Subject Matter Expert Report: FISH PASSAGE. Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population

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EXECUTIVE SUMMARY

Abundances of both juvenile and adult life stages of Westslope Cutthroat Trout (Oncorhynchus clarkii lewisi; WCT) in the upper Fording River (UFR) were substantively lower in 2019 than 2017, indicating a large decline during that two-year period (the Westslope Cutthroat Trout Population Decline Window, also referred to as the Decline Window). Teck Coal Limited (Teck Coal) initiated the "Evaluation of Cause" (EoC) to determine whether and to what extent various stressors and conditions played a role in the decline. One of several potential stressors that has been identified is loss of stream connectivity due to low water levels in the fall migration period, which could limit fish access to overwintering habitat and potentially result in fish mortality. This report investigates potential restrictions to WCT movement in the UFR during the fall migration period and outlines how such potential restrictions may have contributed to the WCT decline in combination with other stressors.

The impact hypothesis evaluated was:

- Did restricted fish passage within the UFR during the fall migration period contribute to the observed WCT population decline?

Our evaluation of potential restrictions in WCT movement during fall migration between September 2017 and September 2019 focused on a critical riffle analysis (CRA) that involves examination of conditions at riffles that may act as barriers at low flows. However, this evaluation was supported by:

- Summarizing passive integrated transponder (PIT) tag data collected at two detecting arrays at the Multi-plate and Henretta culverts;
- Completing additional analyses on radio telemetry data collected by Cope et al. (2016);
- Documenting the recent habitat rehabilitation work that has occurred on the Fording River mainstem and the potential for impacts on migration during construction; and
- Evaluating the occurrence of large log jams on the upper Fording River mainstem.

The CRA followed methods used during the 2018 study for the Fording River Operations (FRO) Operational Environmental Monitoring Plan (OEMP; Johnson et al. 2019) and evaluated fish passage at five critical riffles (FRD-CRA01 to 05) using hydraulic measurements in relation to fish passage criteria. For the EoC, we focussed on the results from the non-linear transects and passability of riffles according to fish passability Criterion 2 (a contiguous section of 10% of wetted width that satisfies the minimum depth criterion) and extended the analysis completed in the 2018 OEMP study to evaluate likely passage conditions at critical riffles using available flow data from other years (1997-2019 for Measuring Point B (near the North Tailings Pond), 2017-2019 for Measuring Point C (upstream of Chauncey Creek)). Results from the CRA were used to evaluate requisite conditions (conditions that would need to be true for loss of stream connectivity to have contributed to the

observed WCT decline) by evaluating spatial extent, duration, location, timing, and intensity for loss of connectivity.

The PIT tag analysis evaluated data collected by the two PIT tag detecting arrays to determine the number of fish detected between 2017 to 2020, along with the timing of activity and movement, to provide insight into the timing of peak movement and timing of the WCT population decline. Additional analysis of the radio telemetry data collected by Cope et al. (2016) between 2012 and 2015 (Appendix A) assessed key trends in WCT movement in the upper Fording River including the distance and timing of movement, and the potential implications of passage barriers. Rehabilitation work that has occurred on the Fording River mainstem between 2016 and 2018 was documented to allow a qualitative assessment of the potential for behavioral avoidance of construction works. Additionally, we used orthophotos from 2007, 2012, 2013, 2016, 2017, 2018 and 2019 to assess the potential for log jam formation to interrupt WCT migration behaviour in the UFR. Log jams were counted for each river segment based on the criteria that they spanned the width of the upper Fording River and had more than approximately 30 logs; these criteria were considered sufficient to influence fish passage or result in channel changes.

Results of the CRA indicate that juvenile and adult WCT movement past two of the critical riffles assessed was likely impeded by insufficient water depth for 80% of the 45-day fall migration period of September 1 to October 15, 2018. These two riffles are located in a reach of the UFR between Chauncey and Kilmarnock creeks that seasonally dewaters; however, passage is predicted to have been impeded on September 26, 2018 due to insufficient depths even when wetted widths were >25 m. The available data also suggest that adult passage at a third critical riffle near the confluence of Henretta Creek and the Fording River was impeded for 40% of the 45-day 2018 fall migration period. It is important to note that these results are based on modelling passability based on bed profile and assumed depth and width requirements, rather than observing whether fish can or cannot pass at a certain discharge. There is some uncertainty, therefore, in the degree to which movement past the riffles was actually impeded in 2018.

