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MEMORANDUM

TO: **Teck Coal Limited**
FROM: **Kevin Akaoka, M.Sc., and Todd Hatfield, Ph.D., R.P.Bio., Ecofish Research Ltd.**
DATE: **December 1, 2022**
FILE: **1229-60**

RE: **Harmer and Grave Creeks Telemetry Movement Analysis**

READER'S NOTE

Background

The Elk Valley (Qukin ʔamaʔkis) is located in the southeast corner of British Columbia (BC), Canada. "Ktunaxa people have occupied Qukin ʔamaʔkis for over 10,000 years. . . . The value and significance of ʔa·kxamis ʼqapi qapsin (All Living Things) to the Ktunaxa Nation and in Qukin ʔamaʔkis must not be understated" (text provided by the Ktunaxa Nation Council [KNC]).

The Elk Valley contains the main stem of the Elk River, and one of the tributaries to the Elk River is Grave Creek. Grave Creek has tributaries of its own, including Harmer Creek. Harmer and Grave Creeks are upstream of a waterfall on Grave Creek, and they are home to isolated, genetically pure Westslope Cutthroat Trout (WCT; *Oncorhynchus clarkii lewisi*). This fish species is iconic, highly valued in the area and of special concern under federal and provincial legislation and policy.

In the Grave Creek watershed[1], the disturbance from logging, roads and other development is limited. The mine property belonging to Teck Coal Limited's Elkview Operations includes an area in the southwest of the Harmer Creek subwatershed. These operations influence Harmer Creek through its tributary Dry Creek, and they influence Grave Creek below its confluence with

[1] Including Grave and Harmer Creeks and their tributaries.

Harmer Creek (Harmer Creek Evaluation of Cause, 2023)[2]. Westslope Cutthroat Trout populations in both Harmer and Grave Creeks are part of Teck Coal's monitoring program.

The Evaluation of Cause Process

The Process Was Initiated

Teck Coal undertakes aquatic monitoring programs in the Elk Valley, including fish population monitoring. Using data collected as part of Teck Coal's monitoring program, Cope & Cope (2020) reported low abundance of juvenile WCT in 2019, which appeared to be due to recruitment failure in Harmer Creek. Teck Coal initiated an Evaluation of Cause — a process to evaluate and report on what may have contributed to the apparent recruitment failure. Data were analyzed from annual monitoring programs in the Harmer and Grave Creek population areas[3] from 2017 to 2021 (Thorley et al. 2022; Chapter 4, Evaluation of Cause), and several patterns related to recruitment[4] were identified:

- *Reduced Recruitment*[5] occurred during the 2017, 2018 and 2019 spawn years[6] in the Harmer Creek population and in the 2018 spawn year in the Grave Creek population.
- The magnitude of Reduced Recruitment in the Harmer Creek population in the 2018 spawn year was significant enough to constitute *Recruitment Failure*[7].
- Recruitment was *Above Replacement*[8] for the 2020 spawn year in both the Harmer and Grave Creek populations.

[2] Harmer Creek Evaluation of Cause Team. (2023*). Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited.

[3] Grave Creek population area" includes Grave Creek upstream of the waterfall at river kilometer (rkm) 2.1 and Harmer Creek below Harmer Sedimentation Pond. "Harmer Creek population area" includes Harmer Creek and its tributaries (including Dry Creek) from Harmer Sedimentation Pond and upstream.

[4] Recruitment refers to the addition of new individuals to a population through reproduction.

[5] For the purposes of the Evaluation of Cause, Reduced Recruitment is defined as a probability of > 50% that annual recruitment is <100% of that required for population replacement (See Chapter 4, Evaluation of Cause, Harmer Creek Evaluation of Cause Team 2023).

[6] The spawn year is the year a fish egg was deposited, and fry emerged.

[7] For the purposes of the Evaluation of Cause, Recruitment Failure is defined as a probability of > 50% that annual recruitment is <10% of that required for population replacement (See Chapter 4, Evaluation of Cause, Harmer Creek Evaluation of Cause Team 2023).

[8] For the purposes of the Evaluation of Cause, Above Replacement is defined as a probability of > 50% that annual recruitment is >100% of that required for population replacement (See Chapter 4, Evaluation of Cause, Harmer Creek Evaluation of Cause Team 2023).

The recruitment patterns from 2017, 2018 and 2019 in Harmer Creek are collectively referred to as Reduced Recruitment in this report. To the extent that there are specific nuances within 2017-2019 recruitment patterns that correlate with individual years, such as the 2018 Recruitment Failure, these are referenced as appropriate.

How the Evaluation of Cause Was Approached

When the Evaluation of Cause was initiated, an *Evaluation of Cause Team* (the Team) was established. It was composed of *Subject Matter Experts* (SMEs) who evaluated stressors with the potential to impact the WCT population. Further details about the Team are provided in the Evaluation of Cause report (Harmer Creek Evaluation of Cause Team, 2023).

During the Evaluation of Cause process, the Team had regularly scheduled meetings with representatives of the KNC and various agencies (the participants). These meetings included discussions about the overarching question that would be evaluated and about technical issues, such as identifying potential stressors, natural and anthropogenic, which had the potential to impact recruitment in the Harmer Creek WCT population. This was an iterative process driven largely by the Team's evolving understanding of key parameters of the WCT population, such as abundance, density, size, condition and patterns of recruitment over time. Once the approach was finalized and the data were compiled, SMEs presented methods and draft results for informal input from participants. Subject Matter Experts then revised their work to address feedback and, subsequently, participants reviewed and commented on the reports. Finally, results of the analysis of the population monitoring data and potential stressor assessments were integrated to determine the relative contribution of each potential stressor to the Reduced Recruitment in the Harmer Creek population.

