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Technical Report Overview

Report: Grave Creek and Harmer Creek Westslope Cutthroat Trout Population Monitoring 2020

Overview: This report presents the 2020 population monitoring results for spawning activity, juvenile and adult abundance, and recruitment of isolated populations of Westslope Cutthroat Trout in the Grave and Harmer Creeks using data from current and previous sampling programs to look at trends and precision of estimates.

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

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GRAVE CREEK AND HARMER CREEK WESTSLOPE CUTTHROAT TROUT POPULATION MONITORING 2020

FINAL REPORT

July 12, 2021

Prepared for: Teck Coal Ltd., Sparwood, BC

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EXECUTIVE SUMMARY

Harmer Creek is a mine-influenced watershed that is a tributary to Grave Creek. Teck Coal Limited's Elkview Operations mine property includes a portion of the Harmer Creek subwatershed. These operations influence Harmer Creek (through its tributary Dry Creek) and Grave Creek below the confluence with Harmer Creek. The Grave Creek watershed above the confluence with Harmer Creek is not mine influenced. Both creeks contain isolated populations of genetically pure Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) that, prior to the construction of the Harmer Creek Sediment dam in 1971, constituted a single, naturally isolated population. Electrofishing data from Grave Creek and Harmer Creek collected between 1996 and 2020 were analyzed using a hierarchical Bayesian framework to estimate fish population abundance and recruitment.

The earliest survey of both creek systems in 1996 found very few age-1 fish. The number of age-1 fish had increased by the next sampling event in 2008. For Grave Creek, recent (2017-2020) age-1 abundances (range: 1300-590) have been somewhat less than the 2008 estimate of 3,400 fish (95% CI 330-53,000), with 600 age-1 fish (95% CI 170-2,900) in 2020. For Harmer Creek, the estimated abundance of age-1 fish declined every year following a 2008 peak of 710 fish (95% CI 120-4,800) and dropped dramatically to 1 fish (95% CI 1-62) in 2019 and 2 fish (95% CI 0-75) in 2020.

Age 2+ fish have followed a similar pattern. Abundances in Grave Creek recovered from a low in 1996 to a high of 1,600 fish (95% CI 360-7,400) in 2008. Recent (2017-2020) abundances have varied between 1,300 and 800 fish, with 800 fish (95% CI 320-2,700) calculated for 2020. In Harmer Creek, age-2+ fish recovered from a low in 1996 to 720 fish (95% CI 230-2,500) in 2008, and have declined since 2017's total of 790 (95% CI 380-2,200), dropping sharply to 22 fish (95% CI 1-150) in 2019 before increasing to 160 fish (95% CI 44-570) in 2020.

Adult fish have seen much less dramatic fluctuations. Grave Creek varied between 190 and 280 adults historically (1996-2013) while recent (2017-2020) estimates have been substantially higher, ranging from 460 to 1,100 fish, with 550 fish (95% CI 220-1,700) in 2020. Harmer Creek varied between 190 and 540 adults historically, with similar recent abundances (range: 280-530) and 280 fish (95% CI 100-900) in 2020.

While condition and fecundity estimates have improved for Grave Creek in 2020, egg to age-1 survival rates have remained steady at 3% (95% CI 0.8-19.0) just below the estimated population-specific replacement level of 10% egg to age-1 survival. In Harmer Creek, however, egg to age-1 survival rates have declined in every year monitored since 2007 and were just 0.01% (95% CI 0-0.5) for the 2018 and 2019 spawn years. The productivity in Grave Creek was 0.3 spawners per spawner (95% CI 0.06-2.2) for the 2019 spawn year compared to just 0.001 (95% CI 0-0.05) for the 2018 and 2019 spawn years in the Harmer Creek population.

While historical inventory data indicate the capacity of these fish populations to recover from periods of poor recruitment, recent survival rates and productivity that remain consistently below replacement levels, especially at low egg densities, are cause for concern for the Harmer Creek population. Age-1 electrofishing data for the past two years suggest negligible levels of recruitment. If this is the case and conditions continue then the population faces the possibility of functional extirpation within the lifespan of an adult Westslope Cutthroat Trout, approximately 6-8 years.

ACKNOWLEDGEMENTS

The organizations and individuals whose contributions have made this analysis report possible include Bronwen Lewis, Carlie Meyer, Lindsay Watson, Warn Franklin, Dan Vasiga, Christine Deynaka and Carla Fraser of Teck Coal Limited; Josh Korman of Ecometric Research; Maggie Branton of Branton Environmental Consulting; Beth Power, Sarah Gutzmann and Ryan Hill of Azimuth Consulting Group Inc.; Matt Neufeld, Josef MacLeod and Herb Tepper of BC Ministry of Forests, Lands and Natural Resource Operations; Ron Ptolemy of the BC Ministry of Environment; Jim Clarricoates, Heather McMahon, Kamila Baranowska of Ktunaxa Nation Council; Brian Ma of ESSA Technologies Ltd.; Todd Hatfield of Ecofish Research Ltd.; Nate Medinski and Isabelle Larocque of Lotic Environmental Ltd.; Nadine Hussein and Evan Amies-Galonski of Poisson Consulting Ltd.; and Scott Cope and Angela Cope of Westslope Fisheries Ltd among others.

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INTRODUCTION

Harmer Creek is a tributary of Grave Creek, which flows into the Elk River in SE British Columbia. Teck Coal Ltd. (Teck) owns Elkview Operations (EVO), a coal mine within the Harmer Creek watershed, and waste rock deposits from these operations occur in the headwaters. In contrast, there is no mining influence in Grave Creek upstream of the confluence with Harmer Creek. There has been small amounts of forestry in the watersheds of both creeks. Harmer Creek and Grave Creek support isolated populations of genetically pure (Cope and Cope 2018) Westslope Cutthroat trout (WCT; *Oncorhynchus clarkii lewisi*). While naturally isolated from the Elk River system by a natural bedrock fall barrier in Grave Creek Reach 1, the WCT populations in Grave Creek and Harmer Creek were further isolated from each other by the construction of the Harmer Sediment Pond Dam in 1971. The current monitoring program for the WCT populations in these two watersheds was established by Teck in 2017 (Cope and Cope 2020).

Westslope Cutthroat trout are a species of Special Concern both provincially and federally and distribution in SE BC is largely restricted to small, isolated headwater streams. Identified threats include genetic introgression from Rainbow Trout, restricted fish passage associated with roads, forest harvest, angling mortalities, climate change and mining (Fisheries and Oceans Canada 2017).

Coal mining impacts on WCT can include habitat loss and fragmentation, and changes in physical and chemical attributes of fish habitat such as riparian clearing, the bioaccumulation of selenium (Se), and leached minerals such as calcite from waste rock (Fisheries and Oceans Canada 2017). Other potential anthropogenic impacts to WCT in these watersheds include stress from handling and electrofishing during monitoring and salvage efforts, climate change and broad scale landscape factors primarily related to forestry, recreation, mining exploration and roads. In Grave Creek and Harmer Creek, recreational angling is prohibited (MFLNRORD 2019).

Fish populations are also subject to variation through stochastic effects and extreme events such as floods. Although Kennedy and Meyer (2015) found that bioclimatic indices such as mean annual air temperature and mean winter stream flow generally explained little of the variation in WCT abundance, recruitment failure can occur at low water temperatures (Coleman and Fausch 2007a), survival declines sharply at temperatures above 19ºC (Bear et al. 2007) and ice conditions can limit available habitat in winter (Brown and Mackay 1995). Small populations are also prone to low genetic variability, genetic drift and inbreeding depression, increasing extinction risk (Soulé and Mills 1998; Taylor et al. 2003; Carim et al. 2016). A detailed account of environmental conditions (natural and anthropogenic) that may be stressors on WCT and influence population dynamics will be found in the Harmer Creek Evaluation of Cause Report (Report pending-Harmer Creek Evaluation of Cause Team 2021).

Cope and Cope (2020) estimated that between 2017 and 2019 the abundance of juvenile WCT (< 150 mm) in Harmer Creek declined by 98%, while the abundance of adult WCT (> 150 mm) in the same creek declined by 25%. In comparison, the estimated abundance of juvenile (<150 mm) and adult (>150 mm) WCT in the adjacent Grave Creek watershed declined by 20% and 38%, respectively (Cope and Cope 2020). To reduce the uncertainty around these estimates we repeated sampling efforts in 2020 and re-analysed all of the existing data using a hierarchical Bayesian framework.

Bayesian methods provide a method to update uncertainty based on data incorporates all the information in the data while also readily dealing with missing values. Hierarchical models are required to separate the contributions of stochastic, site, population, mining and regional effects on the data and explicitly account for problematic sources of variation, such as observer efficiency (Kéry and Royle 2015). Bayesian methods are well suited to this approach. Additionally, Bayesian methods readily handle missing values, do not require minimum sample sizes, allow the incorporation of prior information and facilitate intuitive probabilistic statements about derived parameters (Wyatt 2002). To increase understanding about the magnitude and consequences of the apparent decline, two questions were addressed in this report:

1. What are the juvenile and adult abundances for the Grave Creek and Harmer Creek WCT populations?
2. What is the recruitment to the populations?

METHODS

2020 POPULATION MONITORING STUDY OVERVIEW

In 2020, the Grave Creek and Harmer Creek field program consisted of a spawning survey and a WCT density monitoring program performed through backpack electrofishing, following similar protocols to previous years. The spawning survey completed in 2020 marks the third consecutive year of spawning data (2018, 2019, and 2020). There are four years of recent electrofishing data for this project (2017, 2018, 2019, and 2020) as well as historical electrofishing data from 1996, 2008 and 2013.