There is additional uncertainty when extrapolating beyond 2018, when empirical measurements were taken, to evaluate conditions in other fall migration periods for two reasons. First, if there were channel forming flows between the 2018 fall migration period and other periods of interest there is the potential that morphological changes could have made critical riffles more or less sensitive than when surveyed in 2018. Second, given the distance between the riffles and the hydrometric gauges at Measuring Points B (at North Tailings Pond) and C (upstream of Chauncey Creek), and the small range of variability in flows during the period when loggers were installed at the riffles in 2018, it was not possible to develop accurate stage-discharge relationships relating stage at the critical riffles to discharge at the hydrometric gauges. The evaluation of passage conditions in other years therefore relies on the riffle-specific passage thresholds derived from empirical measurements in fall 2018, and the corresponding discharge at Measuring Points B or C at the time of the survey, to make inferences about when passage may have been restricted in other years. However, if inflow conditions and/or operational water use between the critical riffles and the hydrometric gauges at Measuring Points B and C were different in 2018 than the other years being assessed, then passage conditions at the critical riffles may have been different even if Measuring Point discharge was the same. Despite these uncertainties regarding extrapolating passage conditions at the specific critical riffles assessed, we believe that the identification of passage constraints in the fall of 2018 makes it reasonable to use these data to make general inferences about passage conditions at critical riffles in the upper Fording River in other years.

Flows were higher in 2019 than in 2018 and thus all critical riffles assessed were likely passable through September, although there is uncertainty for the two riffles in the seasonally dewatered reach because the discharge at which the transect is passable is not known. In fall 2017, there is not enough flow data available at Measuring Point C to judge whether the two riffles in the seasonally dewatered reach were passable during the migration period; however, the third riffle in the reach between Chauncey and Kilmarnock creeks was likely passable based on the passage threshold and flows in late October. Flows at Measuring Point B between mid-September and the end of the migration period in 2017 were the lowest in the flow data available (1997-2019), and the riffle near the confluence of Henretta Creek and the Fording River would likely not have been passable for juveniles or adults at these flows. However, there is a data gap from September 7 to 22 so passage conditions within this period are unknown. Given the low flows in 2017, the fourth riffle near the confluence of Clode Creek may also not have been passable for much of the fall migration period, although there is more uncertainty for this riffle because the discharge at which the transect is not passable is unknown.

PIT tag analysis results indicated that detections were substantially reduced by summer of 2019 relative to summers of 2017 and 2018, providing evidence that the decline occurred between the summers of 2018 and 2019. The PIT tag analysis (Section 3.2) and aspects of the telemetry analysis (Section 3.2 in Appendix A) indicated higher levels of activity and movement in the summer rearing period compared to the September 1 to October 15 fall migration period. However, evaluation of movement trends using telemetry data (Section 3.6 in Appendix A) found general alignment with the assumed fall migration period of September 1 to October 15. Nevertheless, if timing of migration differs from the assumed timing in a given year, this could affect conclusions with respect to the potential effects of the identified critical riffles, since flow and water levels would differ during alternative movement periods.

The analysis of telemetry data also identified that the majority of fish do not move large distances from their overwintering location (Appendix A). This was confirmed both in an analysis of home range of fish, and cumulative probability distributions of fish movement. To aid understanding of whether connectivity may influence exposure to some stressors, a hypothetical scenario of a full and permanent barrier to fish passage at the multi-plate culvert (rkm 57.4) or the drying reach (rkm 50) was explored. For either scenario, roughly 25% of the radio-tagged UFR fish would have been affected. The conclusion is that a hypothetical barrier may have affected some individuals, but it would not be responsible for concentrating a majority of fish in a zone they would otherwise not have occupied. The same conclusion holds when evaluating riffle barriers using the CRA.

The assessment of stream rehabilitation and restoration projects that occurred during the Decline Window indicated that the projects were fully permitted and carried out with mitigation measures to minimize effects to WCT in place. Our qualitative assessment concluded that the duration, timing and nature of these projects would not cause a substantial effect to WCT passage. Similarly, log jam formation was considered unlikely to have delayed WCT migration in a way that differed between the Decline Window and prior years. While there were significant log jam formations present in the UFR during the Decline Window, there doesn't appear to be a visible increase compared to previous years, and major log jams appeared to be stable attributes that remain constant for years.