The Overarching Question the Team Investigated

The Team investigated the overarching question identified for the Evaluation of Cause, which was:

> **What potential stressors can explain changes in the Harmer Creek Westslope Cutthroat Trout population over time, specifically with respect to Reduced Recruitment?**

The Team developed a systematic and objective approach to investigate the potential stressors that could have contributed to the Reduced Recruitment in the Harmer Creek population. This approach is illustrated in the figure that follows the list of deliverables, below. The approach included evaluating patterns and trends, over time, in data from fish monitoring and potential stressors within the Harmer Creek population area and comparing them with patterns and trends in the nearby Grave Creek population area, which was used as a reference. The SMEs used currently available data to investigate causal effect pathways for the stressors and to determine if the stressors were present at a magnitude and for a duration sufficient to have adversely impacted the WCT. The results of this investigation are provided in two types of deliverables:

1. Individual Subject Matter Expert reports (such as the one that follows this Note). Potential stressors were evaluated by SMEs and their co-authors using the available data. These evaluations were documented in a series of reports that describe spatial and temporal patterns associated with the potential stressors, and they focus on the period of Reduced Recruitment, including the Recruitment Failure of the 2018 spawn year where appropriate. The reports describe if and to what extent potential stressors may explain the Reduced Recruitment.

   The full list of Subject Matter Expert reports follows at the end of this Reader's Note.

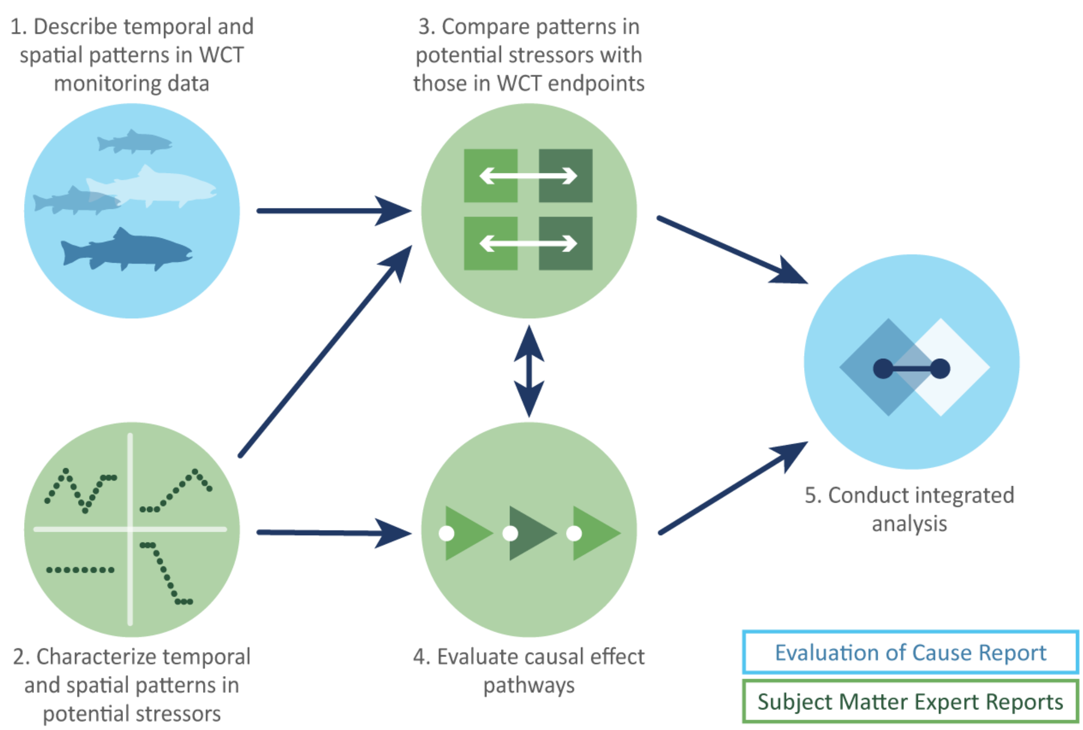
2. The Evaluation of Cause report. The SME reports provided the foundation for the Evaluation of Cause report, which was prepared by a subset of the Team and included input from SMEs.

   The Evaluation of Cause report:

   a. Provides readers with context for the SME reports and describes Harmer and Grave Creeks, the Grave Creek watershed, the history of development in the area and the natural history of WCT in these creeks

b. Presents fish monitoring data, which characterize the Harmer Creek and Grave Creek populations over time

c. Uses an integrated approach to assess the role of each potential stressor in contributing to Reduced Recruitment in the Harmer Creek population area.



Conceptual approach to the Evaluation of Cause for the Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout population.

Participation, Engagement & Transparency

To support transparency, the Team engaged frequently with participants throughout the Evaluation of Cause process. Participants in the Evaluation of Cause process, through various committees, included:

- Ktunaxa Nation Council

- BC Ministry of Forests,
- BC Ministry of Land, Water and Resource Stewardship
- BC Ministry Environment & Climate Change Strategy
- Ministry of Energy, Mines and Low Carbon Innovation
- Environmental Assessment Office

Citations for Evaluation of Cause Team Reports

Focus	Citation
Harmer Creek Evaluation of Cause report	Harmer Creek Evaluation of Cause Team. (2023). *Evaluation of Cause - Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited.
Calcite	Hocking, M. A., Cloutier, R. N., Braga, J., & Hatfield, T. (2022). *Subject Matter Expert Report: Calcite. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Dissolved oxygen	Abell, J., Yu, X., Braga, J., & Hatfield, T. (2022). *Subject Matter Expert Report: Dissolved Oxygen. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Energetic Status	Thorley, J.L. & Branton, M.A. (2023) *Subject Matter Expert Report: Energetic Status at the Onset of Winter Based on Fork Length and Wet Weight. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population*. Report prepared for Teck Coal Limited. Prepared by Poisson Consulting Ltd and Branton Environmental Consulting.

Focus	Citation
Food availability	Wiebe, A., Orr, P., & Ings, J. (2022). *Subject Matter Expert Report: Food Availability. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Minnow Environmental Inc.
Groundwater	Canham, E., & Humphries, S. (2022). *Evaluation of Groundwater as a Potential Stressor to Westslope Cutthroat Trout in the Harmer and Grave Creek Watersheds.* Memo prepared for Teck Coal Limited. Prepared by SNC-Lavalin Inc.
Habitat availability (instream flow)	Wright, N., Little, P., & Hatfield, T. (2022). *Subject Matter Expert Report: Streamflow and Inferred Habitat Availability. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Sediment quality	Wiebe, A., Orr, P., & Ings, J. (2022). Subject Matter Expert Report: Sediment Quality. *Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population*. Report prepared for Teck Coal Limited. Prepared by Minnow Environmental Inc.
Selenium	de Bruyn, A., Bollinger, T., & Luoma, S. (2022). *Subject Matter Expert Report: Selenium. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by ADEPT Environmental Sciences Ltd, TKB Ecosystem Health Services, and SNL PhD, LLC.
Small population size	Thorley, J. L., Hussein, N., Amish, S. J. (2022). *Subject Matter Expert Report: Small Population Size. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Poisson Consulting and Conservation Genomics Consulting, LLC.