STUDY AREA

The study area included Grave Creek, Harmer Creek, its tributary (EVO) Dry Creek and its tributary South Tributary (Table 1), which are all located upstream of a natural fish migration barrier (waterfall located on lower Grave Creek; Figure 1). Grave Creek is a tributary of the Elk River located approximately 9 km north of Sparwood, British Columbia. The natural falls in the first reach isolate the upstream fish from the Elk River, resulting in WCT being the only species present, outside of stocked Kokanee and triploid Rainbow Trout that are restricted to Grave Lake. Reaches 1 through 5 of Harmer Creek are influenced by mining activities in Dry Creek. Harmer Creek Reach 2 is located upstream of a 12 m high dam with a concrete spillway and a constructed sediment pond upstream (the Harmer Sediment Pond). This dam structure has isolated WCT in Reach 2 through Reach 6 of Harmer Creek from those in Reach 1 of Harmer Creek, and Grave Creek. Reach 6 of Harmer Creek is located upstream of the Dry Creek confluence, representing the headwater portions of the stream which are not influenced by mining activities. Grave Creek reaches 1 and 2 are influenced by mining activities since they are located downstream of the Harmer/Grave confluence. Reaches 3 and 4 in Grave Creek are located upstream of the Harmer/Grave confluence and are influenced by exploratory mining and forestry. Further description of the study area and the study design are provided by Cope and Cope (2020). Tributaries in these drainages, except for Dry Creek and its tributary South Tributary, were assumed to make a negligible contribution to the overall population abundance and were ignored when estimating the population abundance (Table 1).

Table 1. Lineal habitat (km) by population and habitat type. The values in brackets were used to calculate the population abundance. Tributaries except Dry Creek and South Tributary were assumed to make a negligible contribution to the population abundance.

Population	Mainstem	Tributary
Grave	9.0 (9.0)	3.4 (0)
Harmer	8.1 (8.1)	6.5 (2.9)

STUDY PERIOD

The spawning (redd) survey took place between June 15 to July 17, 2020. Backpack electrofishing sampling was conducted from September 18 to October 1, 2020. Backpack electrofishing timing was similar to the previous sampling programs in 2017, 2018 and 2019 (Table 2).

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
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

POPULATION MONITORING

SPAWNING (REDD) SURVEY

Five spawning (redd) surveys were completed approximately every 10 days during the June 15 to July 16, 2020 spawning season. Most of the fish bearing stream channel length above the natural barrier in Reach 1 was traversed on foot over a four-day period to identify and map the location of redds distributed within each stream (Figure 1). Where possible, redds were confirmed with observations of paired WCT displaying active courtship and redd construction behaviours (Cope and Cope 2020). Redds identified in the survey were geo-referenced, flagged and the modified Fish Habitat Assessment Procedures (FHAP) form used in meso-habitat characterization completed (Johnston and Slaney 1996). The method of redd confirmation was recorded (*i.e.*, spawning pair observed on redd) and all redds were further documented with photographs (Cope and Cope 2020).

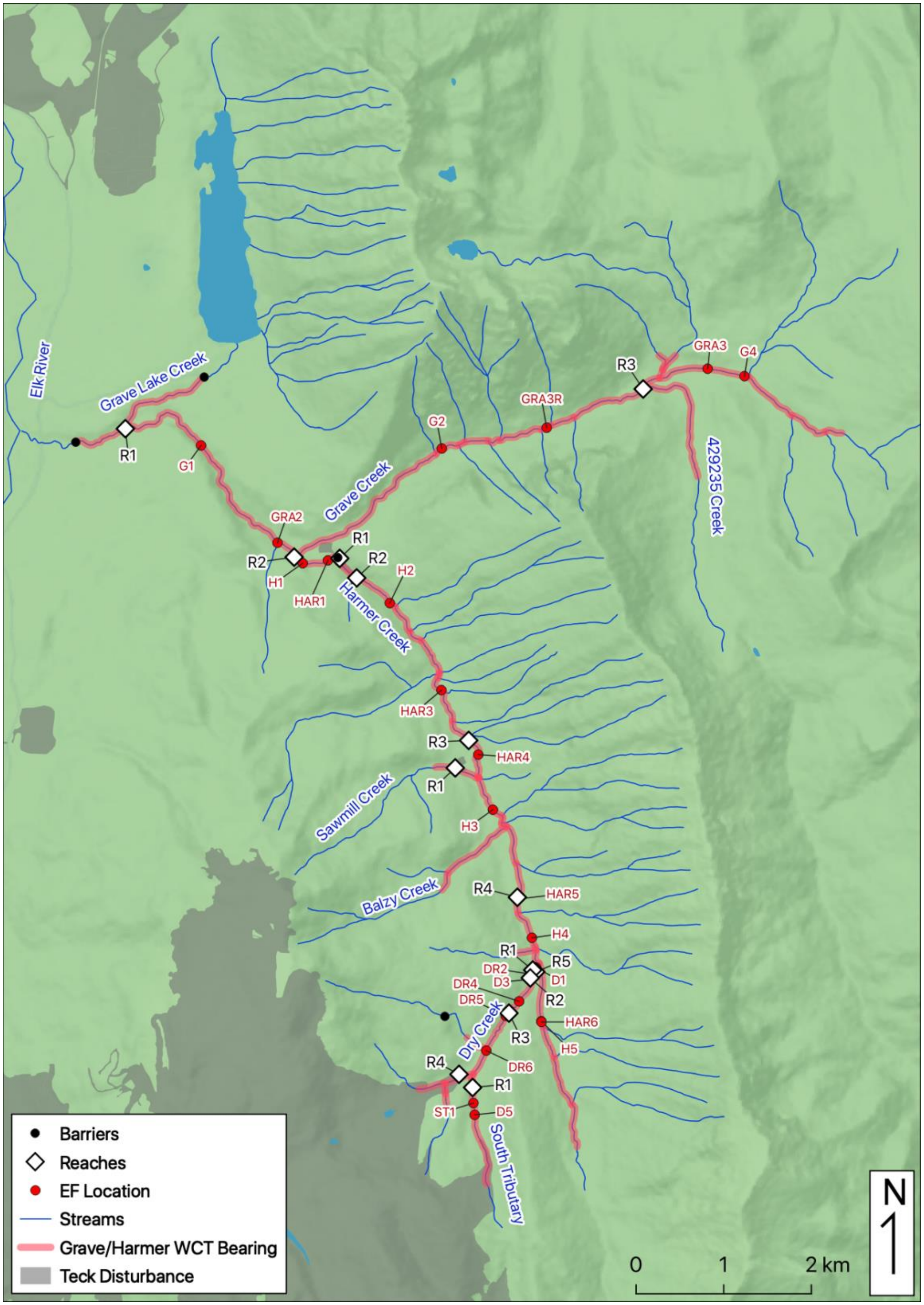

Figure 1. Grave Creek and Harmer Creek study area with barriers, reaches, electrofishing locations and WCT bearing habitat.

REMOVAL DEPLETION ELECTROFISHING SURVEY

Age-1, age-2+ juvenile (referring to fish from the age of 2 years until maturity), and adult WCT of Grave and Harmer populations were examined through three-pass removal-depletion backpack electrofishing surveys. Following Cope and Cope (2020) fish were assumed to be adult at a length of 150 mm. Based on visual examination of length-frequency plots (see Results) the following population specific age-class cutoffs were used (Table 3).

Table 3. The population specific age class cutoffs.

Population	Age-Class	Minimum Length (mm)	Maximum Length (mm)
Grave	Age-1	50	99
Grave	Age-2+	100	149
Harmer	Age-1	45	94
Harmer	Age-2+	95	149

Sampling followed methods and locations from previous monitoring programs (Cope and Cope 2020). Sixteen locations sampled during the 2017-2019 study period were re-visited in 2020 (Figure 1). Depletion-removal estimates were conducted at three distinct mesohabitat units per location (e.g., pool, riffle, run, glide or cascade); see Cope et al. (2016) for a description of mesohabitats.

Crews of 2-3 people used a backpack electrofishing unit (Smith-Root LR24). Upstream and downstream stop nets were deployed perpendicular to shore at all sites. The lead line was anchored to the stream bottom with large cobble and boulders placed as weights along the lead line. Stop nets consisted of 4 mm stretch mesh.

At each site, electrofishing was initiated at the downstream end and consists of a systematic bank to bank search in an upstream direction, followed by a sweep back towards the downstream net. Electrofishing effort (seconds) were recorded at the end of each pass. Each successive pass consisted of similar electrofishing effort. Both the upstream and downstream stop nets were checked for fish that may have drifted into the nets at the end of each pass (Cope and Cope 2020).

DATA PREPARATION

The historical (pre-2020) data were provided by Teck Coal Ltd. as an assortment of Excel spreadsheets and shape files. The 2020 field data were provided by Lotic Environmental Ltd. The estimates of the egg-to-age-1 survival required for population replacement were provided by ESSA Technologies Ltd. as an excel workbook (Lodmell et al. 2017; Ma and Thompson 2021). The watershed, stream, lake and manmade waterbody spatial objects were downloaded from Hillcrest Geographics PostGIS API to a copy of the BC Freshwater Atlas. The data were extracted and cleaned and tidied (Wickham 2014) before being stored in a purpose built SQLite database using R version 4.0.3 (R Core Team 2020).

STATISTICAL ANALYSIS

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

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

The parameters are summarised in terms of the point *estimate*, *lower* and *upper* 95% credible limits (CLs) and the surprisal *s-value* (Greenland 2019). The estimate is the median (50th percentile) of the MCMC samples while the 95% CLs are the 2.5th and 97.5th percentiles. The s-value can be considered a test of directionality. More specifically it indicates how surprising (in units of binary data: bits) it would be to discover that the true value of the parameter is in the opposite direction to the estimate. An s-value of 4.3 bits, which is equivalent to a p-value (Kery and Schaub 2011; Greenland and Poole 2013) of 0.05, indicates that the surprise would be equivalent to throwing 4.3 heads in a row. The condition that non-essential explanatory variables have s-values ≥ 4.3 bits provides a useful model selection heuristic (Kery and Schaub 2011).

