cope and Cope (2018a), recreational angling has been prohibited in Grave and Harmer Creeks since 2020 (MFLNRORD 2021).

In addition to anthropogenic effects, fish population dynamics are also driven by environmental variation which can itself be exacerbated by climate change. Although Kennedy and Meyer (2015) found that bioclimatic indices, such as mean annual air temperature and mean winter stream flow were poor predictors of trends in WCT abundance for populations in Idaho, recruitment failure can occur due to a short growing season associated with low summer temperatures (Coleman and Fausch 2007a). Ice conditions can 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).

A large decline in the catches of fish with a length < 150 mm in Harmer Creek in 2019 that was considered to be consistent with recruitment failure (Cope and Cope 2020) initiated a detailed review of the effects of environmental stressors (natural and anthropogenic) on recruitment in the Grave and Harmer populations. The review, which is being conducted by the Harmer Creek Evaluation of Cause (EoC) Team, should be available in 2022.

The current report uses the conceptual and research framework outlined by Thorley et al. (in prep) which identifies three primary fish population metrics of interest:

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

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

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

This report attempts to answer the first nine questions - the tenth question is dealt with by Thorley et al. (2022) - and identifies key uncertainties or inconsistencies and provides recommendations for future data collection. The carrying capacity, productivity and viability of the WCT populations in Grave and Harmer creeks will be estimated in future years when the Harmer Creek EoC has been completed and the population model of ESSA Technologies Ltd. and Ecofish Research Ltd. (Lodmell et al. 2017; Ma and Thompson 2021) is parameterized for the two populations.

METHODS

STUDY OVERVIEW

Since its initiation in 2017 the Grave and Harmer WCT Population Monitoring program has annually included fall multi-pass electrofishing at approximately 48 small (~15 m long) closed (by stop nets) sites. Spawning (redd) surveys have been conducted in the mainstems of both creeks in the spring at least three times a year since 2018 (Cope and Cope 2020). To address the data gaps identified in Thorley et al. (2021b) the monitoring program was expanded in 2021 to include additional redd surveys as well as single-pass electrofishing at large (~300 m) open sites and bank walks to determine the size of age-0 fish. The nine secondary questions, and the data sources and analytic methods used to answer them, are outlined below in Table 1. The stream network and river kilometres are derived from the Freshwater Atlas of BC and all spatial coordinates are for UTM Zone 11N (NAD83). All fish lengths are fork lengths unless otherwise stated.

Table 1. Summary of Methods and Analysis.

Question	Data Source	Analytic Method
1. What is the geographic range of the fish population?	Electrofishing Redd Surveys GIS	Professional judgement based on fish observations and barriers, stream size and stream gradient
2. What are the life-history strategies within the fish population?	Electrofishing GIS	Professional judgement based on fish size, geographic range and available habitat
3. What is the timing of life history events?	Redd Surveys Stream temperatures	Redd fading and area-under-the-curve (AUC) redd count models
4. What are the sizes of the life stages?	Electrofishing Bank walks	Professional judgment based on length frequency plots and length-at-age models
5. 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.
6. What is the spatial distribution of key life stages	Electrofishing Redd Surveys GIS	Lifecycle model and redd count models
7. What is the abundance of key life stages?	Electrofishing	Lifecycle model (the independent model is included in the current study for comparison with earlier studies)
8. What is the total number of eggs deposited?	Electrofishing	Literature-based length-fecundity relationship parameterized using adult abundance and adult size
9. What is the survival of key life stages?	Electrofishing	Lifecycle model.

STUDY AREA

The study area is the watershed above the natural falls on Grave Creek at river km 2.1. (Figure 1). Prior to 2021 the natural falls on Grave Creek at km 1.0 was considered the downstream limit of the Grave population (Cope and Cope 2020). However, following fieldwork by Lotic Environmental in 2021, the falls at river km 2.1 was classified as a barrier to upstream fish movement. This adjustment means that km 1.0 to 2.1 and the lower 1.2 km of Grave Lake Creek (Figure 1) are not available to the Grave Population. It also provides an alternative explanation to low water temperatures (Cope and Cope 2018b) for why the WCT are genetically pure despite the introduction of diploid Rainbow Trout by MFLRNOD into Grave Lake which drains into Grave Creek at km 1.4.

There are 8.9 km of mainstem habitat, including the lower 0.5 km of Harmer Creek, available to the Grave population and 7.2 km of mainstem habitat (excluding the 0.3 km of the Harmer Sediment Pond) available to the Harmer population. For the purposes of this report all tributary habitat is excluded from the total amount of available habitat except the 1.8 km of EVO Dry Creek downstream of the rock spoils (Figure 1). Harriet Lake, in the headwaters of Grave Creek, is stocked with WCT by MFLRNOD and connected by an ephemeral stream. It is possible, but unlikely, that these fish have contributed to the Grave population consequently they are not considered part of the population.

In the Harmer Creek subwatershed, EVO Dry Creek and to a lesser extent South Tributary are influenced by the presence of waste rock spoils in the upper parts of their catchments. The influence on water quality extends down the lower 6.3 km of Harmer Creek and lower 4.4 km of Grave Creek although concentrations of constituents are increasingly diluted moving downstream. Despite extensive sampling only one WCT has been captured in the Harmer Creek Sediment Pond as reported by Cope and Cope

(2020). For the purposes of this report, the 0.3 km of the Harmer Creek Sediment Pond is considered to have negligible fish densities. In contrast the 2017 electrofishing salvage of EVO Dry Creek reported lineal densities of fish ≥ 150 mm in the EVO Dry Creek Sediment Pond that were comparable to the upstream and downstream lotic habitat. All anthropogenic structures which could restrict upstream fish movement and two falls on Grave Creek at km 1.0 and 2.1 are listed in Table 2. Further description of the study area is provided by Cope and Cope (2020).

Table 2. Known potential barriers to upstream fish movement.

Barrier	Stream	Rkm	Type	Status	Easting	Northing
Balzy Crossing	Balzy Creek	0.1	ford	passable	658972	5519125
East 1	East Tributary	0.0	culvert	passable	661485	5524425
East 2	East Tributary	0.1	culvert	passable	661604	5524464
EVO Dry Sediment Pond	EVO Dry Creek	0.1	pond	passable	659387	5517527
Grave Prairie Bridge	Grave Creek	0.4	bridge	passable	653623	5523375
CP Rail bridge	Grave Creek	0.5	bridge	passable	653739	5523385
Falls 1	Grave Creek	1.0	falls	impassable	654197	5523366
Falls 2	Grave Creek	2.1	falls	impassable	655075	5523746
Grave R3 Lower	Grave Creek	4.6	culvert	passable	656648	5522256
Grave R3 Upper	Grave Creek	7.8	culvert	passable	659271	5523694
Grave R4	Grave Creek	10.2	bridge	passable	661351	5524412
Grave Lake 1	Grave Lake Creek	1.2	culvert	impassable	655449	5524175
Harmer Sediment Pond	Harmer Creek	0.5	pond	impassable	657001	5522175
Harmer R3	Harmer Creek	3.3	bridge	passable	658534	5520193
Harriet 1	Harriet Lake Creek	0.0	culvert	passable	660496	5524250
Harriet 2	Harriet Lake Creek	0.9	culvert	unknown	660961	5525043
LPFGS015 Crossing	LPFGS015 Creek	0.5	ford	passable	657802	5520641
Sawmill Crossing	Sawmill Creek	0.2	culvert	impassable	658551	5519768

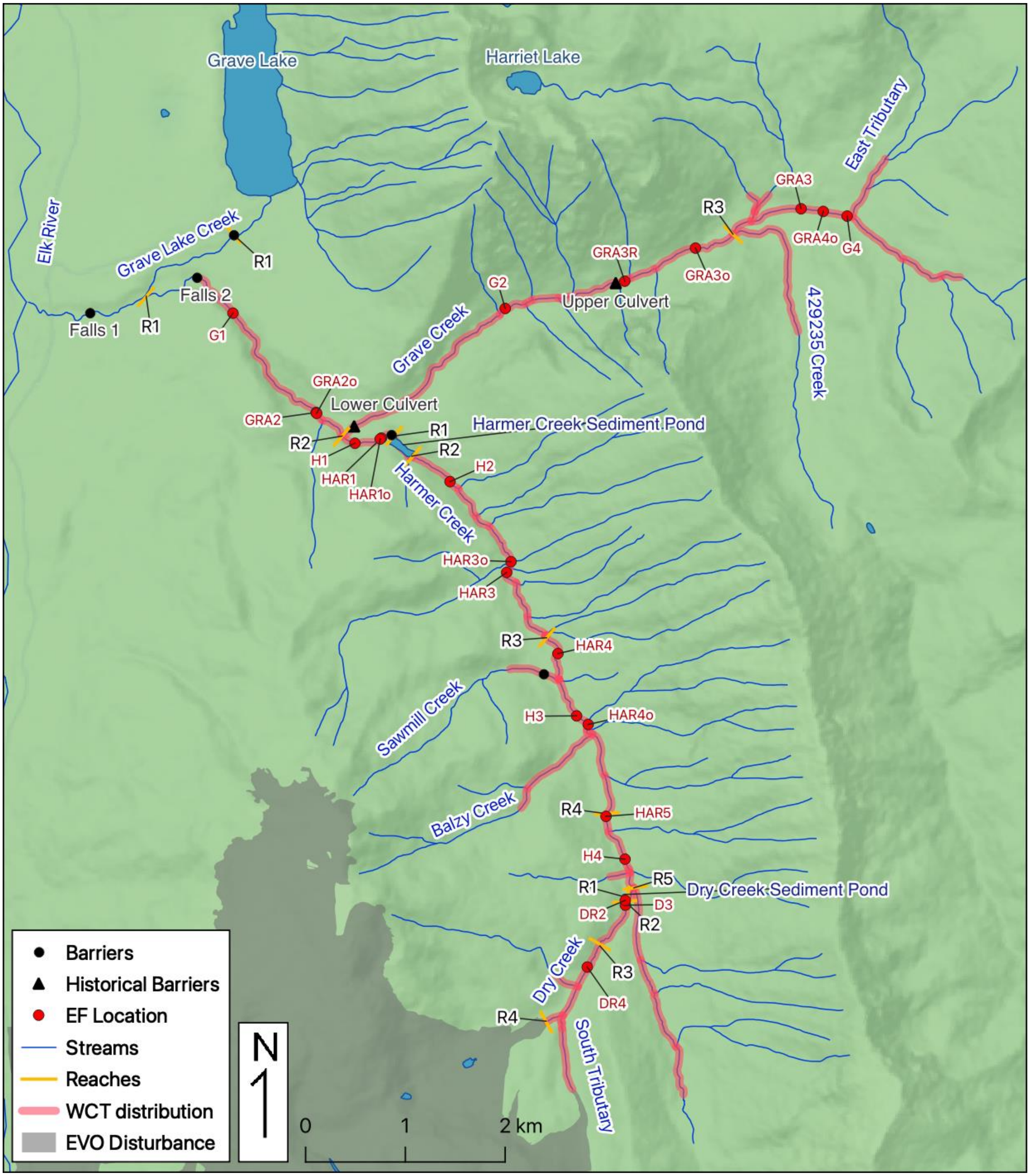

Figure 1. Grave and Harmer Creek study area with upstream historical and current barriers, electrofishing locations, reach breaks and the potential fish distribution.

DATA COLLECTION

SPAWNING (REDD) SURVEYS

Spawning (redd) surveys commenced between June 8 and June 15 and continued until July 4 and July 13, depending on the year. Surveys were conducted approximately once every one to two weeks between 2018 and 2020, and at least once a week in 2021. The surveys covered Grave Creek from the confluence with East Tributary at 10.4 km to the first falls at 1.0 km, the lower 6.3 km of Harmer Creek (from the confluence with EVO Dry Creek) and the lower 1.6 km of EVO Dry Creek from the confluence with South Tributary (Figure 1). In 2021, soon after peak spawning, additional surveys were conducted in the lower 0.6 km of South Tributary and the 1.7 km of Harmer Creek above the confluence with EVO Dry Creek.

Redd surveys consisted of crews of two trained observers who surveyed all lotic habitat recording redds. At least one of the crew members had extensive experience in WCT spawning surveys. 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 (2020). In 2021, following a review of the study design (Thorley et al. 2021b) observers recorded their start and end locations and dates and times and recorded all encountered redds (irrespective of flagging) which they classified as uncertain (also known as test or potential), certain (pit and loose gravel) and no longer certain in the case of previously flagged redds which have become uncertain or even invisible due to fading. The crews also recorded the number of spawning fish and number of nests. To allow individual identification of redds the crews recorded the distance to the left bank (to 0.1 m) and took georeferenced and date-time stamped instream and shoreline photographs. To allow integration with an ongoing study estimating the effects of calcite formation on spawning suitability, redds were flagged in the lower 0.6 km of EVO Dry Creek, the lower 0.5 km of Harmer Creek below the Harmer Creek Sediment Pond and the 0.5 km above the Harmer Creek Sediment Pond as well kms 5.5 to 5.9 in Harmer Creek and 5.3 to 6.6 in Grave Creek. There is some uncertainty as to the extent and timing of surveys in which redds were not observed in the earlier data as start and end locations and date and times of redd surveys were not recorded until 2021 (Thorley et al. 2021b).