Potential restrictions to WCT movement in the UFR during fall migration periods in the Decline Window were identified at specific locations and some requisite conditions to contribute to the decline (Duration, Intensity, Location, and Timing) were met. However, the requisite conditions for Spatial Extent could not be confidently assessed because passage impedances were identified only at a limited number of locations and the influence of impedance at these locations will depend on the number of fish affected. Overall, however, potential restrictions to WCT movement in the UFR during the fall migration periods in the Decline Window were identified; thus, requisite conditions to contribute to the decline were identified. Other stressors would need to interact with the lack of connectivity and confinement of fish within sub-optimal overwintering habitat to result in the documented WCT mortality. Other stressors identified that could have interacted with reduced connectivity in fall 2018 include unusually cold weather during the winter of 2018/2019, which could have caused rapid freeze-up and unusually extensive ice formation. This could have resulted in an increased risk of mortality from dewatering, freezing, predation, and suboptimal water quality (e.g., reduced dissolved oxygen) due to confinement of fish within sub-optimal habitats (likely shallower with less cover).

Several assumptions were made for the analyses conducted for this assessment and uncertainties were identified. Uncertainties were related to assumptions of the model (hydraulic measurements and criteria used to evaluate fish passability), behaviour of WCT (e.g., migration requirements, timing and duration of migration), locations studied (analyses were focused on one area in the UFR), time frame (duration of connectivity losses), and potential differences in conditions (e.g., in riffle morphology, inflows, operational water use) between 2018 when empirical measurements were made at critical riffles and the other years assessed. If the assumptions made do not reflect reality, this could affect potential consequences of identified barriers for fish or interactions with seasonal flow and water level changes. In addition, hydrological data from outside the Decline Window was only available for Measuring Point B (at North Tailings Pond); thus, results for all critical riffles could not be evaluated in comparison to previous years when WCT abundance had not yet decreased and when connectivity issues may also have existed.

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ACRONYMNS AND ABBREVIATIONS

CRA – Critical Riffle Analysis

EoC – Evaluation of Cause

FRO – Fording River Operations

IFS – Instream Flow Study

OEMP – Operational Environmental Monitoring Plan

PIT – Passive Integrated Transponder

SME – Subject Matter Expert

UFR – Upper Fording River

WCT – Westslope Cutthroat Trout

READER'S NOTE

What is the Evaluation of Cause and what is its purpose?

The Evaluation of Cause is the process used to investigate, evaluate and report on the reasons the Westslope Cutthroat Trout population declined in the upper Fording River between fall 2017 and fall 2019.

Background

The Elk Valley is located in the southeast corner of British Columbia (BC), Canada. It contains the main stem of the Elk River (220 km long) and many tributaries, including the Fording River (70 km long). This report focuses on the upper Fording River, which starts 20 km upstream from its confluence with the Elk River at Josephine Falls. The Ktunaxa First Nation has occupied lands in the region for more than 10,000 years. Rivers and streams of the region provide culturally important sources of fish and plants.

The upper Fording River watershed is at a high elevation and is occupied by only one fish species, a genetically pure population of Westslope Cutthroat Trout *(Oncorhynchus clarkii lewisi)* — an iconic fish species that is highly valued in the area. This population is physically isolated because Josephine Falls is a natural barrier to fish movement. The species is protected under the federal Fisheries Act and the Species at Risk Act. In BC, the Conservation Data Center categorized Westslope Cutthroat Trout as *"imperiled or of special concern, vulnerable to extirpation or extinction."* Finally, it has been identified as a priority sport fish species by the Province of BC.

Evaluation of Cause

Following identification of the decline in the Westslope Cutthroat Trout population, Teck Coal initiated an Evaluation of Cause process. The overall results of this process are reported in a separate document (Evaluation of Cause Team, 2021) and are supported by a series of Subject Matter Expert reports.

The report that follows this Reader's Note is one of those Subject Matter Expert Reports.