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 3.6.1 (R Core Team 2019) and the mbr family of packages. Some analyses include parameters from a third watershed, the upper Fording River, to provide further context to the results.

MODEL DESCRIPTIONS

LENGTH-AT-AGE

The individual lengths of the age-0 fish as identified by the fork length cut-offs were analyzed using a mixed effects model with a log transform.

Key assumptions of the 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.
- The residual variation in the fork lengths is normally distributed.

ELECTROFISHING

The single and multipass electrofishing data for Grave Creek and Harmer Creek were analysed by the length-based life stages 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).

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.*

Between 2017 and 2020 three different mesohabitat sites were sampled at each location, all other programs electrofished only one site at each location. Additionally, 1996 and 2008 were single pass efforts that did not use stopnets. The 2017 salvage program in Dry Creek did not use stopnets either.

Key assumptions of the removal 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 seconds/m^2.
- The catch on each pass is binomially distributed, where the number of fish present at the beginning of the pass represents the number of trials and the number of fish caught is the number of successful trials.

The abundance was calculated excluding tributary habitat except EVO Dry Creek and South Tributary.

Preliminary analysis suggests that mesohabitat type was not an informative predictor of density or efficiency and that voltage was confounded with year. These variables were dropped.

BODY CONDITION

The electrofishing length and weight data for fish from Grave Creek and Harmer Creek were analysed using a mass-length model (He et al. 2008). Fish with a fork length < 65 mm were excluded from the analysis as the error in their weight measurements was a relatively high proportion of their absolute weight.

The model was based on the allometric relationship

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

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

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

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

Key assumptions of the condition model include:

- α 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

Following Ma and Thompson (2021) the fecundity was calculated assuming the following allometric relationship from Corsi et al. (2013).

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

The annual fecundity for the Grave and Harmer populations was estimated by calculating the number of eggs for each adult caught by electrofishing based on its length and then taking the arithmetic mean.

RECRUITMENT

The total annual egg deposition was calculated from the annual fecundity (eggs per female) and the estimate of adults, assuming a 1:1 sex ratio and repeat spawning every other year (Liknes and Graham 1998), so that 50% of the adults are female and only 50% of females deposit eggs.

The egg to age-1 survival (Pulkkinen et al. 2013) was calculated by dividing the estimate of the age-1 individuals by the estimated total egg deposition the previous year (or the same year if the previous year's egg deposition was unavailable). The egg deposition was plotted in terms of the number of eggs per 100 m of habitat to allow comparisons among systems.

The egg-to-age-1 survival required for population replacement was taken from the Excel workbook (Table 4) provided by Ma and Thompson (2021) with one modification. The proportion mature by age (P_{age}) was calculated using the following equation (as opposed to a lookup table to allow the uncertainty in the maturation schedule to be quantified through a single parameter - see below). A is the age at which 50% of fish are mature and age^{12} is age to the 12$^{\text{th}}$ power, to produce a maturation curve equivalent to Ma and Thompson (2021).

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

The uncertainty in the egg-to-age-1 survival required for population replacement was quantified by independently sampling from the uncertainty for each parameter (Table 4) assuming a truncated normal distribution of the form

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

Table 4. The life-history parameter estimates for the Grave Creek and Harmer Creek populations from Ma and Thompson (2021).

Parameter	Estimate	Lower	Upper	Description
S_J	0.3835	0.20	0.574	Juvenile Survival (age-1 and -2)
S_A	0.7330	0.68	0.790	Adult Survival (age-3+)
A_max	14	12	16	Maximum age (yr)
L_inf	275	250	300	Mean maximum fork length (mm)
k	0.15	0.11	0.195	Growth rate (yr-1)
a0	-0.45	-0.10	0.212	Age at zero length (yr)
As	5	4	6	Age at 50% maturity

PRODUCTIVITY

To facilitate further comparisons the expected lifetime number of spawners per spawner (Myers 2001) (rho) was calculated by dividing the estimated egg to age-1 survival by the estimated egg to age-1 survival for replacement for each population in each year.

RESULTS

SPAWNING (REDD) SURVEY

Spawning has been documented throughout the mainstem of both Grave Creek and Harmer Creek (Figure 2).

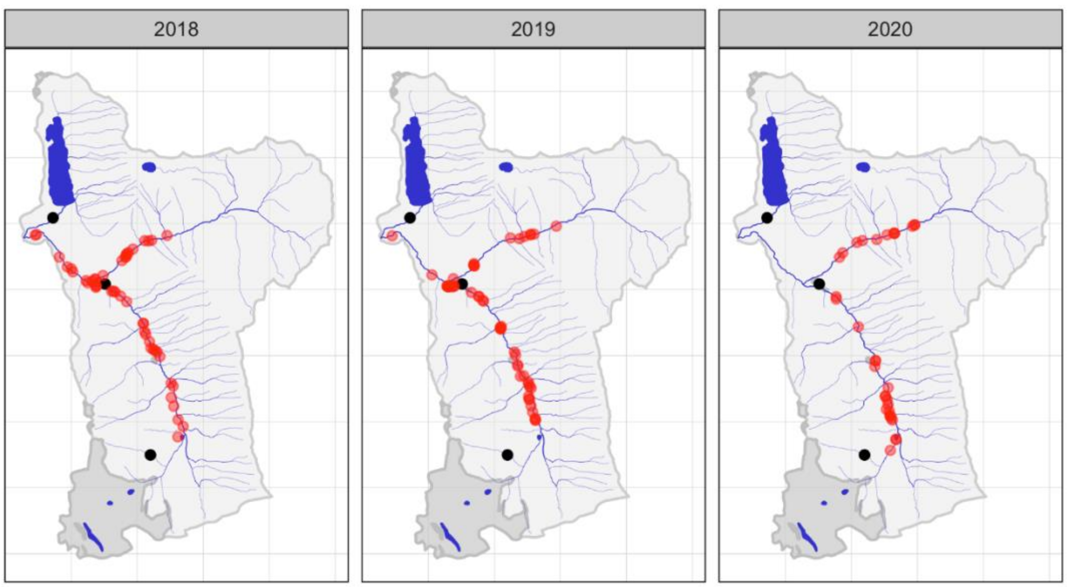

Figure 2. The spatial distribution of recorded WCT redds by year. Red dots are WCT redds, black dots are barriers to fish.

ELECTROFISHING

In 2020, electrofishing surveys in Grave Creek covered 0.6 km, approximately 5% of the fish bearing habitat and surveys in Harmer Creek covered 0.5 km, approximately 4% of the fish bearing habitat (Table 5). These were similar efforts to previous years.

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

Year	Population	Site Length	Age 0	Age 1	Age 2	Adult
1996	Grave	1632	0	0	1	4
2008	Grave	250	0	3	7	2
2013	Grave	300	0	0	2	3
2017	Grave	544	3	20	29	29
2018	Grave	574	4	20	29	17
2019	Grave	586	3	15	24	21
2020	Grave	568	0	4	10	9
1996	Harmer	300	0	0	0	2
2008	Harmer	550	0	6	12	4
2013	Harmer	800	0	0	2	5
2017	Harmer	2540	4	16	56	36
2018	Harmer	528	3	2	12	12
2019	Harmer	486	0	0	1	8
2020	Harmer	534	0	0	3	5

FORK LENGTH

Based on visual examination of length-frequency plots for the Grave Creek WCT population, age-0 fish were < 55 m, and age-1 individuals were considered to be between 55 and 99 mm (Figure 3). Harmer Creek age-0 fish were <45 mm and age-1 fish were between 45 and 94 mm (Figure 4). Adults of both populations were considered to be individuals >= 150 mm. In the current report age-2+ juveniles are those individuals that are too big to be age-1 but too small to be adults.

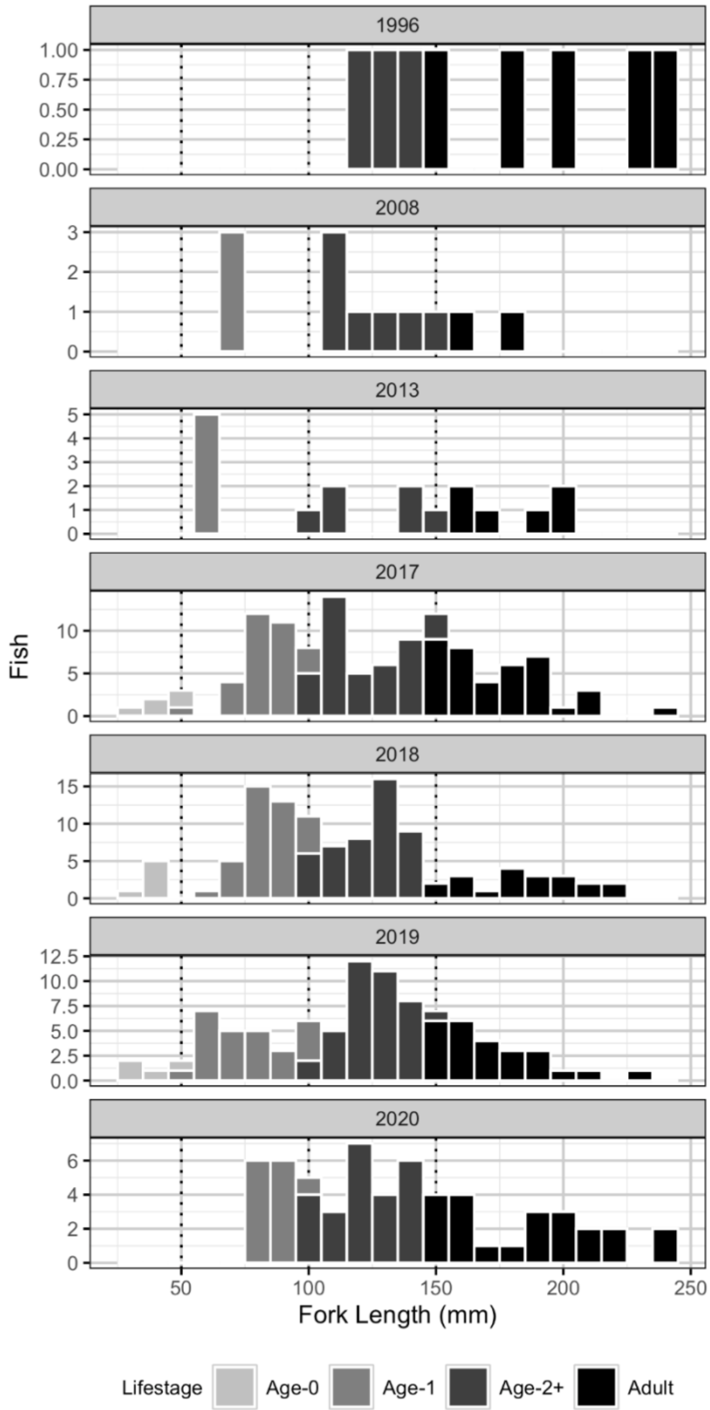

Figure 3. Numbers of fish from the Grave Creek population by fork length, year and lifestage. The dotted lines mark the transition from one life stage to the next.