ELECTROFISHING SURVEYS

Backpack electrofishing surveys were conducted by teams of three or four individuals. In general, the surveys were conducted in September and early October (Table 3) although historical inventory and salvage data that were collected between July and August were also included.

Most of the data are from removal-depletion electrofishing with stop nets at three randomly selected single mesohabitat (pool, riffle, glide or cascade) sites of about 10 to 35 m in length (and approximately 100 m^2 in wetted area) at 16 different index locations (48 sites total), covering approximately 5% of fish-bearing habitat in Grave Creek and approximately 4% of fish-bearing habitat in Harmer Creek (Cope and Cope 2020). See Cope et al. (2016) for a description of mesohabitats. In 2017 a backpack electrofishing salvage of EVO Dry Creek covered most of the habitat. The salvaged fish (all of which were $\geq$ 150 mm in length) were released in Harmer Creek about 200 m downstream from the confluence with EVO Dry Creek.

Table 3. 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
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

All habitat within a selected site was sampled. Upstream and downstream stop nets spanning the entire wetted width of the stream channel provided closed site conditions. Nets were configured into stable positions with ropes, bipod stays, and anchors, with the lead line adjoined to stream bed contours using boulders as weights. Electrofishing was initiated at the downstream net and proceeded upstream in a systematic bank to bank sweep, followed by a sweep back towards the downstream net. Similar search patterns were repeated in each successive electrofishing pass. Downstream nets were monitored for drifting fish. Electrofishing effort (seconds) was recorded at the end of each pass. Fish were weighed (to 0.1 g), measured (to mm), inspected for any external physical anomalies following the DELT protocol (Ings and Weech 2020; results addressed in a separate document) or injuries, and scanned for PIT tags, with PIT tag numbers recorded (in the digital format) if found. Fish were held in a dark, aerated bucket before being released after the last pass.

In 2021, a second electrofishing methodology was implemented to address the potential bias in site selection for the removal depletion methods and increase the proportion of habitat sampled. The method consisted of a single open (without stop nets) pass at long (~300 m) sites. A long site was randomly selected from each of Reaches 2 to 4 of Grave Creek and Reaches 1 to 4 of Harmer Creek. The seven long sites covered an additional 14% of habitat for the Grave population and 13% for the Harmer population.

During the long, open passes, two crew members electrofished in an upstream direction while a third crew member processed fish. The fourth crew member recorded the start and end locations and times and recorded the locations and times of all observed and captured fish. All captured fish were measured (to mm), weighed (to 0.01 g), inspected following the DELT protocol and photographed in a fish viewer. Captured fish were released within 5 m of their point of capture. A fin clip tissue sample (minimum 3 x 3 mm) was taken from the anal fin of all fish ≥ 70 mm and preserved in 95% pure ethanol.

The earliest data (1996) are from an inventory study (Morris, Cope, and Amos 1997) to determine fish presence. The study methodology was comparable with subsequent sampling for population assessment that occurred from 2008 onward. The 1996 methods state that

> *During electroshocking operations optimum output voltage was in the range of 400 - 500 volts at a frequency of 60-80 Hz. The electroshocking procedure involved maneuvering upstream with the*

> *anode while one or two netters captured stunned fish and transferred them to a holding bucket for processing.*

and that

> *Conductivity and temperature measurements were taken to at the time of sampling to provide a level of confidence with respect to electroshocking effectiveness. Electroshocking was initiated at each point and conducted until fish were captured and a minimum of 100 m^2 sampled or gradients exceeded 20%, significant barriers were encountered, or 500 m of all habitat units and a further 500 m of prime habitat had been sampled.*

Additionally, 1996 and 2008 were single pass efforts that did not use stopnets. The 2017 salvage program in Dry Creek was multipass and did not use stopnets either. All passes were used in the analysis under the assumption that the site was closed. The assumption of closure is considered reasonable given the longer length of the open sites.

AGE-0 BANK WALKS

To assess the size of fry at the end of the growing season two daytime and two nighttime bank walks were conducted between October 4 and 6, 2021. The surveys were conducted by teams of two observers who walked the stream margins searching for fish < 65 mm. The crew members recorded their start and end locations and times and recorded the locations and times of all observed WCT. The crew estimated the length of each observed fish and in the case of fish with an estimated length < 65 mm attempted to capture them using dip nets. All captured fish were weighed (to 0.01 g), measured (to mm) and released at the point of capture. The observed and captured fish informed length-frequency plots and age class boundaries.

DATA PREPARATION

The data 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 watershed, stream, lake and manmade waterbody spatial objects were extracted from the BC Freshwater Atlas. The data were cleaned and tidied (Wickham 2014) before being archived in a purpose built SQLite relational database using R version 4.1.2 (R Core Team 2020).

LIFE STAGES

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. Fish are assumed to become adults (mature) when they reach a length threshold. Previously, following Cope and Cope (2020) the maturity threshold was 150 mm. However, as adult fish are able to grow by 20 mm between the spawning period and the fall when the electrofishing surveys occur and because females, which determine the egg deposition, tend to mature at a greater length than males (Downs 1995), the adult length threshold was increased to 170 mm. Based on visual examination of length frequency plots of fish caught by backpack electrofishing and caught and observed during bank walks, fish between 50 and 99 mm in the Grave population and between 45 and 94 mm in the Harmer population were considered to be age-1. Fish that are too big to be age-1 and too small to be adults are categorized as age-2+. The current report recognizes the following five life-stages: eggs, age-0, age-1, age-2+, and adults. However, the abundance of age-0 WCT in Harmer and Grave creek cannot be reliably estimated (due to their patchy distribution and low capture efficiency associated with their small size). Consequently, the lifecycle model that is described below simply estimates the egg-to-age-1 survival. 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 (Figure 2).

STATISTICAL ANALYSIS

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

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

The parameters are summarised in terms of the point *estimate*, *lower* and *upper* 95% credible limits (CLs). The estimate is the median (50th percentile) of the MCMC samples while the 95% CLs are the 2.5th and 97.5th percentiles.

The results are displayed graphically by plotting the modeled relationships between particular variables and the response(s) with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their mean and first level values, respectively, while random variables are held constant at their typical values (expected values of the underlying distributions) (Kery and Schaub 2011). When informative the influence of particular variables is expressed in terms of the *effect size* (i.e., percent change in the response variable) with 95% credible intervals (CIs, Bradford et al. 2005). Credible intervals are the Bayesian equivalent of the confidence intervals used in frequentist statistics.

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

For additional information the reader is referred to *https://poissonconsulting.ca/f/839299341*.

MODEL DESCRIPTIONS

REDD FADING

Redd surveys provide counts of observed certain redds on particular days but over the course of the spawning season, new redds are created while old ones fade and become invisible. To estimate the expected redd count if surveys were conducted every day and all redds were marked to avoid double-counting, an estimate of the number of days for which a redd remains certain is required. Since a subset of redds were flagged in 2021 and their subsequent status recorded, it was possible to estimate the number of days until 50% of redds had faded (transitioned from certain to no longer certain) based on a simple exponential model.

Key assumptions of the redd fading model include:

- The daily probability of fading is constant.

REDD COUNTS

The redd counts were analysed using a hierarchical Bayesian Area-Under-the-Curve (AUC) model (Hilborn, Bue, and Sharr 1999; Su, Adkison, and Van Alen 2001), to estimate the expected annual redd count. This is the number of certain redds that an average observer would be expected to count if they went out every day and marked every certain redd to prevent double-counting.

Key assumptions of the redd counts model include:

- Lineal redd density varies by survey section.
- Lineal redd density varies randomly by survey section within year.
- The expected count varies by the percent lineal coverage.
- Spawning activity is normally distributed through the season.
- Redds are certain for approximately 18 days (based on redd fading rates).
- The variation about the expected redd count is normally distributed.

To include the historical redd counts it was assumed that the 2018 to 2020 redd surveys were conducted with sufficient regularity to avoid missed redds due to redd fading.

LENGTH-AT-AGE

The length of age-0 and adult fish 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 length-at-age model include:

- Fork length varies among populations.
- Fork length varies randomly among years with 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 normally distributed.
- The residual variation varies by observation vs capture.

GROWTH

Annual growth was estimated from the inter-annual PIT tag recaptures using the Fabens method (Fabens 1965) for estimating the von Bertalanffy (VB) growth curve (von Bertalanffy 1938). The VB curve is based on the premise that:

$$\frac{\mathrm{d}L}{\mathrm{d}t} = k(L_\infty - L)$$

where L is the length of the individual, k is the growth coefficient and L_∞ is the mean maximum length.

Integrating the above equation gives:

$$L_t = L_\infty\left(1 - e^{-k(t-t_0)}\right)$$

where L_t is the length at time t and t_0 is the time at which the individual would have had zero length.

The Fabens form replaces the length and age by the length at recapture (L_r) and length at capture (L_c) to give

$$L_r = L_c + (L_\infty - L_c)(1 - e^{-kT})$$

where T is the time between capture and recapture.

Key assumptions of the Fabens growth model include:

- The mean maximum fork length L_∞ lies between 200 and 250 mm.
- The residual variation in growth is normally distributed.

To estimate the age-length based form of the VB curve from L_∞ and k it was assumed that fish were 40 mm at the end of their first growing season.

BODY CONDITION

The electrofishing length and weight data for fish from the Grave and Harmer populations 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 prior to 2021 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 can vary randomly by population and year.
- The residual variation in weight is log-normally distributed.

Preliminary analysis indicated little variation in β by population and year.

FECUNDITY

Fecundity, the number of eggs per spawning female, is a key parameter informing population models. Following Ma and Thompson (2021) the fecundity was calculated based on the average adult length (L) for each population in each year using the following allometric relationship from Corsi et al. (2013).

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

INDEPENDENT MODEL

For consistency with previous studies, the single and multipass electrofishing data were analysed by life stage (age-1, age-2+ and adult) using a hierarchical Bayesian removal model (Wyatt 2002). 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).

Between 2017 and 2021 three different mesohabitat sites were sampled at each index location. The 1996 data are from an inventory study (Morris, Cope, and Amos 1997) while the 2017 data in EVO Dry Creek and South Tributary were collected as a multipass removal salvage. The new sites in 2021 consisted of 300 m long open single pass sites (as does H4 in 2021). To reduce the over-representation of sites in EVO Dry Creek DR4, DR5 and DR6 were considered sites with the same location (DR4).

Key assumptions of the independent model include:

- Lineal density varies by year within population.
- Lineal density varies randomly by location.
- The number of fish at each site in each year is described by an over-dispersed Poisson distribution.
- The capture efficiency varies with the electrofishing effort (measured in electrofishing seconds/m^2).
- The catch on each pass is binomially distributed.

The abundance was calculated excluding tributary habitat except EVO Dry Creek. Preliminary analysis indicated that mesohabitat type was not an informative predictor of density or efficiency

LIFECYCLE MODEL

To account for changes in the density of life-stages from one year to the next, a hierarchical Bayesian removal stage-based lifecycle model (Schaub and Kery 2022) was fitted to all the single and multipass electrofishing data simultaneously (Figure 2). The model recognises three life stages (age-1, age-2+ and adult). 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 $t + 1$.

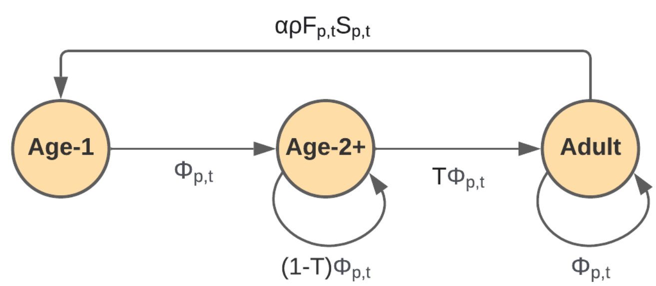

Figure 2. Life stages and parameters for the lifecycle model.

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 female spawning is 50%.
- The fecundity for each population in each year is as calculated from the estimated mean length based on the allometric relationship of Corsi et al. (2013).
- 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 (range 3-5 years old).
- There is demographic variation in the egg to age-1 and age-1 and older survival.

- The number of fish at each site in each year is described by an over-dispersed Poisson distribution.
- The over-dispersion varies by life stage.
- The capture efficiency varies by life stage.
- The capture efficiency varies randomly by population within year.
- The catch on each pass is binomially distributed.