Focus	Citation
Telemetry analysis	Akaoka, K., & Hatfield, T. (2022). *Harmer and Grave Creeks Telemetry Movement Analysis.* Memo prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Total suspended solids	Durston, D., & Hatfield, T. (2022). *Subject Matter Expert Report: Total Suspended Solids. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Water quality	Warner, K., & Lancaster, S. (2022). *Subject Matter Expert Report: Surface Water Quality. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by WSP-Golder.
Water temperature and ice	Hocking, M., Whelan, C. & Hatfield, T. (2022). *Subject Matter Expert Report: Water Temperature and Ice. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.

1. INTRODUCTION

In this memo, telemetry data collected by Cope and Cope (2020) for Westslope Cutthroat Trout in Harmer and Grave Creeks are analyzed to characterize fish movement patterns.

Teck Coal undertakes aquatic monitoring programs in the Elk Valley, including fish population monitoring. Using data collected from 2017 to 2019 in Harmer and Grave Creeks, Cope & Cope (2020) reported low abundance of juvenile Westslope Cutthroat Trout (WCT; *Oncorhynchus clarkii lewisi*), which indicated apparent recruitment failure in Harmer Creek. Teck Coal initiated an Evaluation of Cause — a process to evaluate and report on what may have contributed to the apparent recruitment failure. Data were analyzed from annual monitoring programs in the Harmer and Grave Creek population areas[9] from 2017 to 2021 (Thorley et al. 2022; Chapter 4, Evaluation of Cause), and several patterns related to recruitment[10] were identified:

- *Reduced Recruitment*[11] occurred during the 2017, 2018 and 2019 spawn years[12] in the Harmer Creek population and in the 2018 spawn year in the Grave Creek population.
- The magnitude of Reduced Recruitment in the Harmer Creek population in the 2018 spawn year was significant enough to constitute *Recruitment Failure*[13].
- Recruitment was *Above Replacement*[14] for the 2020 spawn year in both the Harmer and Grave Creek populations.

The recruitment patterns from 2017, 2018 and 2019 in Harmer Creek are collectively referred to as Reduced Recruitment in this report. To the extent that there are specific nuances within 2017-2019

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[9] "Grave Creek population area" includes Grave Creek upstream of the waterfall and Harmer Creek below Harmer Sedimentation Pond. "Harmer Creek population area" includes Harmer Creek and its tributaries (including Dry Creek) from Harmer Sedimentation Pond and upstream.

[10] Recruitment refers to the addition of new individuals to a population through reproduction.

[11] For the purposes of the Evaluation of Cause, Reduced Recruitment is defined as a probability of > 50% that annual recruitment was < 100% of that required for population replacement (See Chapter 4, Evaluation of Cause, Harmer Creek Evaluation of Cause Team, 2022).

[12] The spawn year is the year a fish egg was deposited, and fry emerged.

[13] For the purposes of the Evaluation of Cause, Recruitment Failure is defined as a probability of > 50% that annual recruitment is < 10% of that required for population replacement (See Chapter 4 Evaluation of Cause, Harmer Creek Evaluation of Cause Team, 2022).

[14] For the purposes of the Evaluation of Cause, recruitment Above Replacement is defined as a probability of > 50% that annual recruitment is > 100% of that required for population replacement (See Chapter 4 Evaluation of Cause, Harmer Creek Evaluation of Cause Team, 2022)

recruitment patterns that correlate with individual years, such as the 2018 Recruitment Failure, these are referenced as appropriate.

The Evaluation of Cause Project Team investigated one overarching question: **What potential stressors can explain changes in the Harmer Creek Westslope Cutthroat Trout population over time, specifically with respect to patterns of Reduced Recruitment?** To investigate this question, the Team evaluated trends in WCT population parameters, including size, condition, and recruitment, and in the potential stressors[15] that could impact these parameters. They evaluated the trends in WCT population parameters based on monitoring data collected from 2017 to 2021 (reported in Thorley et al., 2022 and Chapter 4, Harmer Creek Evaluation of Cause Team, 2022). The Grave Creek population area was used as a reference area for this evaluation.

The approach for analyzing potential stressors for the Evaluation of Cause was to: (1) characterize trends in each stressor for the Harmer and Grave Creek populations, (2) compare the trends between the two population areas, (3) identify any changes in Harmer Creek during the period of Reduced Recruitment, including the Recruitment Failure of the 2018 spawn year where appropriate, and (4) evaluate how each stressor trended relative to the fish population parameters. The Team then identified mechanisms by which the potential stressors could impact WCT and determined if the stressors were present at a sufficient magnitude and duration to have an adverse effect on WCT during the period of Reduced Recruitment. Together, these analyses were used in the Evaluation of Cause report to support conclusions about the relative contribution of each potential stressor to the Reduced Recruitment observed in the Harmer Creek population area.

As part of the EoC, Ecofish Research Ltd. (Ecofish) was asked to undertake additional analysis of the telemetry data presented in Cope and Cope (2020) to inform a detailed understanding of fish movements and timing in Grave and Harmer creeks and their tributaries, and to understand whether the influence of some stressors may be dependent on movements or restrictions to movements. This analysis also considers the impact of the presence of two culverts in Grave Creek, at river kilometres (rkms) 4.54 and 7.82. This memo summarizes the additional analysis conducted on the telemetry data to provide a detailed look at movement patterns within the species annual periodicity of key life history activities.

[15] The Evaluation of Cause process was initiated early in 2021 with currently available data. Although the process continued through mid-2022, data collected in 2021 were not included in the Evaluation of Cause because most stressor reports were already complete. Exceptions were made for the 2021 fish monitoring data and (1) selenium data because the selenium report was not complete and substantive new datasets were available and (2) water temperature data for 2021 in the temperature report because a new sampling location was added in upper Grave Creek that contributed to our understanding of the Grave Creek population area.