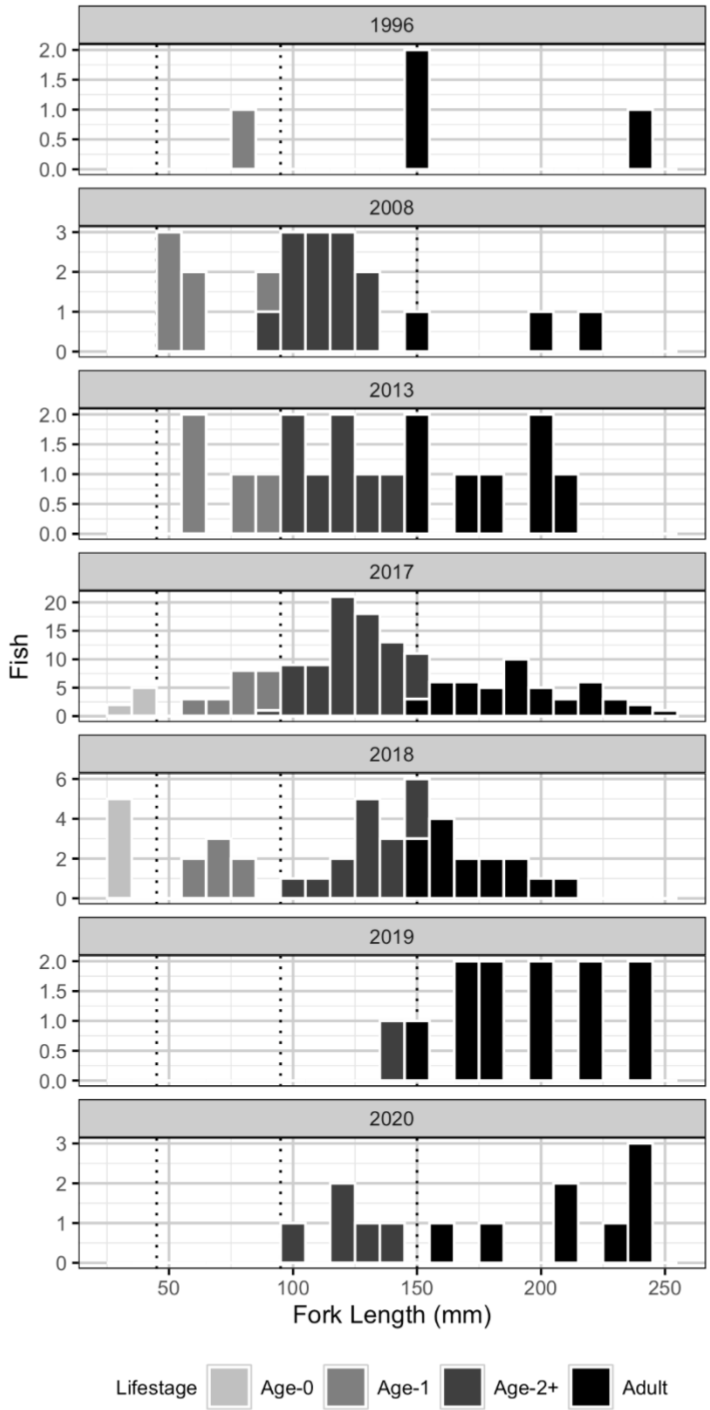

Figure 4. Numbers of fish from the Harmer Creek population by forklength, year and lifestage. The dotted lines mark the transition from one life stage to the next.

The average size of age-0 fish is 37 mm (95% CI 26-49) for Grave Creek population and 31 mm (95% CI 21-44) for the Harmer Creek population. Annual average sizes of age-0 fish in the upper Fording River are included for context (Figure 5).

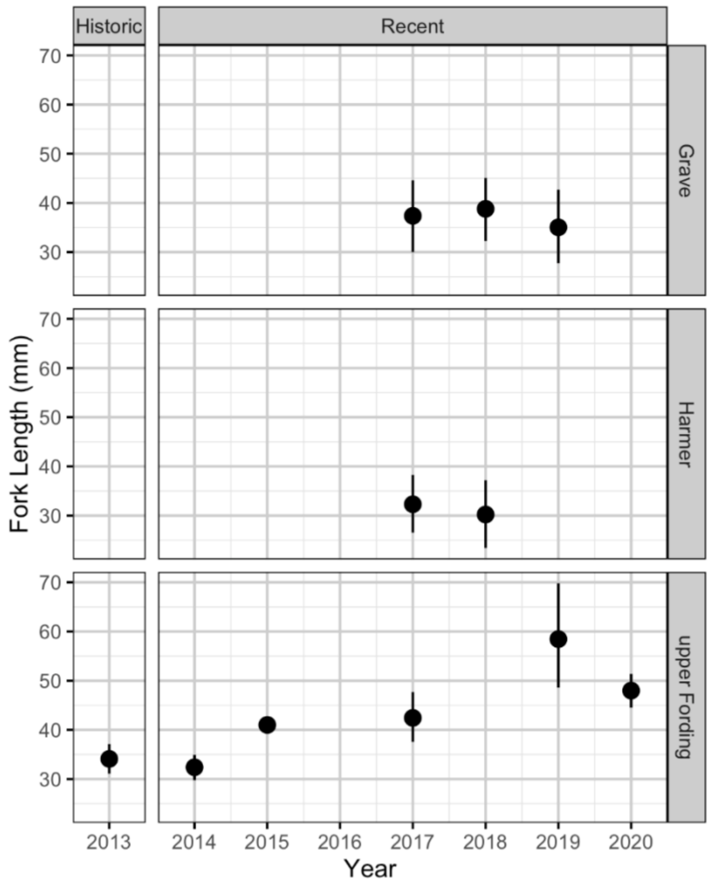

Figure 5. Annual fork length for age-0 fish in Grave Creek , Harmer Creek and the upper Fording River on September 15th.

Electrofishing results show high variability both between locations and within locations by year (Figure 6). For 2020 total absence of age-1 fish caught during the first pass in Harmer Creek are notable, as well as the absence of age-1 fish in the 1996 inventory, in both creeks.

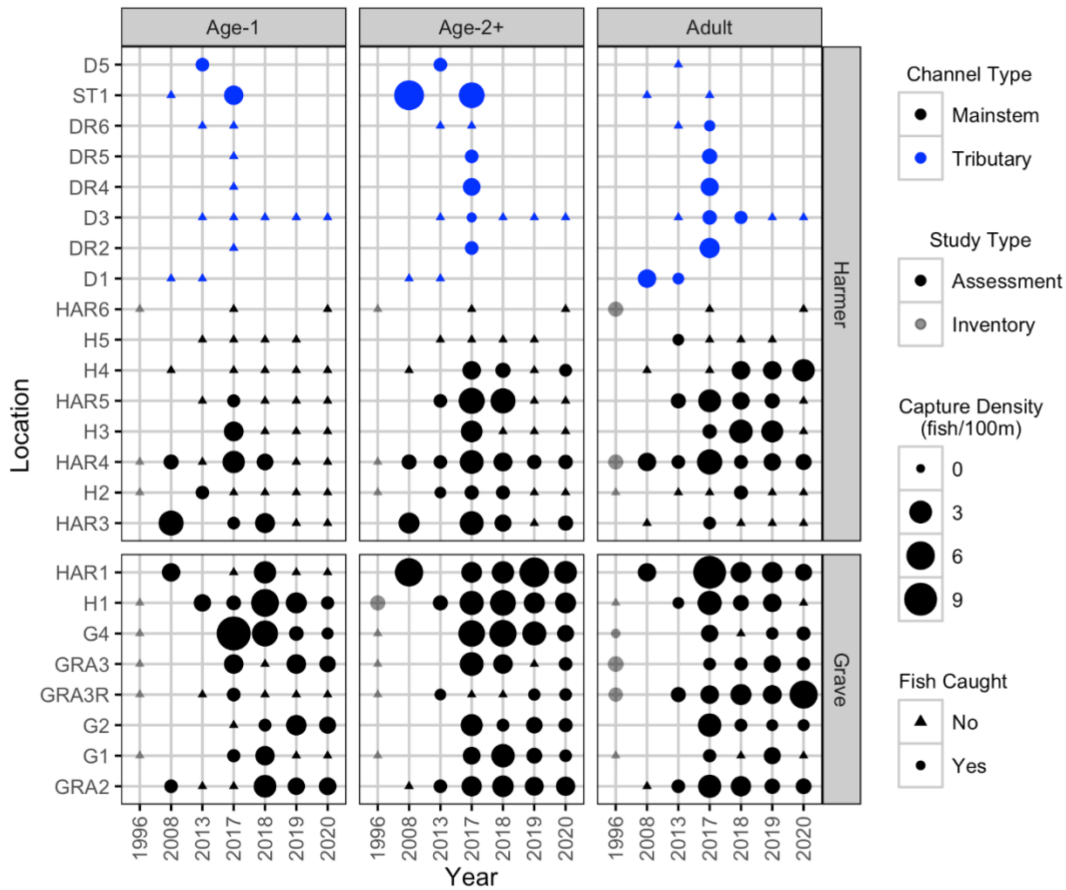

Figure 6. The electrofishing capture density averaged across the first three passes by year, location, life-stage, population, channel type and study type. Locations on the y axis are listed in an upstream direction (refer to Figure 1).