Preliminary analysis indicated that assuming fish become adult at an average age of 5 only had a small effect on the estimates.

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.

RESULTS

SPAWNING (REDD) SURVEY

REDD FADING

The redd fading model estimated that redds are certain for approximately 18 days on average.

REDD COUNTS

Based on the redd count model, spawning was estimated to begin by late May, peak in mid-June and end in mid-July (Table 4).

Table 4. Estimated timing of spawning activity with lower and upper 95% CLs.

Event	Estimate	Lower	Upper
Start (2.5%)	16-May	04-May	25-May
Peak (50%)	15-Jun	12-Jun	20-Jun
End (97.5%)	15-Jul	03-Jul	02-Aug

The distribution of redds has been relatively consistent across the four years of monitoring with the notable exception of 2020 when no redds were recorded for the Grave population below km 5.8 in the mainstem or below the Harmer Creek Sediment Pond (Figure 3). For the Grave population, most redds have been recorded between the two culverts at 4.5 and 7.8 km and the 0.5 km of Harmer Creek below the sediment pond. The current year (2021) marked the first year that a redd was recorded above 7.8 km in Grave Creek. For the Harmer population, all redds have been recorded between the Harmer Creek Sediment Pond and the confluence with EVO Dry Creek with the exception of 2020 when three redds were recorded in EVO Dry Creek.

The estimated annual total redd counts were similar for the Grave and Harmer populations in 2018 and 2021 but lower in the Grave population in the intervening two years. The estimated total count was 17 redds (95% CI 10-27; Figure 4) in 2021 for the Grave population versus 18 redds (95% CI 10-30) for the Harmer population. The trend in the redd counts suggest an overall decline in the number of spawning females in both populations over the past four years (Figure 4). As discussed below, this is consistent with the decline in adults estimated from the electrofishing data by the lifecycle model.

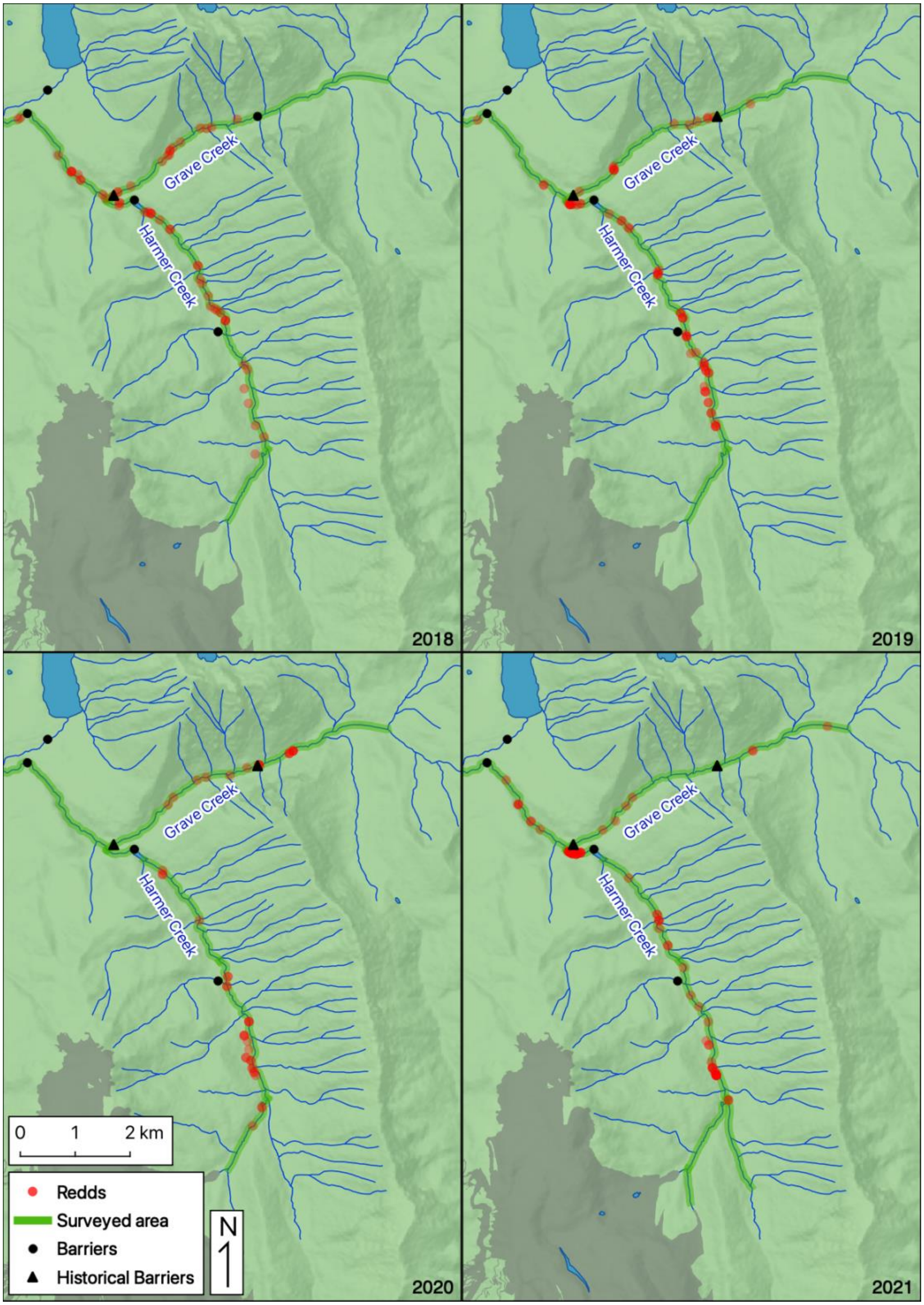

Figure 3. The spatial distribution of certain redds by year. Redds are indicated as transparent points so that more intense color indicates higher densities.

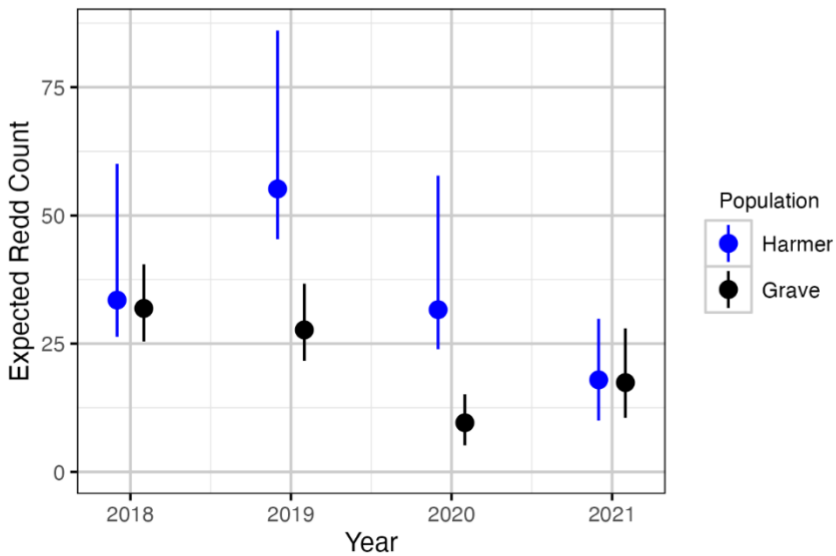

Figure 4. Estimated total expected redd count by year and population. Error bars represent 95% CIs.

ELECTROFISHING COVERAGE

In 2021, the backpack electrofishing surveys for the Grave population covered 1.7 km which corresponds to approximately 19% of the habitat used in the calculation of the population abundance. In the case of the Harmer population the surveys covered 1.6 km or approximately 17% of habitat (Table 5). These were more extensive efforts than the previous three years which only covered 6 to 7% of the habitat.

Table 5. The total site length, percent habitat coverage and number of fish caught on the first pass by population, year and lifestage.

Population	Year	Site length	Coverage	Age-0	Age-1	Age-2+	Adult
Grave	1996	1632	18%	0	0	1	4
Grave	2008	250	3%	0	3	8	1
Grave	2013	300	3%	0	0	3	2
Grave	2017	544	6%	3	20	39	19
Grave	2018	574	7%	4	20	33	13
Grave	2019	586	7%	3	15	33	12
Grave	2020	568	6%	0	4	13	6
Grave	2021	1702	19%	6	26	39	10
Harmer	1996	200	3%	0	0	1	0
Harmer	2008	450	6%	0	6	5	3
Harmer	2013	600	8%	0	0	4	2
Harmer	2017	1938	27%	4	6	41	28
Harmer	2018	454	6%	3	2	18	6
Harmer	2019	412	6%	0	0	2	7
Harmer	2020	455	6%	0	0	4	4
Harmer	2021	1249	17%	0	17	21	24

LENGTH-FREQUENCIES

As detailed in the methods, fish were categorized into lifestages based on length thresholds. Based in part on Figure 5, fish between 50 and 99 mm in the Grave population and between 45 and 94 mm in the Harmer population were considered to be age-1.

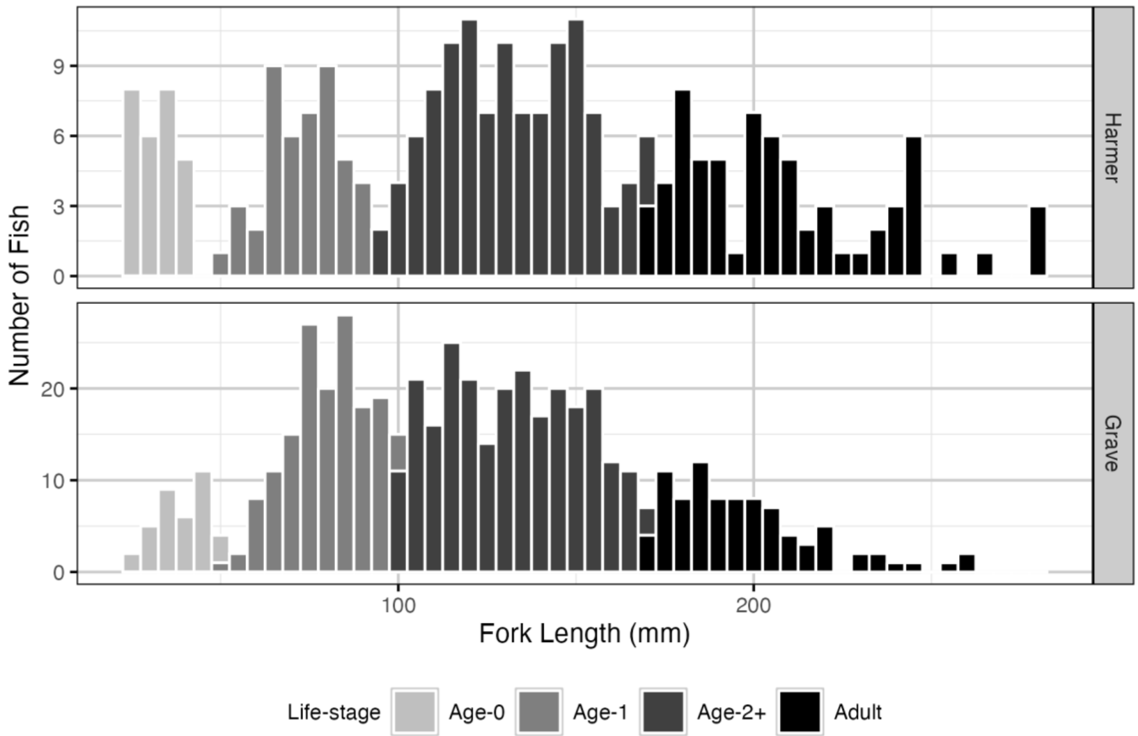

Figure 5. Fork lengths from electrofishing and bank walk fish captures and bank walk observations, by population and life stage.

LENGTH-AT-AGE

AGE-0 LENGTH-AT-AGE

The length-at –age analysis estimated that in a typical year age-0 fish are 40 mm (95% CI 36-45 mm) at the end of the growing season in the Grave population compared to 34 mm (95% CI 30-39 mm) for the Harmer population (Figure 6).

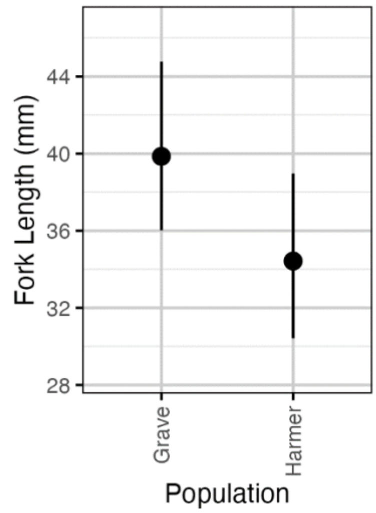

Figure 6. Estimated average fork length of age-0 fish on October 1 (end of growing season) in a typical year by population. Error bars represent 95% CIs.