This document is one of a series of Subject Matter Expert (SME) reports that supports the integrated Harmer Creek Westslope Cutthroat Trout Evaluation of Cause (Harmer Creek Evaluation of Cause Team, 2022). For more information, see the preceding Reader's Note.

2. METHODS

2.1. Species Periodicity

Assumed life history activity periods were provided by the EoC Subject Matter Expert team in a periodicity table (Table 1).

Table 1. **WCT life history periodicity table for the Grave Creek Watershed. Within the incubation periodicity, two scenarios are provided based on observations of red construction and WCT spawning habits: incubation for eggs spawned early in the spawning period (dark grey) and incubation for eggs spawned late in the period (light grey).**

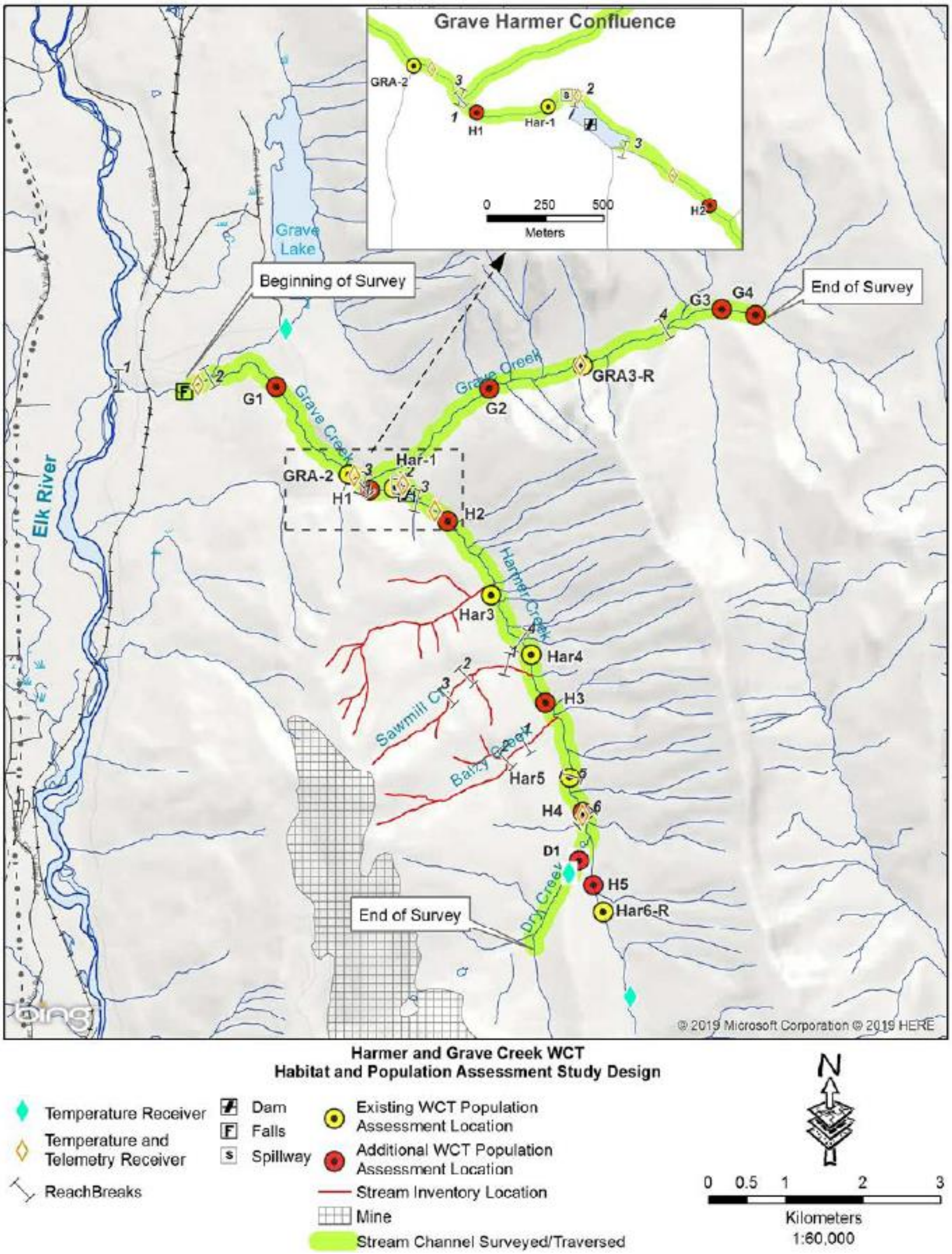
Life History Activity	Jan				Feb				Mar				Apr				May				Jun				Jul				Aug				Sep				Oct				Nov				Dec			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Spawning																						■	■	■	■	■																						
Incubation (egg and alevin)																						■	■	■	■	■	■	■	■	■	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒								
Summer Rearing (>5ºC)																				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■										
Over-wintering	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																				■	■	■	■	■	■	■	■	■	■

2.2. Telemetry Data

Cope and Cope (2020) assessed a variety of study questions related to the Grave Creek population and the Harmer Creek population. The study area includes the areas accessible to the separate Grave and Harmer populations. The Grave Creek population area consists of Grave Creek from its headwaters (Reach 4) to a natural permanent falls barrier 2.1 km from the confluence with the Elk River, and the section of Harmer Creek (Reach 1) downstream of the Harmer Sedimentation Pond. The Harmer Creek population area consists of Harmer Creek upstream of the Harmer Spillway (Reach 3) to its headwaters in Reach 6; this population area also includes Dry Creek. A description of the reaches is provided in Table 2.