AGE-1 DENSITY AND ABUNDANCE

Capture efficiencies for age-1 WCT are indicated in Figure 7. Estimated age-1 densities at electrofishing sites are generally higher for Grave Creek than Harmer Creek, where densities are quite low (Figure 8, Figure 9). In Grave Creek densities of age-1 fish show a general increasing trend moving up the watershed. In contrast, Harmer Creek densities show a general declining trend from HAR3 to H4 and then consistently low densities until ST1 and D5 are reached in South Tributary (Figure 9).

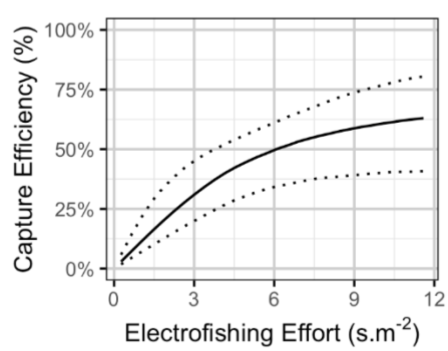

Figure 7. The estimated age-1 capture efficiency by electrofishing effort (with 95% CIs).

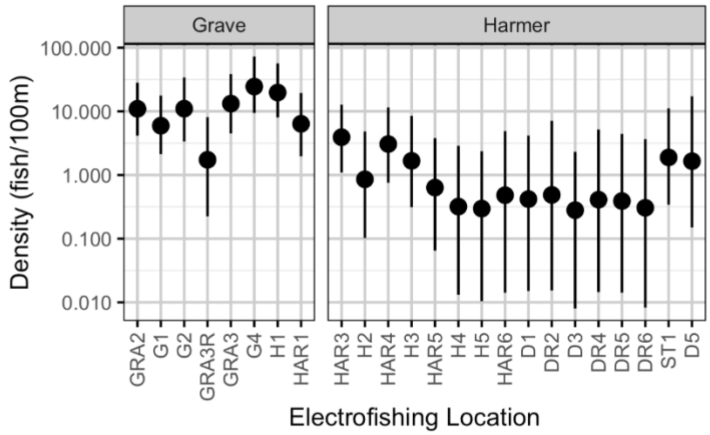

Figure 8. The estimated age-1 density by location and population scaled for 2018 (with 95% CIs). Locations on the x axis are listed in an upstream direction for the Grave watershed followed by an upstream direction for the Harmer watershed, including Reach 1 in Harmer Creek which is part of the Grave Creek WCT population (Figure 1).

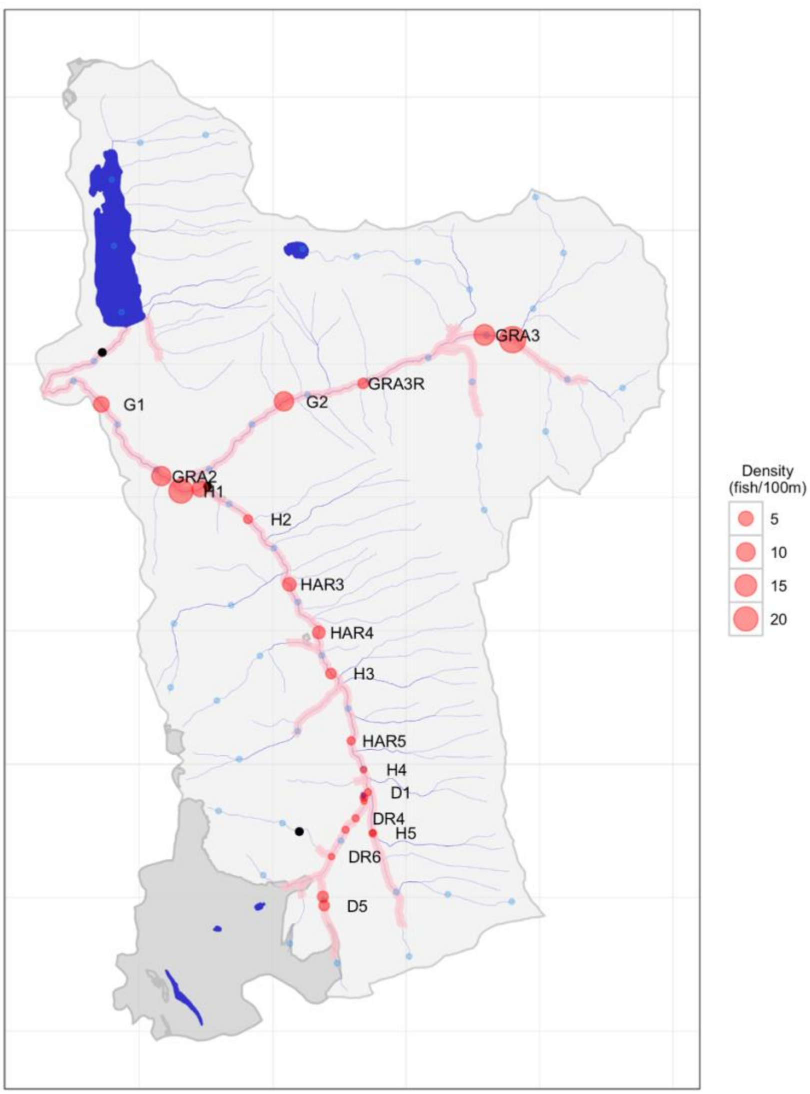

Figure 9. Mapped locations of age-1 WCT densities in Grave Creek and Harmer Creek scaled for 2018.

Except for the two most recent monitoring seasons, Harmer Creek shows very similar pattern to Grave Creek. Age-1 numbers were very low in 1996, at 9 fish (95% CI 0-1,400), then much higher in 2008 at 670 fish (95% CI 120-5,100) with slight declining trend from 2013 to 2018 (Figure 10). However, subsequent fish numbers dropped precipitously from 150 fish (95% CI 37-750) in 2018 to 1 fish in 2019 (95% CI 0-59) and 2 fish in 2020 (95% CI 0-76).

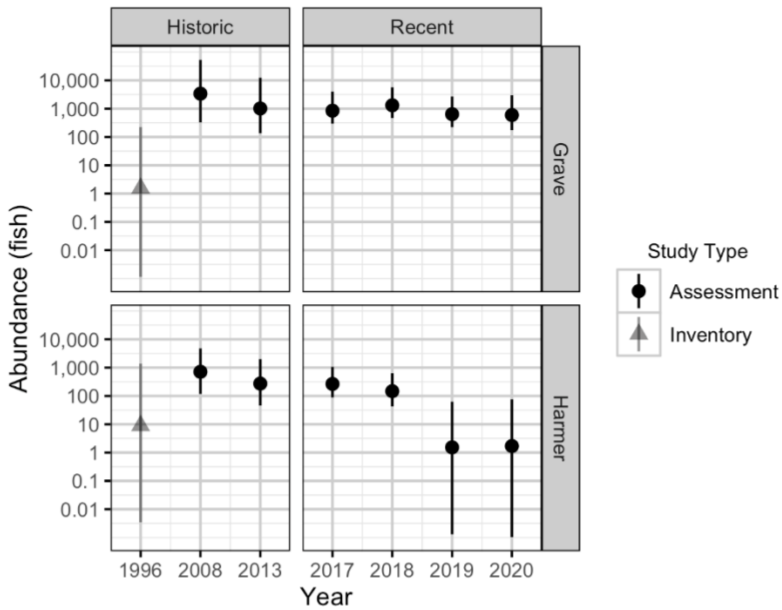

Figure 10. The estimated age-1 abundance by year and population (with 95% CIs).

AGE-2+ JUVENILE DENSITY AND ABUNDANCE

The relationship between increased effort and electrofishing efficiency is a flatter curve for age-2+ fish (Figure 7, Figure 11), increasing effort (the time spent searching a given area) does not yield increased capture efficiency above 6 seconds per m^2. Densities of age-2+ juvenile fish tend to be higher in Grave Creek than Harmer Creek, although there is considerable overlap (Figure 12). Grave Creek age-2+ juvenile abundance was very low in 1996, at 21 (95% CI 1-390; Figure 13). However, in 2008, age-2+ WCT abundance was the highest recorded, at 1,700 fish (95% CI 360-8,200). More recently, numbers have declined somewhat to 840 fish (95% CI 310-2,900) in 2020. Harmer Creek age-2+ juvenile fish also reached very low numbers in 1996, with an estimated 8 fish (95% CI 0-170) and subsequently climbed to 610 fish (95% CI 200-2,100) in 2008. The peak abundance for Harmer Creek was recorded in 2017 at 710 fish (95% CI 330-2,100). There was a steep decline in 2019 to 22 fish (95% CI 1-160) followed by a slight recovery in 2020 to 140 (95% CI 41-560) fish. Over the monitoring period, general trends for age-2+ are similar to that of the age-1 life stage and consistent between the two populations, with the exception of the substantial decline in the Harmer population for the 2019 and 2020 monitoring seasons.