Since 2017, average annual age-0 lengths have varied between 33 and 36 mm for the Harmer population and between 37 and 42 mm for the Grave population (Figure 7).

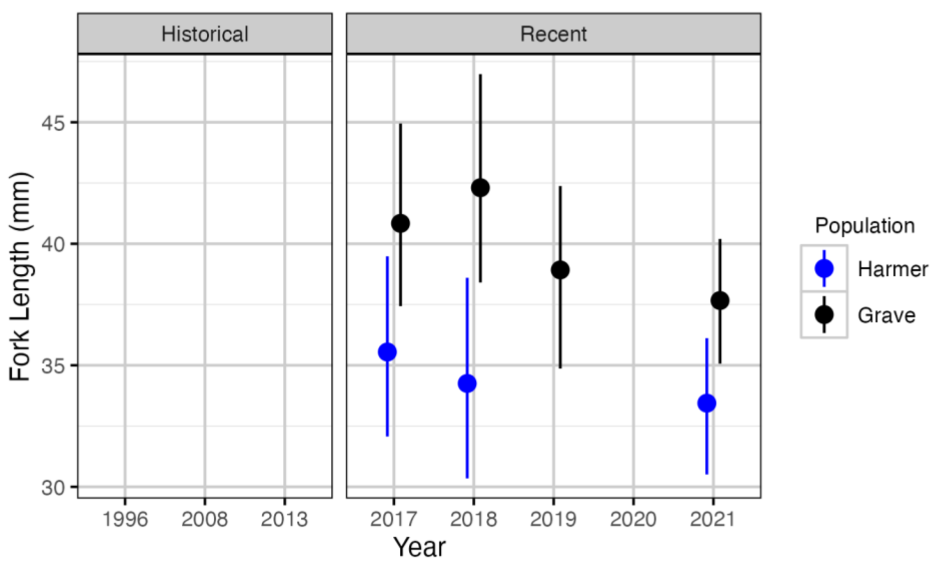

Figure 7. Estimated average fork length of age-0 fish on October 1 (end of growing season) by year and population. Error bars represent 95% CI.

ADULT LENGTH-AT-AGE

In the case of the adults, fish were on average larger in the Harmer population in a typical year at 209 mm (95% CI 194-224 mm) compared 196 mm (95% CI 183-209 mm) in the Grave population (Figure 8).

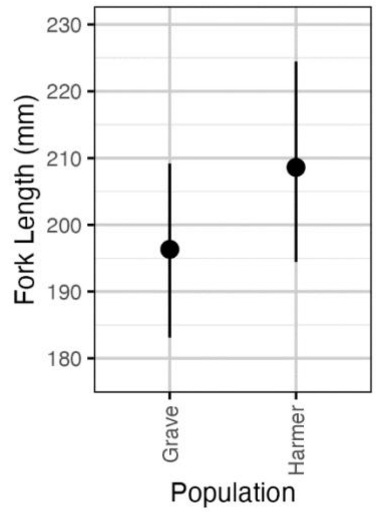

Figure 8. Estimated average fork length of adult fish on October 1 (end of growing season) in a typical year by population. Error bars represent 95% CIs.

The Harmer population adults also showed more variation in annual size (range 196 - 226 mm) than the Grave population adults (range 190 - 206 mm; Figure 9).

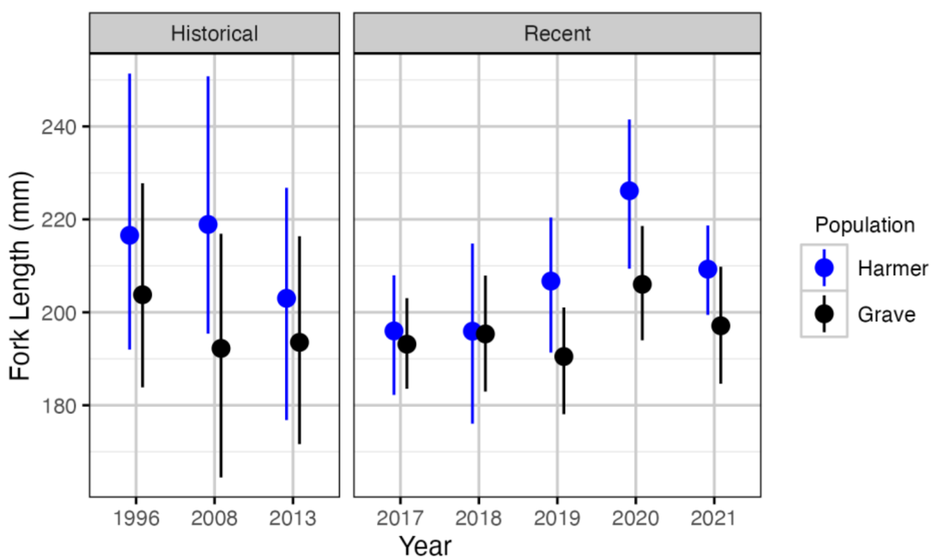

Figure 9. Estimated average fork length of adult fish on October 1 (end of growing season) by year and population. Error bars represent 95% CIs.

FISH GROWTH

Growth is important because it is a strong determinant of the number of eggs a female produces. Inter-annual recaptures of PIT tagged fish indicate large individual variation in growth (Figure 10). Analysis of the recaptures using the Fabens form of the VB growth curve suggests that a typical fish matures at age 4 (Figure 11).

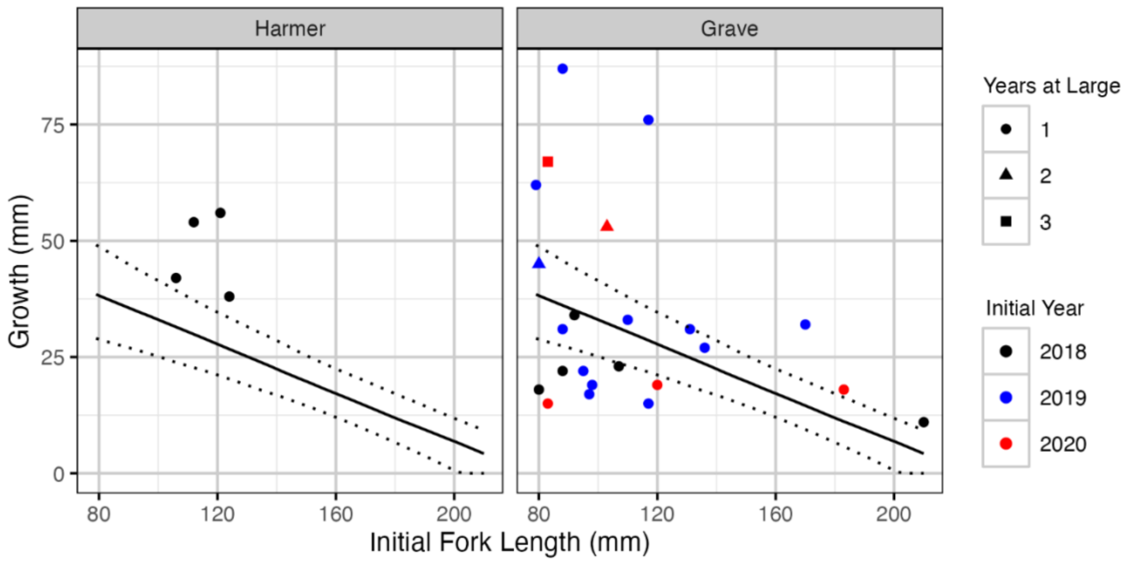

Figure 10.The estimated growth increment by fork length for one year at large by population (with 95% CIs). The points are the reported growth increments per year by years at large.

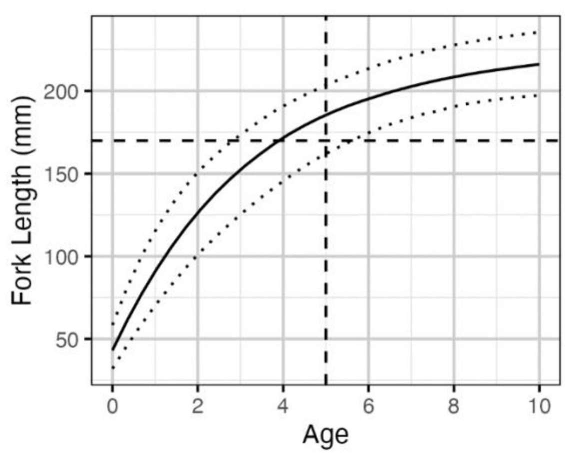

Figure 11. The estimated VB growth curve based on the growth model (with 95% CIs). The dashed horizontal line indicates the current length threshold for maturity (170 mm) while the dashed vertical line indicates the age threshold (age 5) suggested by Ma and Thompson (2021) for a typical WCT population.

BODY CONDITION

The body condition of fish in the Grave and Harmer populations are very similar through time. The body condition (weight of a 100 mm fish relative to a typical year) was lowest in 2018, at -4.0% (95% CI -7.2--1.3%) for the Grave population and -2.5% (95% CI -6.6--0.8) for the Harmer population (Figure 12). In 2021 the body condition was at a typical level for both populations at 0.4% (95% CI -2.5-3.4%) for Grave -0.9% (95% CI -4.3-1.9%) for Harmer.

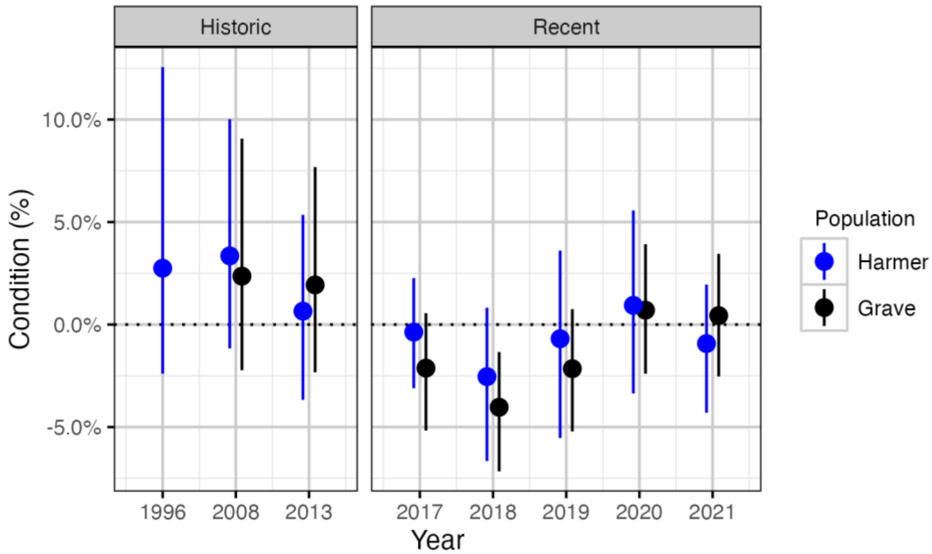

Figure 12. The percent change in the body condition (weight) for a 100 mm fish relative to a typical year (0% change) by population and year. Error bars represent 95% CIs.

FECUNDITY

The estimated annual fecundity based on the mean fork lengths varied between 171 and 207 eggs/female for the Grave population and between 185 and 280 eggs/female for the Harmer population (Figure 13).

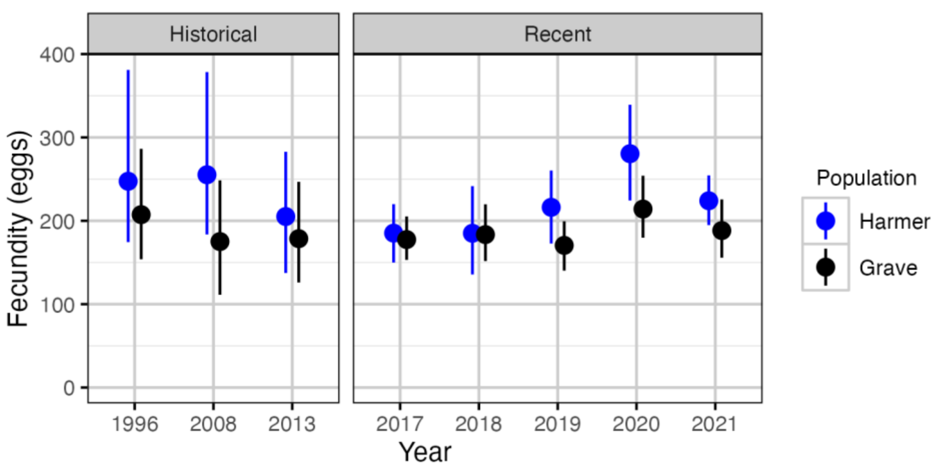

Figure 13. The calculated eggs per female by population and year. Error bars represent 95% CIs.