One of the study questions posed in Cope and Cope (2020) focused on temporal and spatial patterns of fish movement. Two cohorts (39 fish in 2017 and 40 fish in 2018; 79 total) were radio-tagged and then tracked in a telemetry study using a combination of fixed-station receivers and mobile tracking (Figure 1). Within each cohort, the sample was split equally between Grave and Harmer populations. In 2017, the number of tagged fish corresponded roughly to 1.8% of the adult Grave Creek population and 3.8% of the adult Harmer Creek population (Thorley *et al.* 2021). For Year 2, the proportions of radio-tagged fish were roughly 4.4% and 5.0%, respectively, due to smaller estimated population sizes in 2018 (Thorley *et al.* 2021). All radio-tagged fish were adults or sub-adults, with an average length of 221 mm across all radio-tagged individuals. Due to the relatively small size of the fish, the radio tags needed to also be small in size, resulting in relatively short battery life. To extend battery life, the tags were operated on a 12 hour on/off cycle; however, even with this operation limitation the lifespan of the tags was expected to be 225 days or less. Radio telemetry data in Year 1 (2017) covered the period of late July through early January. In Year 2 (2018), further attempts were made to improve battery life by modifying the tag radio outputs. The modifications resulted in poorer than expected output and range, leading to few detections in the fall and overwintering periods in both populations. As such, the Year 2 data were limited mostly to the late July through October period.

Figure 1. Grave and Harmer telemetry study area map showing location of fixed receivers (from Cope and Cope 2020).



2.3. Data Organization and Location of Initial Fish Captures

Fish in the two populations were radio tagged using a random stratified sampling design, weighted by reach length. Radio tags were randomly applied within each reach, and the number of radio tags attempted to be deployed in each reach were determined by the length of the reach (Cope and Cope 2020). Due to the low densities of fish in the system, this design was used as guidance, meaning the actual number of tagged fish varied based on what was achievable. Capture effort was estimated to be approximately 20 days at a rate of roughly 2 tagged fish per day (Cope and Cope 2020). The number of fish radio tagged across both years of the study in each reach, along with the location of the fixed station receivers are summarized in Table 2. The majority of detections are at the fixed telemetry stations, but mobile tracking effort was also used.

The raw telemetry data collected during the Cope and Cope (2020) study were processed to simplify and more easily identify patterns. For each cohort of radio-tagged fish, the telemetry data were organized as a time series corresponding to each fixed-station and mobile tracking detection. Each detection was then cross-referenced to the associated river km using the UTM coordinates of the detection.

Table 2. Summary of initial fish captures and receiver locations in the Grave-Harmer telemetry study.

Population	Stream	Reach	Reach Length (km)	# of Fish Captured for Radio	Fixed Telemetry Receiver?
Harmer	Dry Creek	DC-R3	0.53	2	No
	Harmer Creek	HRM-R5	0.93	1	Yes
		HRM-R4	2.18	14	No
		HRM-R3	2.61	21	Yes
Grave	Harmer Creek	HRM-R1*	1.45	7	Yes
	Grave Creek	GRV-R4	3.95	1	No
		GRV-R3	4.75	15	Yes
		GRV-R2	2.95	17	No
		GRV-R1	1.45	1	Yes

*Considered part of Grave population

2.4. Movement Analysis

Analysis was conducted on the telemetry data to determine patterns of fish movement in terms of timing, distance, and location. To assess the amount of each population area used, the home range of each fish was calculated. The home range was defined as the distance between the upstream-most and downstream-most detections for each fish. Home range was also examined more coarsely to investigate the number of reaches where each fish was detected. One fish detection was classified as belonging to Sawmill Creek Reach 1; upon further review it was determined that the detection was at the confluence of Sawmill Creek and Harmer Creek. Consequently, for the purposes of this analysis, this detection was re-classified as belonging to Harmer Creek Reach 4.

It is also important to recognize the presence of two culverts in Grave Creek that are barriers to fish passage, located at rkms 4.54 and 7.82. These lower and upper culverts were replaced with bridges in November 2017 and October 2018, respectively, suggesting that they may impact fish movement patterns for some of the study period.

The telemetry data were also summarized using a web-based HTML viewer. This viewer included five interactive views of the data:

- A plot showing the time series of fish detections by stream reach;
- A plot showing the time series of fish detections by river km for the Grave population;
- A plot showing the time series of fish detections by river km for the Harmer population;
- A map showing the location of fish captured for the telemetry study; and
- A map showing the locations of all fish detections over the course of the telemetry study.

The interactive plots and maps were created using R statistical programming software (R Core Team 2021). The R packages used to create the interactive plots and maps include sf (Pebesma 2018), plotly (Sievert 2020), leaflet (Cheng *et al.* 2021), and flexdashboard (Iannone *et al.* 2020).

3. RESULTS AND DISCUSSION

3.1. Movement Analysis

The home range analysis indicates that the majority of sub-adult and adult fish in both populations do not move large distances within the study area (Figure 2 and Figure 3). The majority of fish (62%) across both populations were not detected outside of the same reach where they were initially tagged. Furthermore, only 30% of fish were detected in 2 reaches, and just 8% were detected in 3 reaches. In terms of distance, the median home range for both populations was less than 500 m (Grave = 160 m, Harmer = 330 m), indicating a lack of long-distance movement by most of the tagged individuals during the periods of available data. There were 5 individuals observed in the Harmer population with home ranges larger than 2 km; all but 1 of these fish were observed to have movement both to and from Harmer Reach 5, and 2 of these fish were also observed to have entered Dry Creek. Home ranges in the Grave population were smaller and less variable; all fish had home ranges less than 1 km, and movement between the downstream section (near the R1/R2 boundary), the middle section (near Harmer confluence), and the upper section (upstream R3) was not observed; although falls, culverts and a fish fence influenced the maximum movement distances possible within some sections of both Grave and Harmer creeks.

The relatively small sample size and the incomplete coverage of some periods made analysis of intra- and inter-annual movement challenging and was done qualitatively. There were no clear differences in movement patterns between years. The Grave Creek population had small home ranges in both years, and all movement occurred within lower, middle, or upper sections of the river (i.e., no movements were detected between these sections). Similarly, the Harmer Creek population had mostly small home ranges in both years, with very few fish moving longer distances in each year.

Movements within Grave Creek were possibly influenced by the presence of impassable culverts during parts of the study, which may have constrained (i.e., truncated) the observed movement distances. However, movement patterns did not notably change following replacement of the culverts. Likewise, individuals were not constrained in their movement in the opposite directions; that is, fish upstream of a culvert had opportunity to move within a broad area upstream of the culvert, and fish downstream of a culvert had opportunity to move in a downstream direction. Despite this opportunity, the fish did not move large distances. Acknowledging the potential constraints of the culverts and the small sample size, we interpret the available movement data to indicate that fish in both Harmer are Grave had small home ranges during the periods of monitoring and do not emphasize apparent differences between the two population areas.