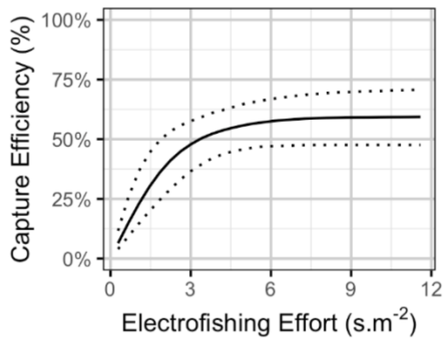

Figure 11. The estimated age-2+ electrofishing capture efficiency by electrofishing effort (with 95% CIs).

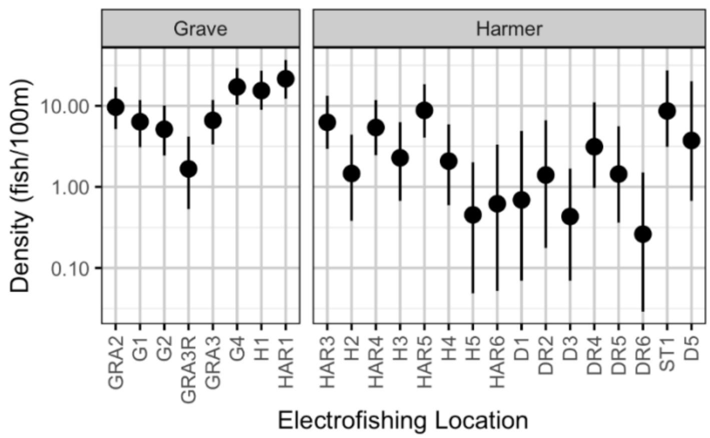

Figure 12. The estimated age-2+ juvenile density by site and population scaled for 2018 (with 95% CIs). Locations on the x axis are listed in an upstream direction for the Grave watershed followed by an upstream directions for the Harmer watershed, including Reach 1 in Harmer Creek which is part of the Grave Creek WCT population (Figure 1).

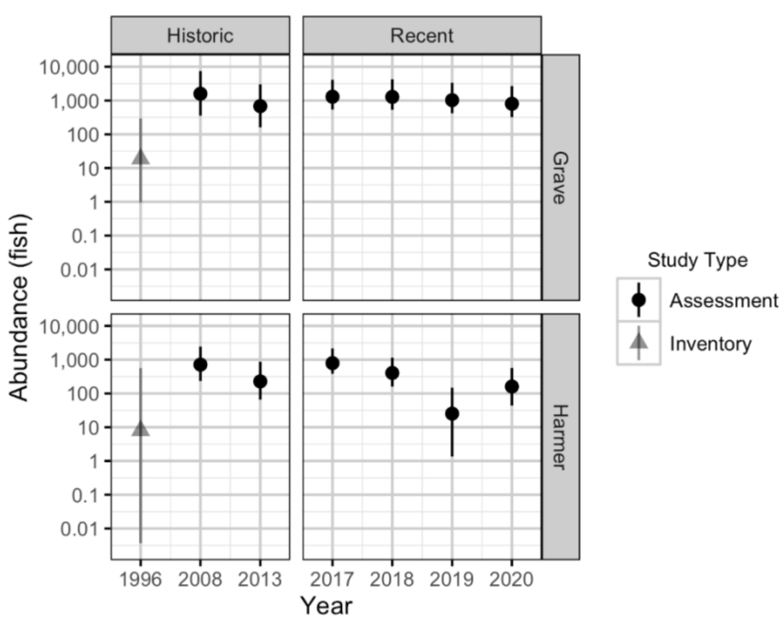

Figure 13. The estimated age-2+ juvenile abundance by year and population (with 95% CIs).

ADULT DENSITY AND ABUNDANCE

Electrofishing capture efficiencies for adults were higher than either age-1 or age-2+ WCT, reaching close to 75% (Figure 14) at an effort 5 seconds per m^2.

The densities of adult fish at sampled sites in Grave Creek were generally similar to or higher than densities in Harmer Creek (Figure 15). Adult numbers in both populations have remained comparatively stable. Although adult abundance in Grave Creek was low in 1996 at 240 fish (95% CI 50-1,300), this difference was not as dramatic as observed for juvenile life stages. Abundance peaked in 2017 at 1,100 fish (95% CI 460-3,200) and was down to 550 fish (95% CI 220-1,700) in 2020, but numbers remain slightly above the range of historic abundances of 240-320 fish, measured in 1996, 2008 and 2013 (Figure 16). In contrast, Harmer Creek adult abundance peaked in 1996, at 580 fish (95% CI 64-3,900), and was lowest in 2013 at 190 fish (95% CI 57-710). More recent sampling efforts have resulted in population estimates that fall within this range, with a smaller peak in 2017 at 430 fish (95% CI 210-1,100) and 260 fish (95% CI 89-790) in 2020.

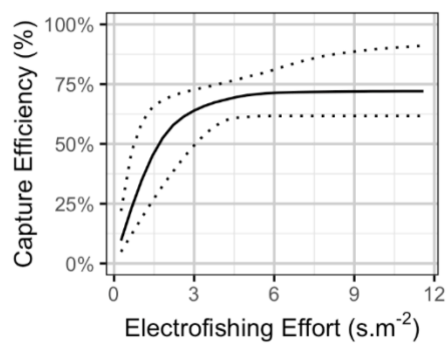

Figure 14. The estimated adult electrofishing capture efficiency by electrofishing effort (with 95% CIs).

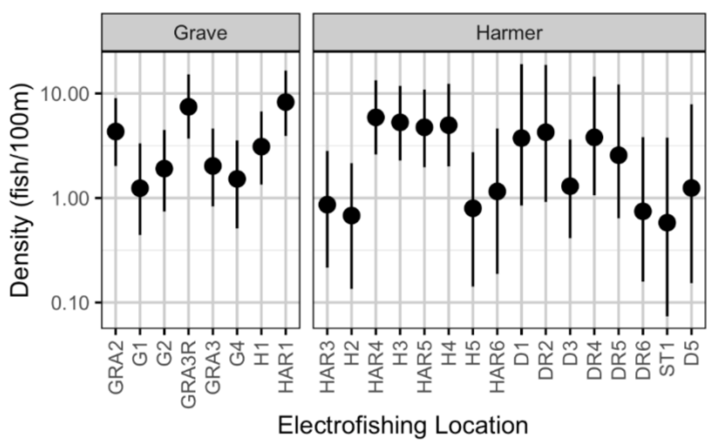

Figure 15. The estimated adult density by site and population scaled for 2018 (with 95% CIs). Locations on the x axis are listed in an upstream direction for the Grave watershed followed by an upstream directions for the Harmer watershed, including Reach 1 in Harmer Creek which is part of the Grave Creek WCT population (Figure 1).

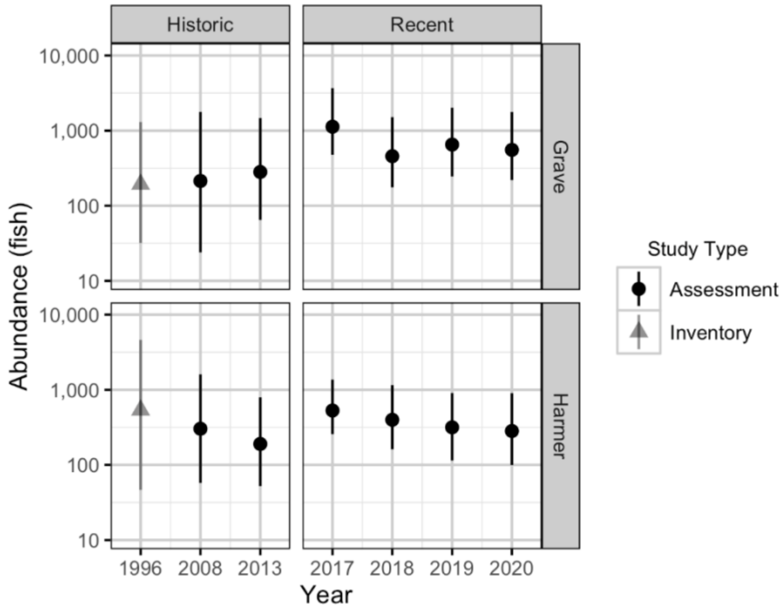

Figure 16. The estimated adult abundance by year and population (with 95% CIs).

CONDITION

In Grave Creek the body condition (weight) of an average length (100 mm) fish was at its lowest in 2018, -3.8% (95% CI -6.8--0.8), relative to an average year (Figure 17). In 2020 condition was better than average, 2.3% (95% CI -1.4-5.8). WCT body condition in Harmer Creek has followed a very similar trend, with the poorest condition in 2018 at -2.5% (95% CI -6.4--1.3) and slightly above average condition in 2020 at 1.5% (95% CI -3.5-6.8). WCT condition for another watershed, the upper Fording River, are included for comparison. Inter-annual patterns in condition for the upper Fording River do not appear to match those of Grave Creek or Harmer Creek.