ELECTROFISHING CAPTURE DENSITIES

The electrofishing data indicate high annual variability in capture densities both among and within electrofishing locations (Figure 14). The high capture densities of age-1 and age-2+ fish in Harmer Creek above the sediment pond in 2021 is noteworthy as it follows two consecutive years without any age-1 captures. However, the plot must be interpreted with caution since it represents raw data and does not account for capture efficiency.

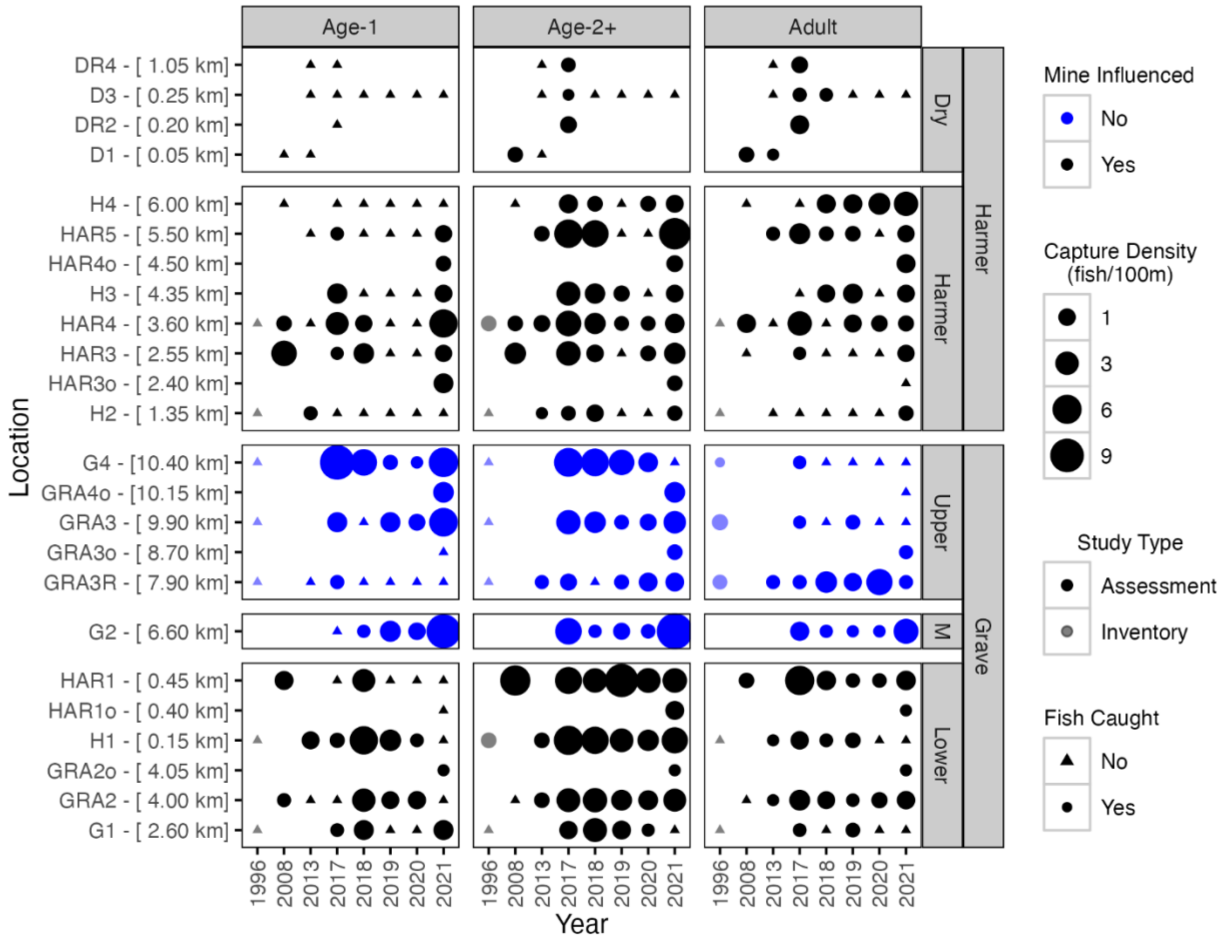

Figure 14. The electrofishing capture density averaged across passes by year, location, life stage, population, subpopulation, mine influence and study type. Locations on the y axis are listed in an upstream direction as indicated by the river km in square brackets, (refer to Figure 1). Large 300 m open sites are named with a 'o' suffix with the exception of H4 in 2021 which was sampled as a 300 m open site.

INDEPENDENT MODEL

CAPTURE EFFICIENCY

The independent model, which was applied to the electrofishing data for each life stage in isolation, estimated capture efficiencies (based on removal rates at the closed sites) under the assumption that efficiency varies by electrofishing effort. The estimated capture efficiency for age-1 WCT was just over 25% at an electrofishing effort of 3 s/m^2 before increasing to around 66% with an effort of 12 s/m^2 (Figure 15). The estimated capture efficiency for age-2+ fish was higher at around 50% at 3 s/m^2 before reaching its maximum of around 66% with an effort of 6 s/m^2. For adults, capture efficiencies exceeded 66% with an effort of 3 s/m^2 (Figure 15).

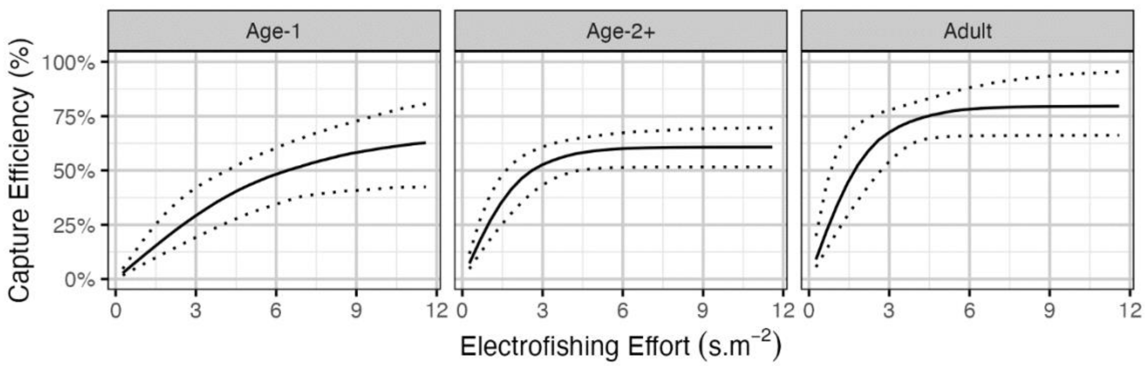

Figure 15. The estimated capture efficiency by electrofishing effort and lifestage (with 95% CIs).

ABUNDANCE

AGE-1

The estimated abundance of age-1 fish in the Grave population was consistently higher than in the Harmer population (Figure 16). The one exception was 1996 when there was estimated to be 1 (95% CI 0-209) and 7 fish (95% CI 0-1,200), respectively. Both creeks had their highest estimated age-1 abundance in 2008 at 4,000 fish (95% CI 450-51,000) and 960 fish (95% CI 150-9,200), respectively. For the Harmer population the number of age-1 fish dropped from 150 (95% CI 37-680) in 2018 to 1 in 2019 (95% CI 0-51) and 2 (95% CI 0-84) in 2020 before increasing to 620 age-1 fish (95% CI 200-2,500) in 2021. The estimated abundance of age-1 fish in the Grave population was consistent over time and in 2021 was 1,300 fish (95% CI 460-4,900).

AGE-2+

The estimated abundance of age-2+ fish in the Grave population was also very low in 1996, at 13 fish (95% CI 1-150; Figure 16). More recently, the estimated abundance has exhibited a moderate decline from 1,200 fish (95% CI 710-2,200) in 2017 to 710 fish (95% CI 410-1,400) in 2021. The abundance of age-2+ fish in the Harmer population was relatively low in 1996 at 150 fish (95% CI 8-1000). There was a steep decline from 410 fish (95% CI 210-810) in 2018 to 55 fish (95% CI 12-170) in 2019, followed by an increase to 120 fish (95% CI 39-300) in 2020 and 390 fish (95% CI 200-740) in 2021. For the Harmer population, the large increase in the estimated number of age-2+ fish in 2021 is inconsistent with the very low estimated abundance of age-1 fish in 2020.

ADULT

Unlike the other life stages, the estimated adult abundance in the Grave population was relatively high in 1996 at 200 fish (95% CI 35-1,100). In contrast, the Harmer population adult abundance was very low in 1996, at 6 fish (95% CI 0-590). For the Grave population the estimated abundance was highest in 2017 at 515 fish (95% CI 210- 1,500). Since then, the estimated abundance has declined steadily to 160 fish (95% CI 60-490) in 2021 (Figure 16). The estimated abundance of adult fish in the Harmer population was highest in 2017 at 390 fish (95% CI 180-1,100) and at similar levels in 2021 at 330 fish (95% CI 130-1,000).

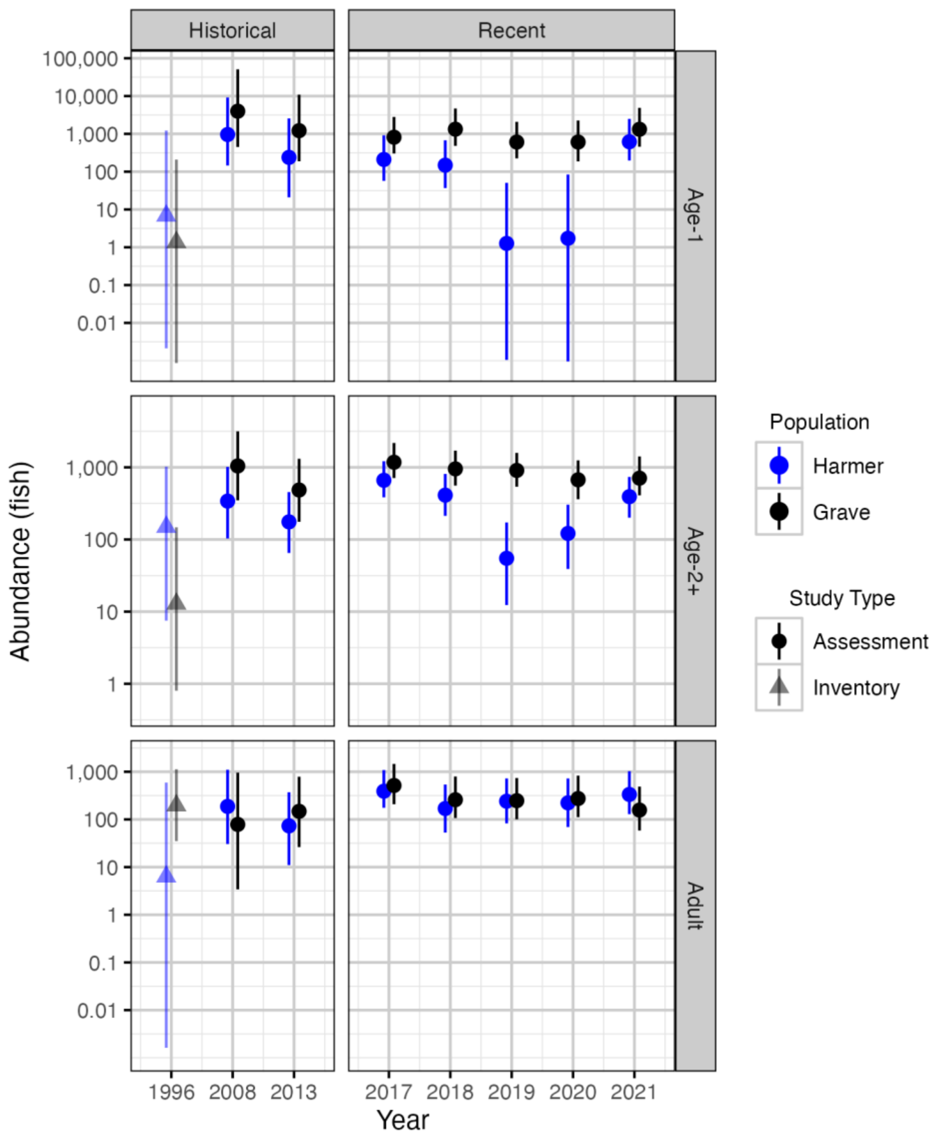

Figure 16. The estimated age-1, age-2+ and adult abundance (on a log scale) by year and population. Error bars represent 95% CIs.

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 2).

CAPTURE EFFICIENCY

The lifecycle model estimated that the capture efficiency increased by life stage from 27% (95% CI 10-47%) for age-1 fish through 50% (95% CI 33-63%) for age-2+ fish to 72% (95% CI 57-83%; Figure 17) for adults.