Figure 2. Frequency histogram of home range by cohort. Home range is expressed as the number of stream reaches in which each fish was detected.

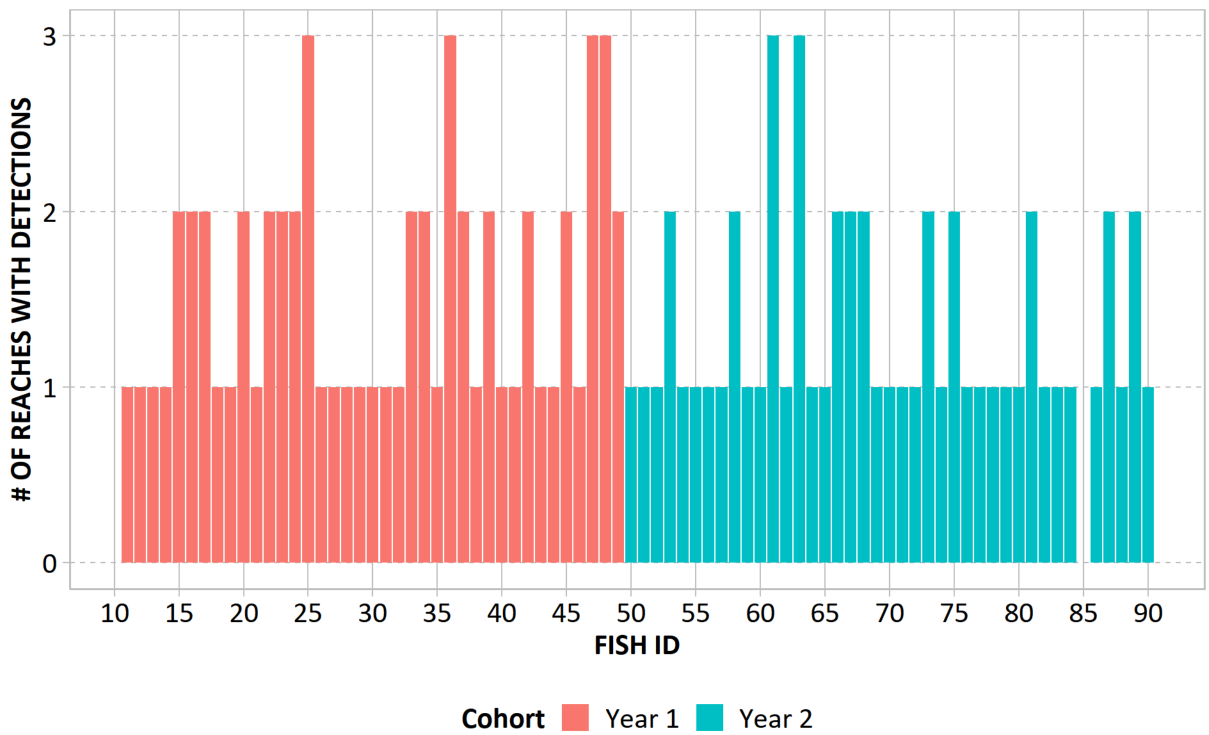
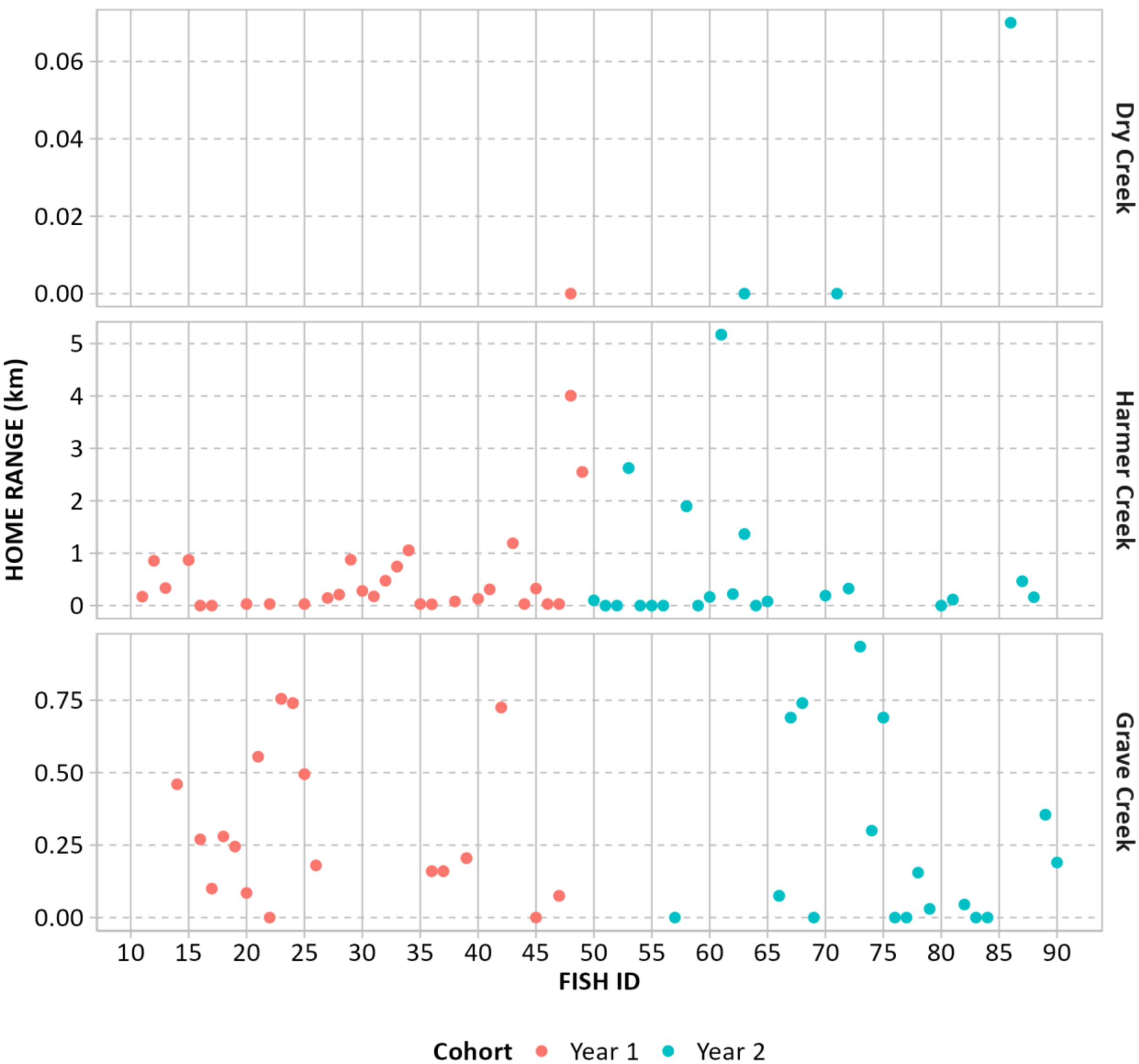