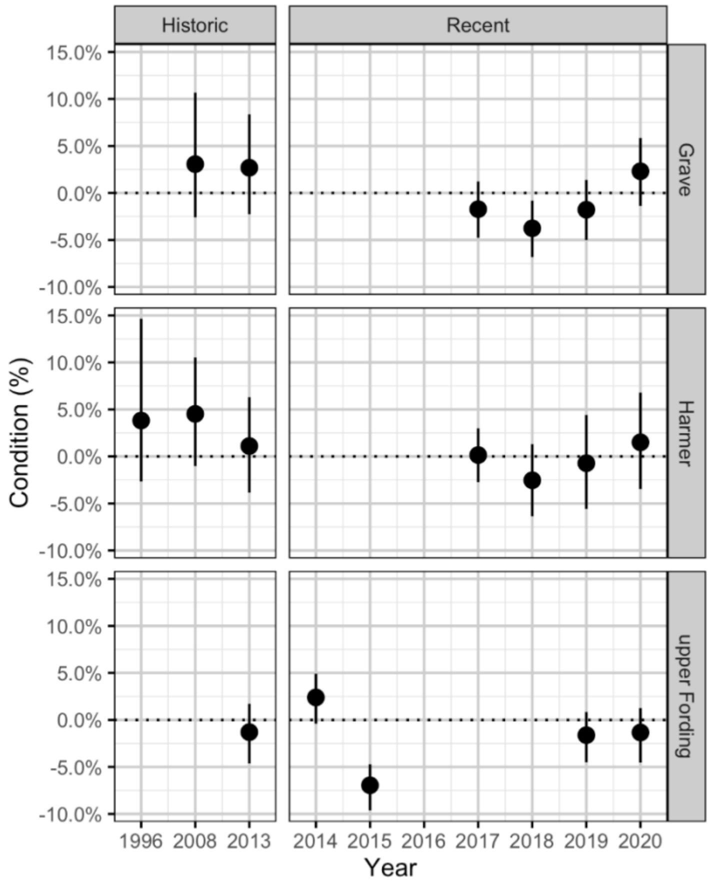

Figure 17. The percent change in the body condition (weight) for an average length fish relative to an average year (0% change) by population and year (with 95% CRIs).

FECUNDITY

Following Ma and Thompson (2021) the fecundity was calculated from the fork length using the same equation as Corsi et al. (2013). The relationship between fork length and fecundity is plotted together with those from other studies for comparison in Figure 18. Fecundity rates for Grave Creek varied between 125 and 210 eggs/female, with 2020 near the middle at 170 eggs/female (Figure 19). Most of the Harmer Creek fecundity rates were within a similar range (130-200 eggs/female) except for in 2020, the highest, calculated at 250 eggs/female.

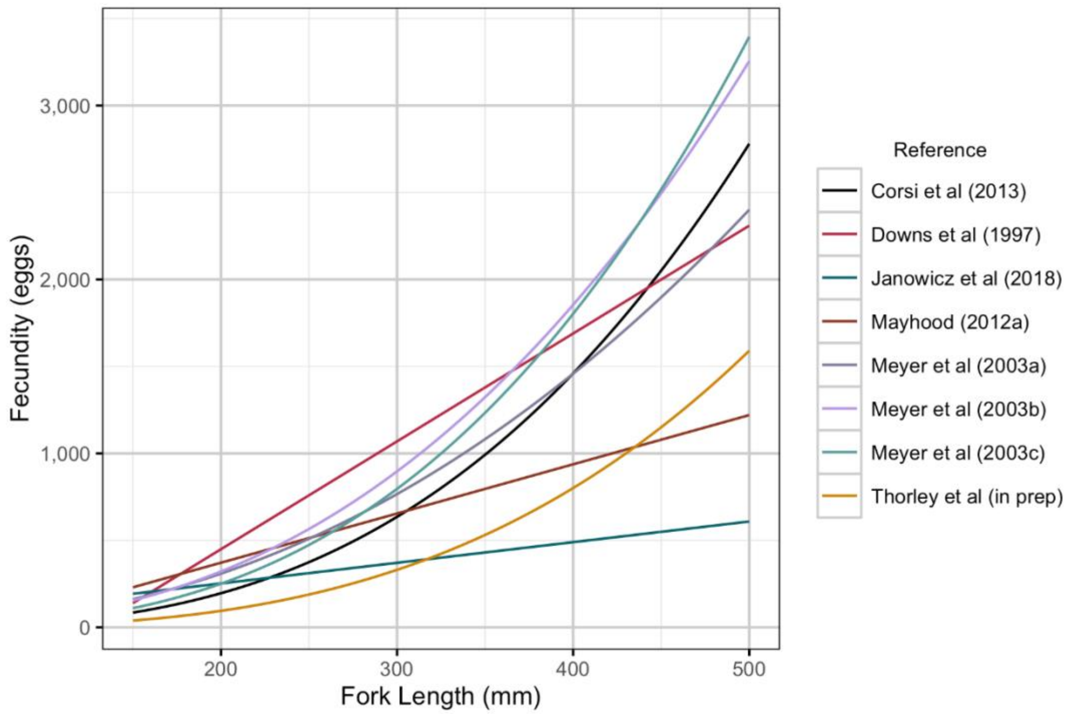

Figure 18. Examples of WCT fecundity-fork length relationships derived from literature.

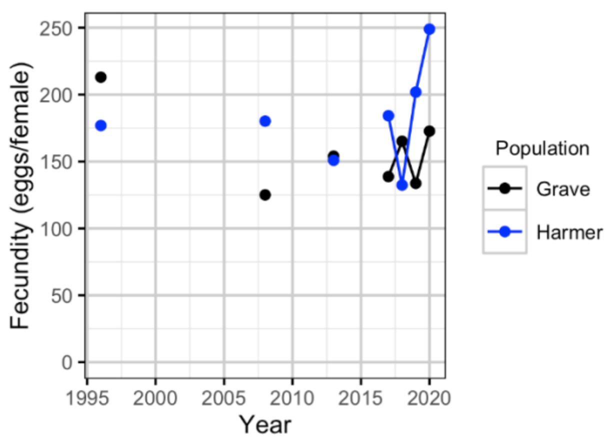

Figure 19. The calculated eggs per female by population and year, based on the recorded lengths.

RECRUITMENT

For the 1995 spawn year, the estimated egg to age-1 survival rate was 0.01% (95% CI 0.00-0.02) for Grave Creek and 0.03% (95% CI 0.00-0.06) for Harmer Creek (Figure 20). Grave Creek survival rates were well above the general literature based replacement value of 5% in 2007 at 50% and in 2012 at 9.4% (95% CI 1.2-91). Since then, egg to age-1 survival in Grave Creek have varied between 2.1% and 3.4%. Harmer Creek egg to age-1 survival rates declined from 3.8% (95% CI 0.6-27.8) in 2012 to 1.0% (95% CI 0.36-4.3) and 0.6% (95% CI 0.2-2.6) in 2017 before dropping to just 0.01% (95% CI 0-0.05) in 2018 and 2019. Survival rates in the nearby watershed of the upper Fording River are included for comparison.

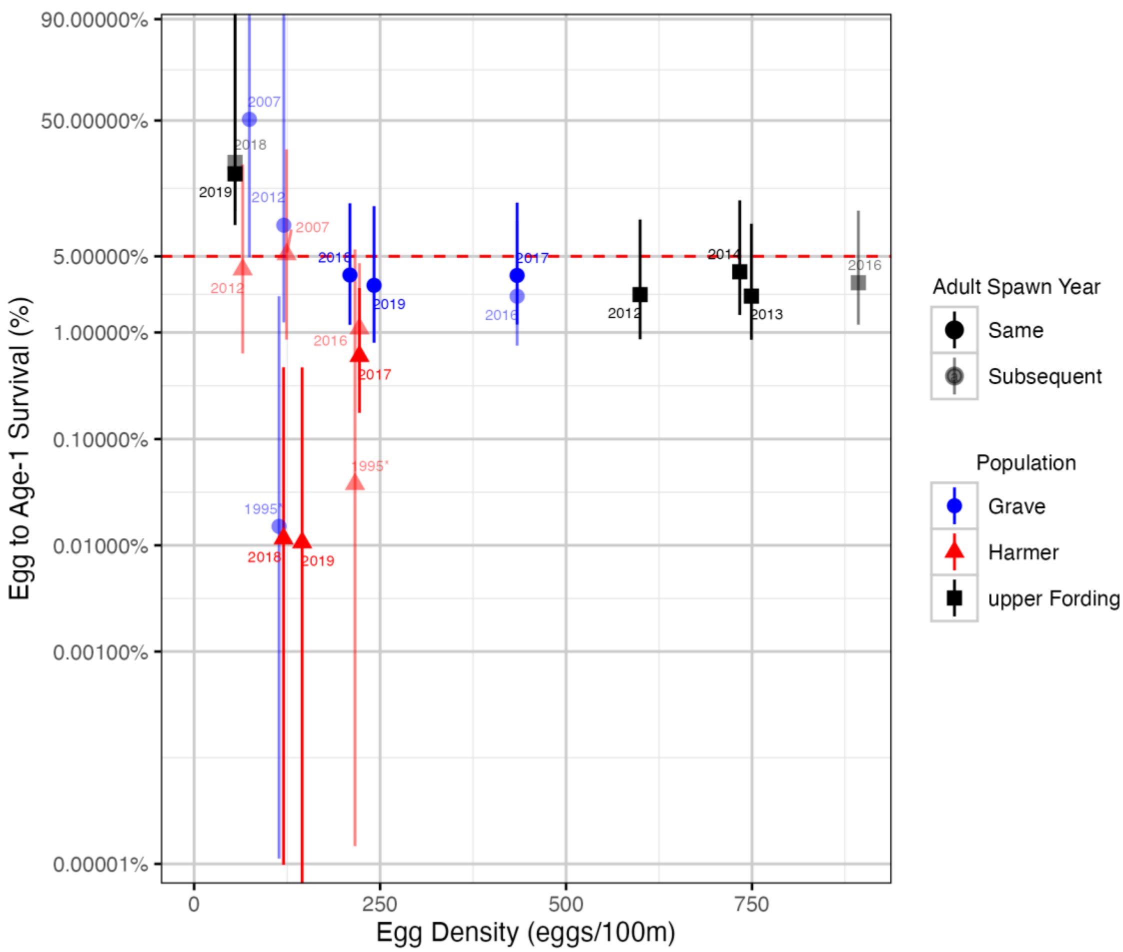

Figure 20. The egg to age-1 survival by total egg deposition, population and spawn year. The dashed red line indicates the egg-to-fry survival required for replacement based on the literature.