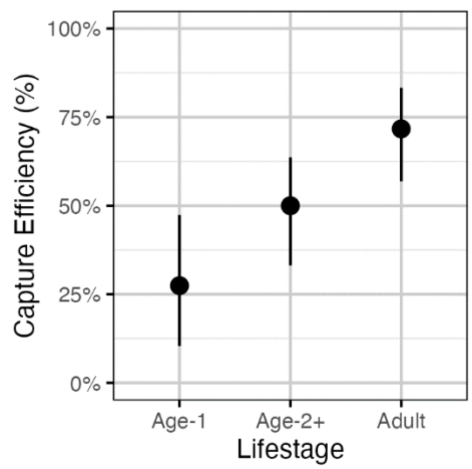

Figure 17. The estimated electrofishing capture efficiency by life stage (with 95% CIs) in a typical year. Error bars represent 95% CIs.

The lifecycle model also estimated that the capture efficiency was exceptionally low for the Harmer population in 2019 relative to the Grave population at 19% (95% CI 4-51%; Figure 18) versus 42% (95% CI 18-61%) and low in both creeks in 2020.

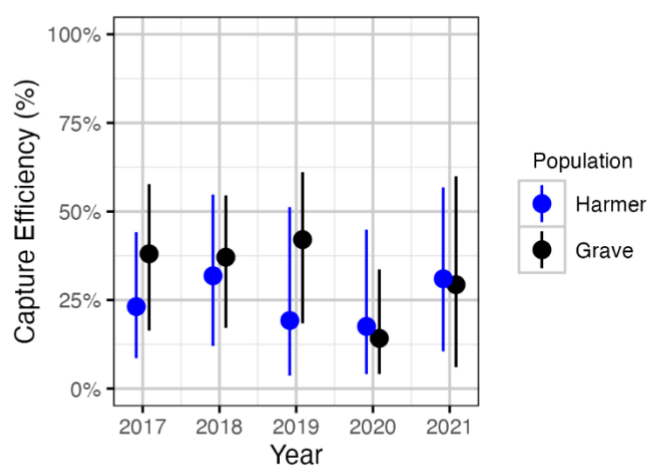

Figure 18. The estimated age-1 electrofishing capture efficiency by year and population. Error bars represent 95% CIs.

ABUNDANCE

The lifecycle model estimated that all life stages (age-1, age-2+, adult and eggs) were higher in the Grave population than in the Harmer population in each year (Figure 19).

AGE-1

The estimated abundance of age-1 fish was relatively stable for the Grave population in all years at around 1,000 individuals. In contrast, the abundance of age-1 fish for the Harmer population fell to a low of just 19 fish (95% CI 0-320) in 2019 before increasing to 640 fish (95% CI 210-2,200) in 2021.

AGE-2+

The estimated abundance of age-2+ fish in the Grave population declined steadily from 790 fish (95% CI 480-1,400) in 2017 to 470 fish (95% CI 240-1,300) in 2021. The Harmer population showed a rapid decline from 470 fish (95% CI 280 – 850) in 2017 to a low of 76 fish (95% CI 36-270) in 2020 followed by a substantial recovery in 2021 to 200 fish (95% CI 99-460).

ADULT

Estimated adult abundances for the two populations also declined steadily from 520 fish (95% CI 270-1000) in 2017 to 260 fish (95% CI 95-610) in 2021 for the Grave population, and from 280 fish (95% CI 140-550) in 2017 to 170 fish (95% CI 77-360) in 2021 for the Harmer population (Figure 19). The mean annual decline was 16% (95% CI 0-32) for the Grave adult population and 12% (95% CI 0-27) for the Harmer adult population.

EGGS

The estimated egg abundances (Figure 19) 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 (Figure 2). For the Grave population, the estimated deposition declined from 23,000 eggs (95% CI 12,000-46,000) in 2017 to 12,000 eggs (95% CI 4,500-29,000) in 2021, while the Harmer population also declined, from 13,000 eggs (95% CI 6,600-25,000) in 2017 to 9,500 eggs (95% CI 4,300-20,000) in 2021 (Figure 19).

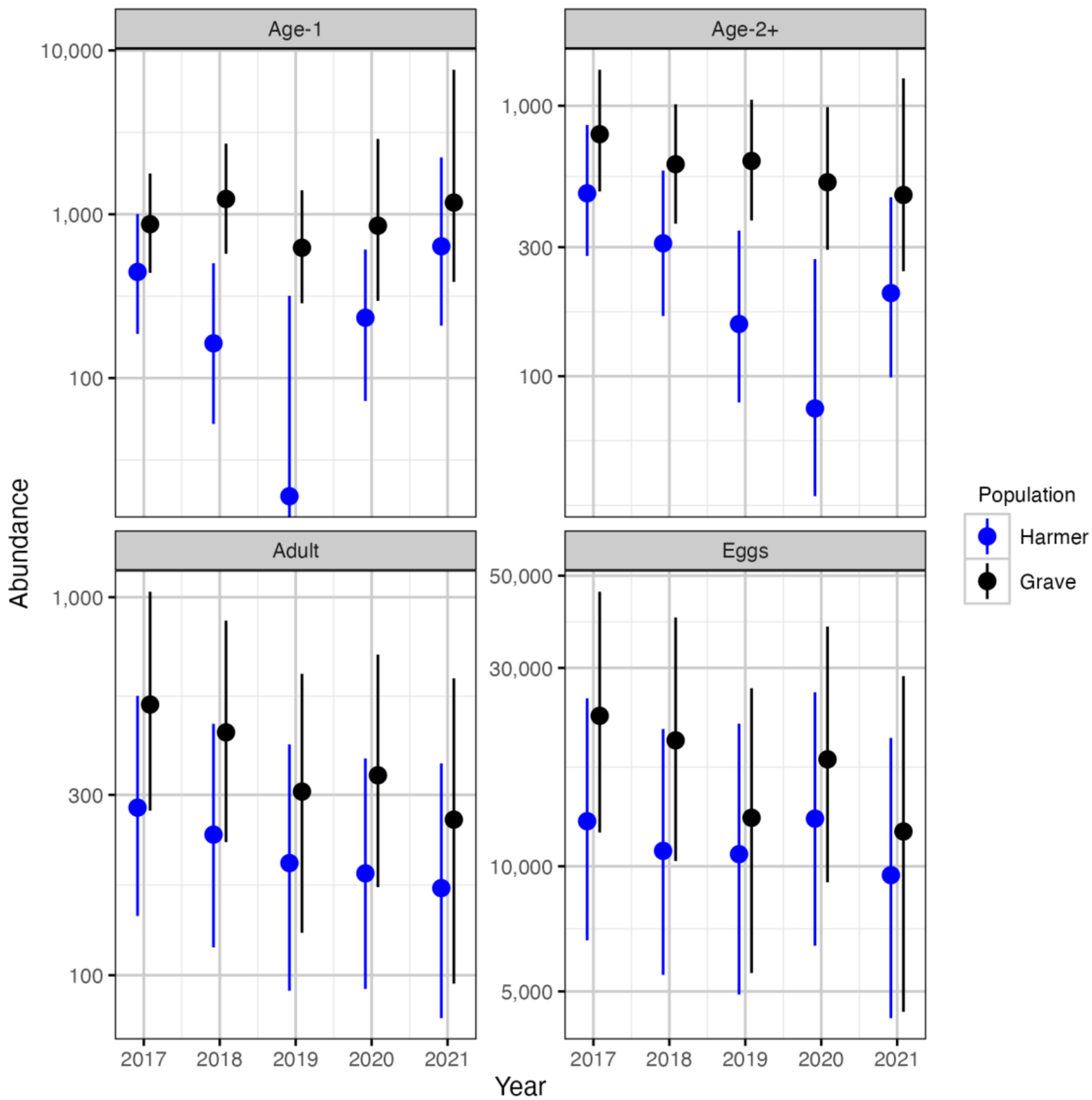

Figure 19. The estimated population abundance (on a log scale) by year, life stage and population. Error bars represent 95% CIs.

SPATIAL DISTRIBUTION

The estimated lineal densities of age-1 fish averaged across all years are relatively high at the top of Grave Creek, between the culverts on Grave Creek and below the Harmer Creek Sediment Pond. For the Harmer population age-1 densities are highest in the middle of Harmer Creek and subsequently decline upstream and downstream (Figure 20). Overall, the estimated densities of age-2+ fish show a roughly similar pattern to those for age-1 fish (Figure 21). For the adults the highest estimated densities are in proximity to the culverts in Grave Creek, below the Harmer Creek Sediment Pond and towards the upper end of Harmer Creek and into EVO Dry Creek (Figure 22).

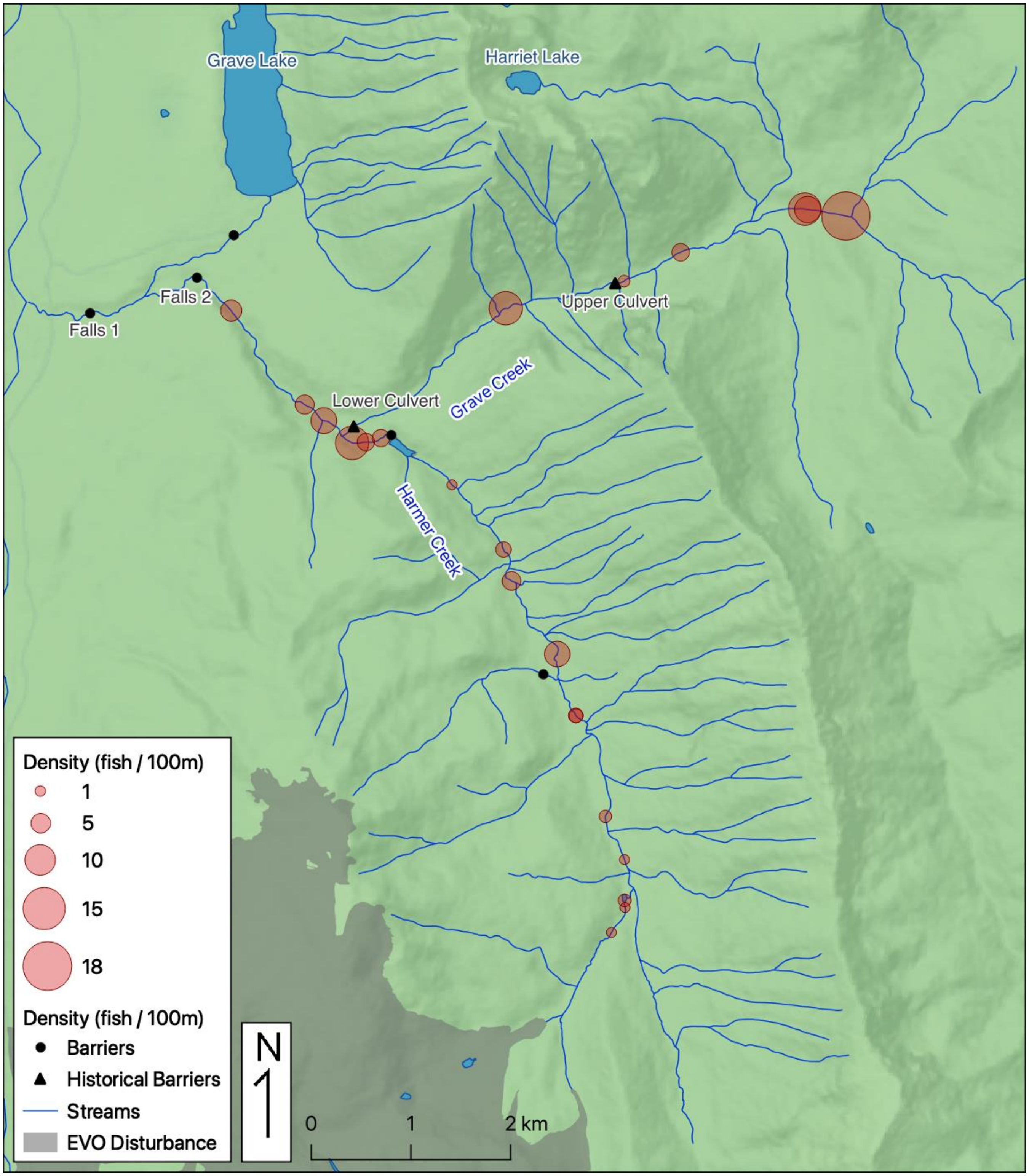

Figure 20. The estimated age-1 lineal density averaged across all years by location.