Figure 3. Summary of home range by stream and cohort. Home range is expressed as distance between upstream-most and downstream-most telemetry detections. Note that the scale on the y-axis differs by stream.



3.2. Migration and Life History

Home ranges for small, isolated headwater tributary populations have been "typically documented as 1 km or less" in previous literature (Muhlfeld *et al.* 2003, Brown 1999, Jakober *et al.* 2000, Young 1998). The home range patterns observed in both Grave and Harmer population areas are consistent with this statement. A fall migration to distant overwintering locations was not observed, and the majority of both populations spent the summer rearing period in the same approximate location as overwintering. However, we cannot exclude the possibility of longer-distance movements occurring within the periods for which we have no data.

The Harmer Creek population included 5 fish associated with larger home ranges (>2 km) than all other individuals. 4 of these 5 fish were observed to have movement in the upstream direction in late August-late September, followed by downstream movement in October-January. However, due to the relatively low temporal and spatial resolution of the data, exact timing of these movements is unclear. The other (1) fish with a large home range was observed to move in a downstream direction towards Harmer Dam in October, and then back upstream in early November. Additionally, two fish were detected first downstream of Harmer Dam, then upstream of Harmer Dam, and then again downstream of Harmer Dam. As this movement pattern is impossible, these detections were considered to be erroneous.

The majority of fish in the Harmer population (Figure 5) did not move long distances. The limited patterns of movement into and out of Dry Creek can be seen, along with the two fish captured and tagged in Dry Creek in Year 2. A single tagged fish migrated into Dry Creek in September 2017 but was then relocated as part of salvage efforts during the erection of a temporary exclusion fence as part of the Baldy Ridge Extension Project. This temporary exclusion fence was in place until December 3, 2017 (Cope and Cope 2020).

Figure 4 and Figure 5 provide a summary of all the telemetry data over time. In the Grave Creek population (Figure 4), the detections indicate an overall lack of movement, and an absence of movement between three general regions: the upper portion of Reach 3 and Reach 4; the area near the Harmer confluence and Harmer Dam; and the downstream portion of Grave Creek in Reach 1 and 2; however, the presence of barriers (falls and culverts) may have restricted movements for some or all of the study period. The upstream-most fixed telemetry station was located just upstream to the upper culvert that was present for the majority of the study period. Some fish in 2017 that were detected at this fixed station were also detected downstream of the culvert via mobile tracking, and it is unclear if these patterns were caused by data errors, a lack of precise spatial resolution with the mobile or fixed receivers, or possibly movements across the culvert. At the lower culvert, no fish were observed crossing the location of the barrier either before or after its removal in November 2017. (Note: in Figure 4, some fish appear to cross the barrier, but in all cases represent movement into Harmer Creek Reach 1 rather than movement further upstream into Grave Creek Reach 3 where the barrier is located). Overall, the figures illustrate the gap in observations between years, the scarcity of data after September/October 2018 due to the failure of the experimental radio tags, and no apparent change in movement patterns between summer rearing and overwintering.

Figure 4. Time series of fish detections for the Grave Creek population. Detections from HRM-R1 are also included here and are overlaid on the plot as rkms 4.45-4.98. The fixed telemetry station in HRM-R1 is located at rkm 4.94.