The watershed specific replacement value (which corresponds to 1 spawer per spawner) was calculated to be of 10.5% (95% CI 0.05-0.33). The calculated productivity (rho) values for Grave Creek were generally slightly below replacement levels of 1 spawner per spawner in all years monitored except 1995 with a low of 0.001 spawners per spawner (95% CI 0.0-0.21) and 2007 with a high of 4.7 spawners per spawner (95% CI 0.34-85). In 2019 there were 0.27 spawners per spawner (95% CI 0.05-1.54; Figure 21). With the exception of 1995, Grave Creek demonstrates increasing productivity at lower egg densities.

Harmer Creek productivity was also low in 1995 at 0.004 spawners per spawner (95% CI 0.0-0.66) and highest in 2007 at 0.49 spawners per spawner (95% CI 0.06-4.3). From 0.35 (95% CI 0.05-3.2) spawners per spawner in 2012 the productivity declined to 0.1 spawners per spawner (95% CI 0.02-0.50) in 2016, and 0.06 spawners per spawner (95% CI 0.01-0.29) in 2017 before fall dramatically to just 0.001 spawners per spawner (95% CI 0.0-0.05) in 2018 and 2019. Productivity in the upper Fording River watershed has been near or above replacement in all years.

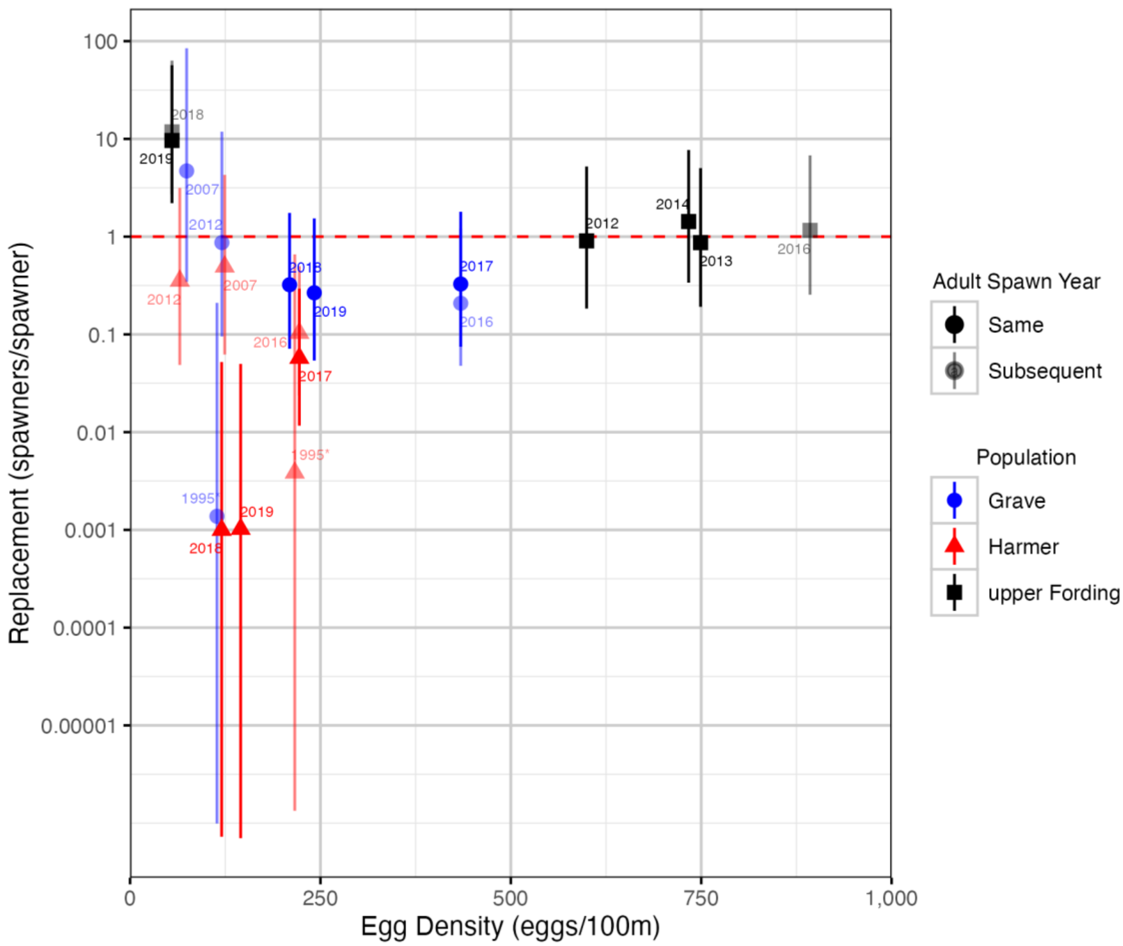

Figure 21.The calculated expected lifetime spawners per spawner on a log scale by egg density, population and spawn year. The dashed red line indicates replacement (rho = 1).

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

Thorley, J.L. (2021) East Kootenay Westslope Cutthroat Trout Population Dynamics 2020b. A Poisson Consulting Analysis Appendix. URL: https://www.poissonconsulting.ca/f/1226316656.

DISCUSSION

Determining population abundance estimates with sufficient accuracy and precision is essential for tracking changes in at-risk populations potentially impacted by industrial activities. For many trout populations, high levels of uncertainty make the determination of the magnitude of trends difficult, in particular, large, biologically important declines may occur but are unable to be discerned with any confidence (Dauwalter et al. 2009). The current report used a hierarchical Bayesian approach to maximize the use of the available information and because it provides easy to interpret probabilistic conclusions.

The occurrence and distribution of WCT redds testifies to the continued presence of spawning activity in Grave Creek and Harmer Creek. With more frequent, systematic redd surveys it may be possible to develop an area-under-the-curve based (Millar et al. 2012) metric of the total spawning activity. Area-under-the-curve based metrics estimate the total number of redds rather than the redds counted by taking into account observer error and redd fading.

Size selective overwinter mortality in age-0 fish has been documented for WCT and other species (Sogard 1997; Coleman and Fausch 2007b). Small age-0 fish may lack sufficient energy reserves to survive winter. Consequently, the smaller age-0 fish in Harmer Creek may result in reduced recruitment to age-1 fish. Unfortunately, there is no information on the size of age-0 fish in the Harmer Creek for the 2018 and 2019 spawn years.

Fish populations frequently show high temporal variation in abundance (Dauwalter et al. 2009). Both Grave Creek and Harmer Creek WCT populations had very low numbers of age-1 and age-2+ juveniles in the 1996 inventory. Heidt (2003) reported that

> *The flood peaked on June 7, 1995 during the spawning season for westslope cutthroat trout, and the resulting bed load movement, heavy siltation and high flows likely reduced egg to fry survival and juvenile/adult survival. In response to this event, the Elk River and its' tributaries were regulated catch and release for 3 years (until 1998/1999) so remaining cutthroat stocks could rebuild.*

Whether or not the 1995 flood caused the low juvenile abundance in Grave Creek and Harmer Creek the following year is uncertain.

Compensatory density dependence occurs when survival, growth or fecundity increase due to reduced competition at low densities, thereby promoting population recovery (Rose et al. 2001). Density dependent mortality is typically strongest during the earliest life stages, i.e. from egg to age-1 survival (Shepherd and Cushing 1980; Yant et al. 1984; Elliott 1989; Johnston and Post 2009). Although the recent increasing trend for body condition and size in both Grave Creek and Harmer Creek populations suggests compensatory growth in individual fish, Harmer Creek had egg to age-1 survival rates approaching 0%, compared to the 5% considered sufficient for replacement in a typical population (Ma and Thompson 2021) or the 10% calculated for these specific watersheds. Survival rates are expected to increase at low fish densities, but the currently observed survival rates are inadequate to maintain the Harmer Creek population.

Productivity is typically strongly related to egg viability and survival to age-1. By definition, productivity (lifetime spawners per spawner) must equal 1 for population replacement, while a value >1 indicates a growing population and a value <1 a decreasing population. Myers (1999) calculated a lifetime reproductive rate, at low population densities, of between 4-27 spawners per spawner for 7 different species of Salmonidae. However, despite being at low densities, the productivity of the Harmer population was calculated at 0.001 spawners per spawner during the two most recent years of monitoring, three orders of magnitude below the levels required for replacement.

In Harmer Creek, despite the resilience demonstrated historically, recent data suggesting the continued absence or near absence of age-1 fish, paired with a steady decline in egg survival rates and population productivity indicate a serious conservation risk. The diverging population trajectory, compared to Grave Creek, suggest chronic impacts specific to the Harmer Creek watershed. Although fish condition and the calculated fecundity are improving, this positive response is more than negated by the egg to age-1 survival rate of close to 0%. The moderate increase in age-2+ fish in Harmer Creek, 122 fish from 2019 to 2020, raises the possibility that some recruitment may still be occurring, however, this apparent increase is within the range of sampling error. If, as is suggested by the age-1 abundance estimates, recruitment is negligible then this 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).

The study design of the current fish population monitoring program suffers from a number of limitations including underestimation of abundance from depletion-removal electrofishing (Meyer and High 2011), bias due to the non-random selection of electrofishing sites at the mesohabitat scale and the limited coverage (~5%) of the available habitat (Korman et al. 2016). There is also uncertainty surrounding the total egg deposition and the distribution of fish within the tributaries. Nonetheless the general conclusion that the Harmer Creek population is experiencing an ongoing recruitment failure, here defined as negligible recruitment, is considered reasonably robust.

RECOMMENDATIONS

- Prompt action should be taken to mitigate or minimize further impacts to the Harmer Creek WCT population.
- Continue annual monitoring efforts using electrofishing to assess population trajectories for Grave Creek and Harmer Creek. Specific recommendations for modified data collection techniques are provided in a separate report.

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