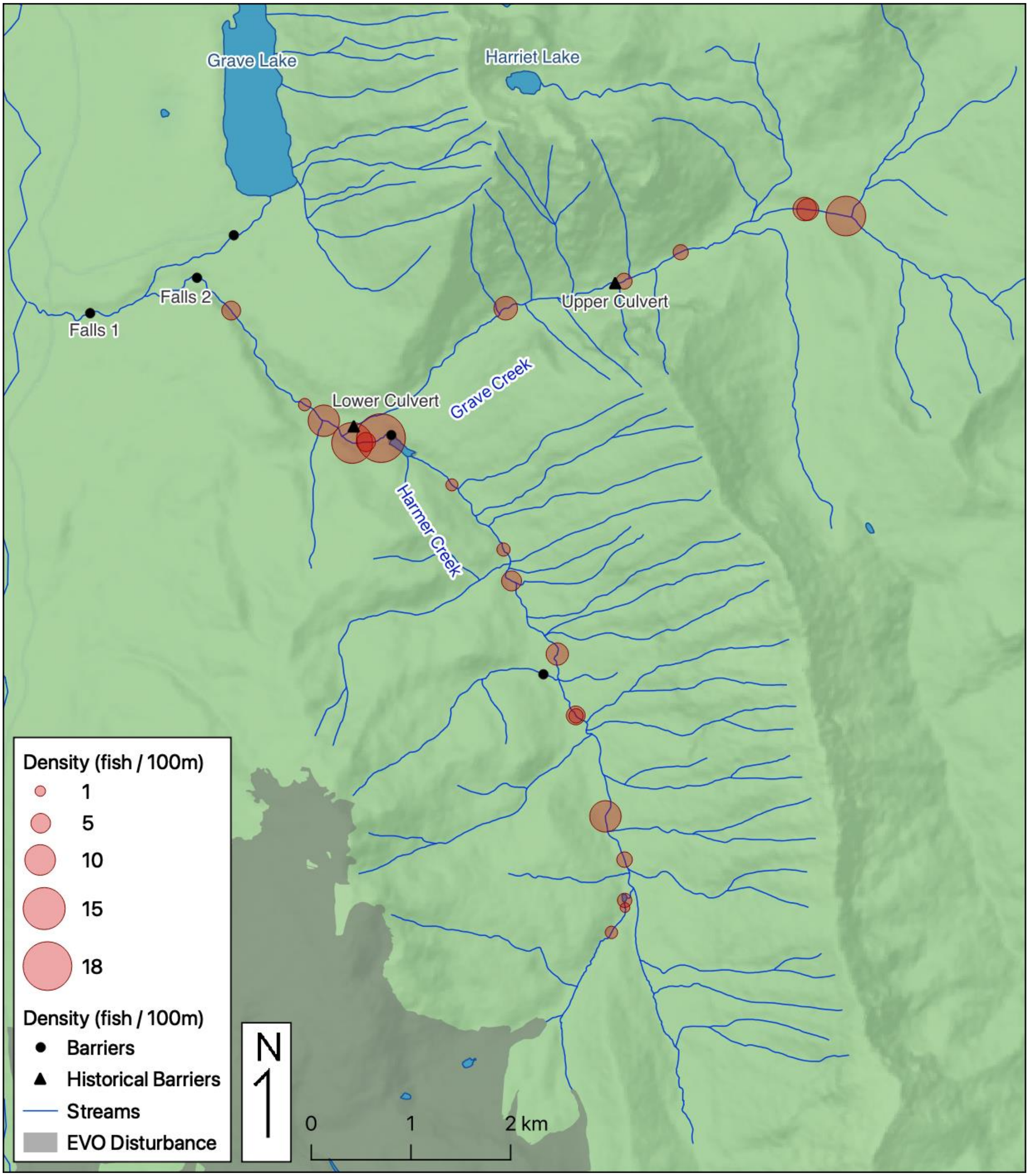

Figure 21.The estimated age-2+ lineal density averaged across all years by location.

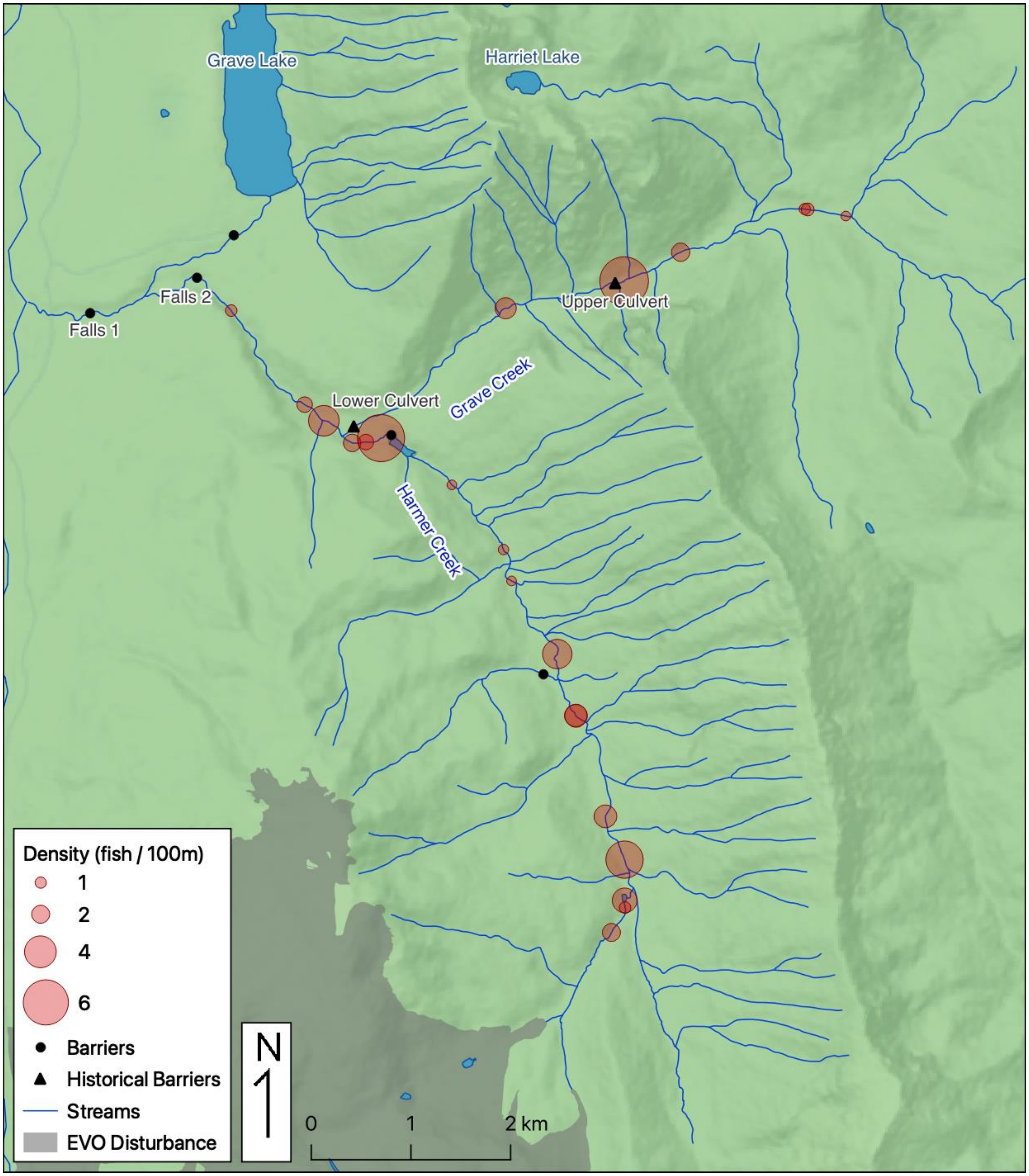

Figure 22. The estimated adult lineal density averaged across all years by location.

REDDS PER FEMALE SPAWNER

The estimated redds from the redd count model were compared to the estimated number of female spawners from the lifecycle model. The results indicate that the redds per female spawner were substantially below 1 for the Grave population in all years with a range of 0.1 to 0.4 and below 1 for the Harmer population in all years except 2019 (Figure 23).

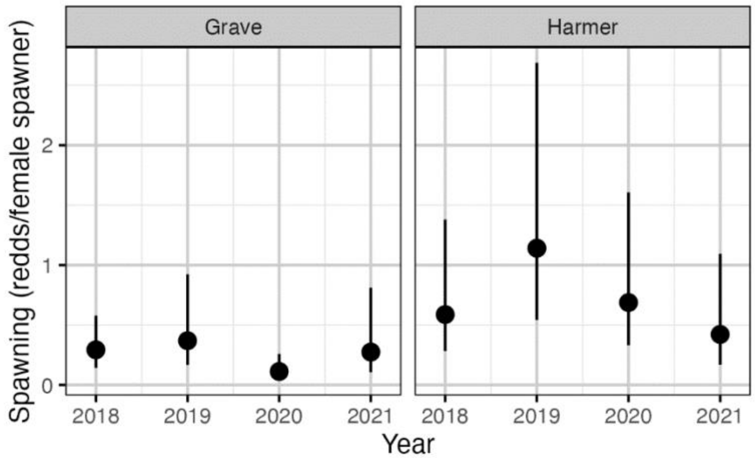

Figure 23. The estimated redds per female spawner based on the redd count and lifecycle models. Error bars represent 95% CIs.

ANNUAL SURVIVAL

The annual survival of age-1 and older fish in a typical year was estimated to be 57% (95% CI 41-80%). The annual survival in both populations was estimated to be ~ 50% from 2017 to 2018 and from 2018 to 2019 (Figure 24). However, while the annual survival in the Grave population remained ~ 50% the annual survival in the Harmer population increased to 75% (95% CI 47-98%) from 2020 to 2021.

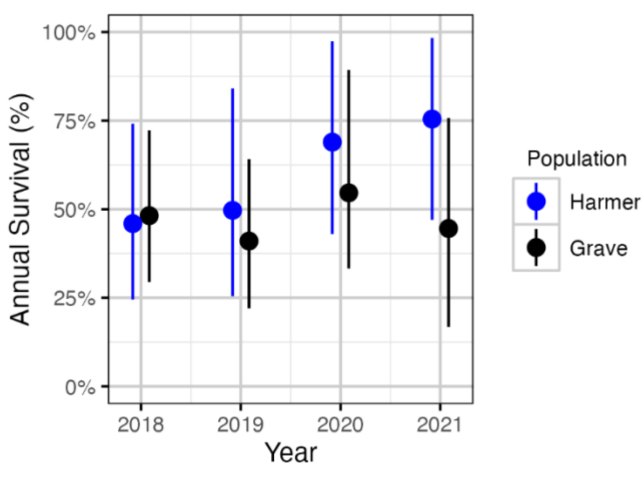

Figure 24. The estimated annual age-1 and older survival from year-1 to year by year by population. Error bars represent 95% CIs.

EGG TO AGE-1 SURVIVAL

The estimated egg to age-1 survival rates are plotted in Figure 25. Although, total egg deposition is lower for the Harmer population than the Grave population the egg densities are similar for both populations because almost all Harmer population fish spawn within the mainstem below EVO Dry Creek and not in the 1.8 km of EVO Dry Creek. Neither population demonstrates a clear density dependent relationship although this is not unexpected given the relatively narrow range of egg densities (Figure 25).

A literature review suggested that in a typical population an egg to age-1 survival of 5% is required for population replacement (Ma and Thompson 2021) while the lifecycle model estimated the value to be 4% (95% CI 1-10%).

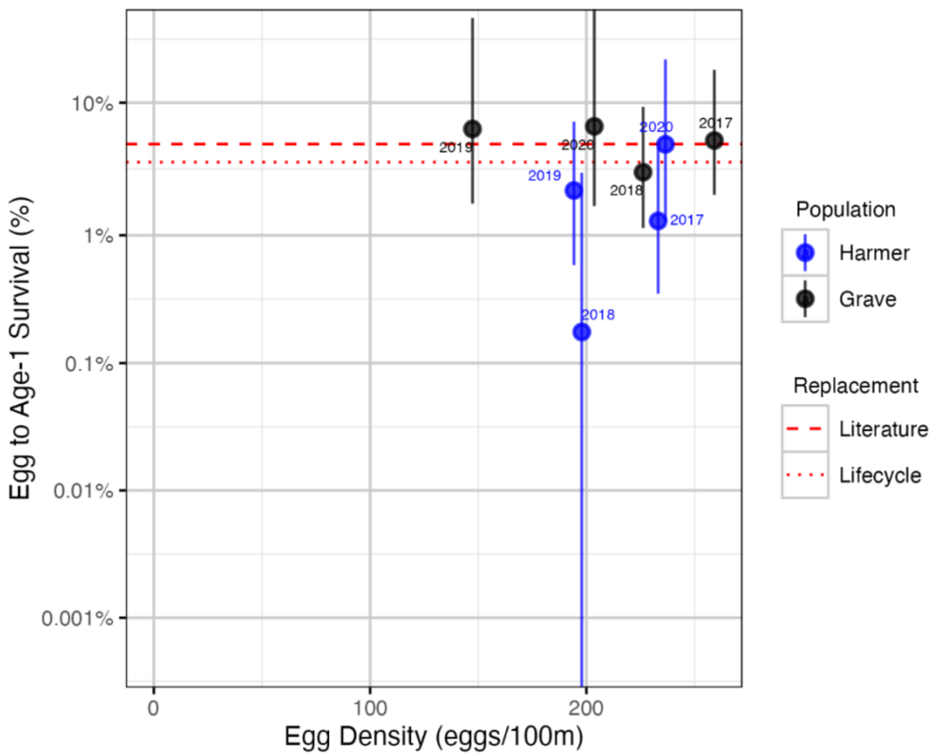

Figure 25. The egg to age-1 survival (on a logistic scale) by egg density, spawn year and population. The red lines indicates the egg-to-fry survival required for replacement based on the literature (Ma and Thompson 2021) and the lifecycle model. Error bars represent 95% CIs.