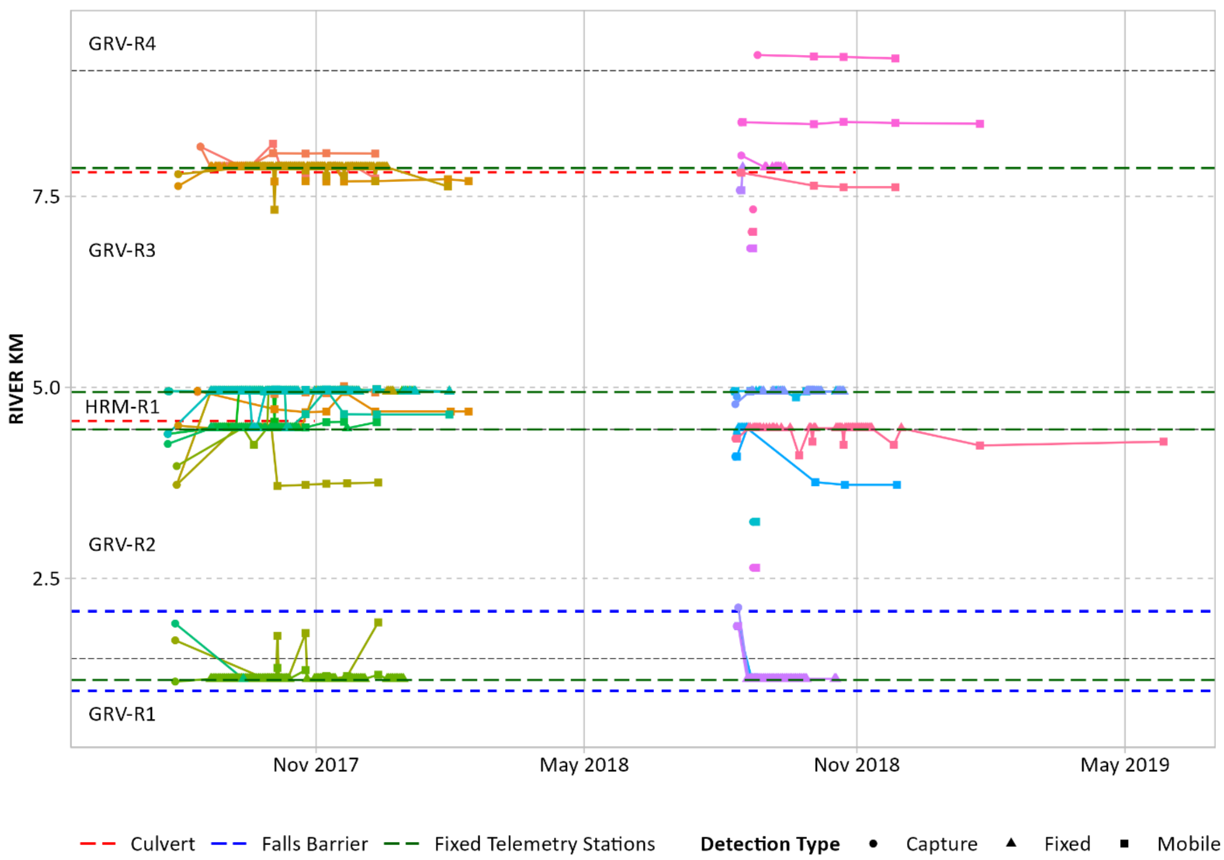
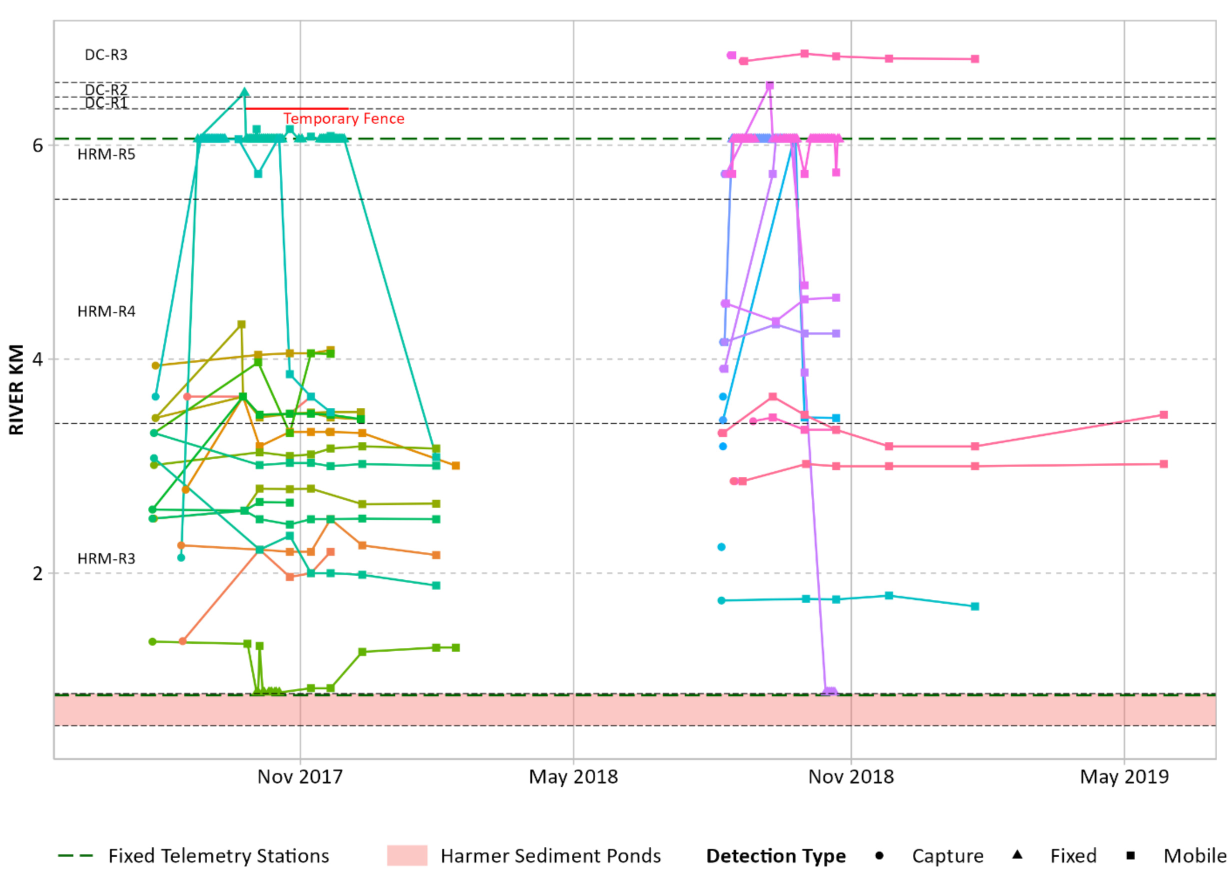


Figure 5. Time series of fish detections for the Harmer Creek population (including Dry Creek). The location and duration of the temporary exclusion fence in Dry Creek is indicated by a red line.



4. CONCLUSIONS

Detailed analyses of the telemetry data presented in Cope and Cope (2020) highlight key trends in the movement of WCT in Grave and Harmer creeks. The data are generally limited to summer rearing and fall migration in two years, and overwintering in one year, yet show consistent patterns. The majority of adult and sub-adult fish in both populations do not move large distances during these periods. This is confirmed both in an analysis of home range of fish, and a review of the locations of both fixed station and mobile detections. The absence of large distance movement within and between summer rearing and overwintering periods imply a lack of movement during spring migration; although we cannot exclude the possibility of short-duration, longer-distance movements during the periods for which we have no data. Movements within Grave Creek were possibly influenced by the presence of impassable culverts during parts of the study; however, the available movement data indicate that fish in both Harmer are Grave had small home ranges during the periods of monitoring. Implications of movement patterns on exposure to stressors are to be assessed as relevant by each Subject Matter Expert.

Yours truly,

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Disclaimer:

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