To better understand the uncertainty regarding population replacement, the egg to age-1 survival rates were divided by the lifecycle model-based replacement rate to give the percent replacement where 100% indicates that the egg to age-1 survival is sufficient for population replacement under typical conditions. The resultant replacement rates were then plotted as probability densities where the width of the density indicates the probability of each replacement rate (Figure 26). The results indicate that the Grave population was likely above 100% replacement every year except the 2018 spawn year while the Harmer population productivity was likely below 100% replacement every year except the 2020 spawn year, and likely below 10% replacement in the 2018 spawn year.

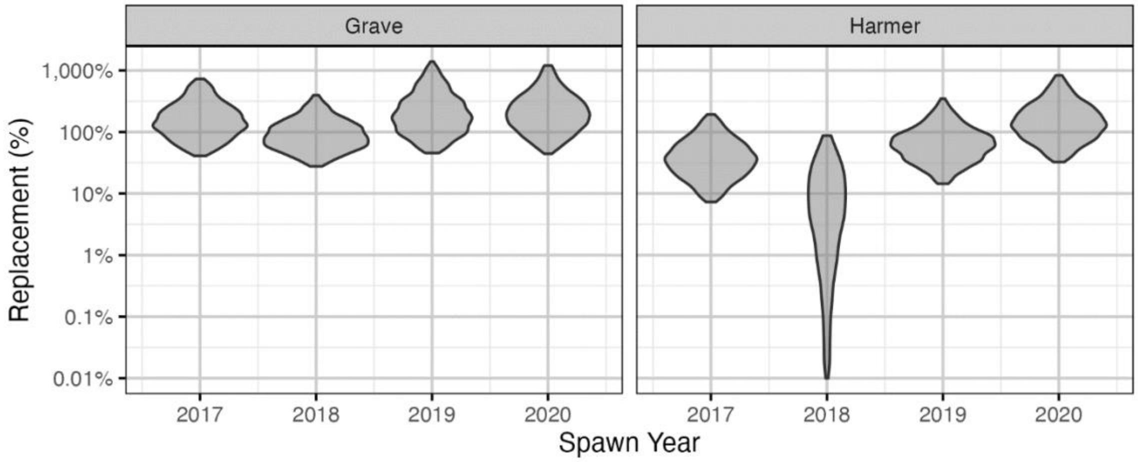

Figure 26. The population replacement rate by spawn year and population as a probability density. Only the values in the 95% CI are plotted.

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The analytic appendix which includes model templates, parameter descriptions and parameter coefficient tables is available from [*https://poissonconsulting.ca/f/839299341*](https://poissonconsulting.ca/f/839299341).

DISCUSSION

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

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

The geographic range of the Grave population extends from the natural falls on Grave Creek at river km 2.1 upstream to at least river km 10.5. It also includes the lower 0.5 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.

The Harmer population range extends from the Harmer Creek Sediment Pond Dam to approximately river km 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 fish bearing.

WHAT ARE THE LIFE-HISTORY STRATEGIES WITHIN THE FISH POPULATION(S)?

All the fish in the Grave and Harmer 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 river km 1 and 2.1 and because fish densities in the Harmer Sediment Pond appear to be negligible.

WHAT IS THE TIMING OF KEY LIFE-HISTORY EVENTS?

In a typical year, spawning commences by May 25, peaks around June 15 and continues to about July 15. 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 (2007) 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 EoC (in prep) 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.

WHAT ARE THE SIZES OF KEY LIFE-STAGES?

Analysis of fry lengths suggests that age-0 fish from the Harmer population are typically ~34 mm by the onset of winter compared to ~40 mm for the Grave 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 2020). Studies on Colorado Cutthroat Trout suggest that fry below a threshold of 30-35 mm may lack sufficient energy reserves to survive the winter with consequences for subsequent recruitment (Sogard 1997; Coleman and Fausch 2007a, 2007b). Based on visual examination of fish length frequency plots, individuals between 50 and 99 mm in the Grave population and between 45 and 94 mm in the Harmer population are considered to be age-1. The adult length threshold was increased from 150 to 170 mm in the fall as females, which determine the egg deposition, tend to mature at a greater length than males (Downs 1995) and because fish are able to grow approximately 20 mm between spawning and the fall electrofishing surveys.

WHAT IS THE GROWTH RATE OF KEY LIFE STAGES?

The available evidence suggests that due to warmer water temperatures, WCT in the Grave population emerge earlier and attain bigger size by the onset of winter than WCT in the Harmer 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. As discussed below increased PIT tagging of individuals to collect information on inter-annual growth is recommended.

WHAT IS THE SPATIAL DISTRIBUTION OF KEY LIFE-STAGES?

Over the past four years, redds have been recorded throughout the mainstems of Grave and Harmer Creek, where suitable spawning habitat exists. However, over the same period, despite similar effort, only three redds have been recorded in EVO Dry Creek, which is heavily calcified due to the influence of the rock spoils. Age-1 fish have been recorded at all electrofishing index locations except EVO Dry Creek and Harmer Creek just below the confluence with EVO Dry Creek. In contrast Age-2+ WCT have been recorded at all locations while adults have been recorded at all index locations.

Analysis of the electrofishing capture data suggests that age-1 densities are highest (> 10 fish/100 m) in the upper part of Grave Creek and highest in Harmer Creek in the middle part of the river. 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+ densities follow a similar general pattern but are highest (~10 fish/100 m) in Harmer Creek below the Harmer Creek Sediment Pond (these are part of the Grave population) and as much as 3 fish/100 m in EVO Dry Creek. Adult densities for the Grave population are highest in Grave Creek from km 4.0 to 8.7 and in Harmer Creek below the Harmer Creek Sediment Pond. Adult densities for the Harmer population are highest (~3 fish/100 m) in Harmer Creek from km 3.6 to 6.0 and in EVO Dry Creek up to and including the EVO Dry Creek Sediment Pond.

WHAT IS THE ABUNDANCE OF KEY LIFE-STAGES?

Although the abundances were estimated using two different models only the results from the lifecycle model which incorporated survival rates and transition probabilities are discussed below. This is because the alternative independent model estimated just 2 age-1 individuals in the Harmer population in 2020 which is inconsistent with the same model's estimate of an increase in the number of age-2+ individuals by 270 individuals the following year. There are several possible complementary explanations for the discrepancy in the independent estimates. The first is that the capture efficiency of Harmer population fish was low in 2020 and/or high in 2021. However, the results of the lifecycle model which allows the capture efficiency to vary by year for each population suggest that the capture efficiency of Harmer population fish was low in both 2020 and 2021. A second possibility is that the capture efficiency for age-1 fish declines substantially at lower density (Korman et al. 2009) – a possibility that is hard to test using removal depletion at small sites. A third possibility is that at lower density fish congregate at the most suitable sites (Greenberg 1994; Ayllón et al. 2013) increasing the noise in the data. Increasing the coverage using mark-recapture at large open sites should allow the relative contributions of the last two possibilities to be quantified and accounted for. A fourth possibility is that increased growth in 2021 caused many age-1 fish to exceed the age-1 to age-2+ length threshold of 94 mm. To evaluate this possibility, it is recommended that all fish be scaled.

The age-1 abundance estimates for the Grave population have remained relatively stable at around 1,000 fish since 2017. In contrast, the age-1 abundance estimates fell from 440 in 2017 to just 19 fish in 2019 before increasing to 640 age-1 individuals in 2021.

Despite the stability in the age-1 abundance estimates for the Grave population, the number of age-2+ individuals steadily declined from approximately 790 fish in 2017 to 470 fish in 2021. This decline is accounted for by the below average annual survival in the Grave population (see the section on survival below). The number of age-2+ fish in the Harmer population declined from approximately 480 fish in 2017 to just 76 individuals before increasing to 200 age-2+ fish in 2021.

The estimated adult numbers steadily declined in both populations from approximately 520 adults in 2017 to around 260 adults in 2021 for the Grave population and from approximately 280 adults in 2017 to around 170 adults in 2021. Overall, the Grave and Harmer adult populations have declined by 16% and 12% per year since 2017, respectively. As discussed in the survival section below the declines in the adult population appear to be driven by below average annual survival in the Grave population and reduced recruitment in the Harmer population.

WHAT IS THE TOTAL NUMBER OF EGGS DEPOSITED?

Based on the adult abundance estimates from the lifecycle model and the assumptions of a 1:1 sex ratio, a 50% probability of spawning each year and the population and year specific fecundities based on the length of adults, the total egg deposition for the Grave population was estimated to drop from about 23,000 eggs in 2017 to about 12,000 eggs in 2021. The same calculation for the Harmer population produced a drop from about 13,000 eggs in 2017 to 9,500 eggs in 2021.

The estimated redds per female spawner were substantially below 1 for the Grave population in all years and below 1 for the Harmer population in all years except 2019. One possible explanation is that the lifecycle based adult abundance estimates are too high. A second possibility is that the probability of spawning is less than 50%, e.g., if females don't spawn every second year. The third possibility is that redd observer efficiency is relatively low. A contributing factor may be that fish are spawning on top of existing redds (superimposition). Another possibility is that substantial spawning may be occurring prior to the surveys in some years particularly for the Grave Creek population. As discussed below spawner surveys in late May are recommended if viewing conditions allow.

WHAT IS THE SURVIVAL OF KEY LIFE-STAGES?

The lifecycle model estimated that the average annual survival of age-1 and older WCT was ~57%. The annual survival in the Grave population has remained below average at about 50% since 2017 and was around 50% in the Harmer population until it increased to approximately 75% over the past two years.

The lifecycle model estimated egg to age-1 survival rates for the Grave population of around 3 to 7% which are close to the literature-based rate of 5% and within the lifecycle model-based rate of 4% required for population replacement. However, for the Harmer population the estimated egg to age-1 survival rates for the 2017, 2018 and 2019 spawn years were just 1%, 0.1% and 2.2%, respectively. The egg to age-1 survival rate for the Harmer population was 5% for the 2020 spawn year.

It is likely (> 50% probability) that egg to age-1 survival was below that required for replacement (based on the lifecycle model) in the Grave population for the 2018 spawn year and the Harmer population for the 2017 to 2019 spawn years and substantially below that required for replacement in the Harmer population for the 2018 spawn year.

CONCLUSIONS

Thorley et al (2021a) concluded that:

If, as is suggested by the age-1 abundance estimates, recruitment is negligible then this [Harmer] population faces the potential for functional extirpation within the lifespan of an adult WCT, approximately 6-8 years (Behnke 1992; Downs 1995; Janowicz et al. 2018).

In the context of their report, they were using *negligible recruitment* to refer to a replacement rate of < 1%. The updated analyses with an additional year of data indicate that the 2018 spawn year in the Harmer population is the only year when recruitment could have been negligible (with a probability of 27%). Consequently, there are currently no short-term concerns regarding the viability of the Harmer population.

Cope and Cope (2020) raised the concern that the 2018 spawn year may have constituted a recruitment failure. To evaluate this possibility, we here define a *recruitment failure* to be a replacement rate <10% as a review of the literature failed to identify a precise definition. Under these terms it is likely that the 2018 spawn year was a recruitment failure (with a probability of 64%). The results also indicate that recruitment was likely *reduced* (below that required for replacement) in the Harmer population for the 2017 to 2019 spawn years and in the Grave population for the 2018 spawn year. For context, it is worth noting that fish populations are expected to have reduced recruitment at least 50% of the time. For the most recent (2020) spawn year, recruitment was likely above replacement in both populations. The estimated 16% per year decline in the number of Grave population adults appears to have been driven by below average annual survival while the similar 12% year on year decline in the Harmer population adults appears to have been primarily driven by below average recruitment. The ongoing Evaluation of Cause is expected to provide important additional information on the key drivers of the recruitment dynamics of both populations.

RECOMMENDATIONS

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

- increase the coverage of both populations to around 30% using mark recapture at large open sites to account for the variability in densities at individual sites (Korman et al. 2016),
- reinstitute PIT tagging to provide valuable information on capture efficiency, abundance, growth and movement.
- sample scales from all fish < 170 mm to allow age-based separation of age-1 to age-2+ fish.
- commence redd surveys in late May if viewing conditions allow.

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