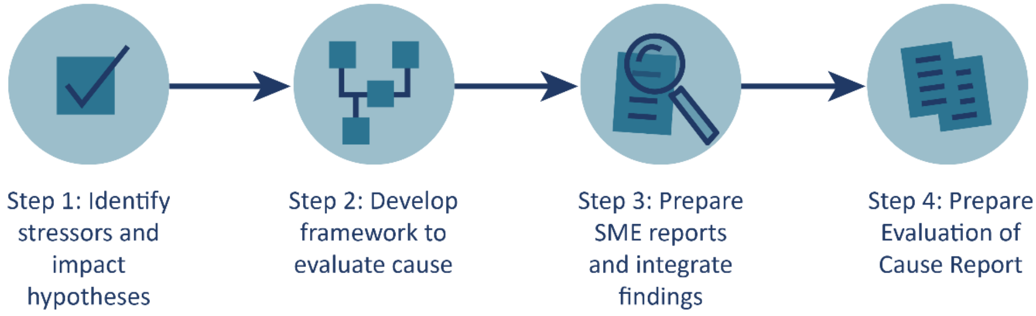
The upper Fording River watershed is influenced by various human-caused disturbances including roads, a railway, a natural gas pipeline, forest harvesting and coal mining. Teck Coal Limited (Teck Coal) operates the three surface coal mines within the upper Fording River watershed, upstream of Josephine Falls: Fording River Operations, Greenhills Operations and Line Creek Operations.

Monitoring conducted for Teck Coal in the fall of 2019 found that the abundance of Westslope Cutthroat Trout adults and sub-adults in the upper Fording River had declined significantly since previous sampling in fall 2017. In addition, there was evidence that juvenile fish density had decreased. Teck Coal initiated an *Evaluation of Cause* process. The overall results of this process are reported separately (Evaluation of Cause Team, 2021) and are supported by a series of Subject Matter Expert reports such as this one. The full list of SME reports follows at the end of this Reader's Note.

Building on and in addition to the Evaluation of Cause, there are ongoing efforts to support fish population recovery and implement environmental improvements in the upper Fording River.

How the Evaluation of Cause was approached

When the fish decline was identified, Teck Coal established an *Evaluation of Cause Team* (the Team), composed of *Subject Matter Experts* and coordinated by an Evaluation of Cause *Team Lead.* Further details about the Team are provided in the Evaluation of Cause report. The Team developed a systematic and objective approach (see figure below) that included developing a Framework for Subject Matter Experts to apply in their specific work. All work was subjected to rigorous peer review.



Conceptual approach to the Evaluation of Cause for the decline in the upper Fording River Westslope Cutthroat Trout population.

With input from representatives of various regulatory agencies and the Ktunaxa Nation Council, the Team initially identified potential stressors and impact hypotheses that might explain the cause(s) of the population decline. Two overarching hypotheses (essentially, questions for the Team to evaluate) were used:

- Overarching Hypothesis #1: The significant decline in the upper Fording River Westslope Cutthroat Trout population was a result of a single acute stressor[1] or a single chronic stressor[2].
- Overarching Hypothesis #2: The significant decline in the upper Fording River Westslope Cutthroat Trout population was a result of a combination of acute and/or chronic stressors, which individually may not account for reduced fish numbers, but cumulatively caused the decline.

The Evaluation of Cause examined numerous stressors in the UFR to determine if and to what extent those stressors and various conditions played a role in the Westslope Cutthroat Trout's decline. Given that the purpose was to evaluate the cause of the decline in abundance from 2017 to 2019[3], it was important to identify stressors or conditions that changed or were different during that period. It was equally important to identify the potential stressors or conditions that did not change during the decline window but may, nevertheless, have been important constraints on the population with respect to their ability to respond to or recover from the stressors. Finally, interactions between stressors and conditions had to be considered in an integrated fashion. Where an *impact hypothesis* depended on or may have been exacerbated by interactions among stressors or conditions, the interaction mechanisms were also considered.

The Evaluation of Cause process produced two types of deliverables:

1. **Individual Subject Matter Expert (SME) reports** (such as the one that follows this Note): These reports mostly focus on impact hypotheses under Overarching Hypothesis #1 (see list, following). A Framework was used to align SME work for all the potential stressors, and, for consistency, most SME reports have the same overall format. The format covers: (1) rationale for impact hypotheses, (2) methods, (3) analysis and (4) findings, particularly

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[1] Implies September 2017 to September 2019.

[2] Implies a chronic, slow change in the stressor (using 2012–2019 timeframe, data dependent).

[3] Abundance estimates for adults/sub-adults are based on surveys in September of each year, while estimates for juveniles are based on surveys in August.

whether the requisite conditions4 were met for the stressor(s) to be the sole cause of the fish population decline, or a contributor to it. In addition to the report, each SME provided a summary table of findings, generated according to the Framework. These summaries were used to integrate information for the Evaluation of Cause report. Note that some SME reports did not investigate specific stressors; instead, they evaluated other information considered potentially useful for supporting SME reports and the overall Evaluation of Cause, or added context (such as in the SME report that describes climate (Wright et al., 2021).

2. **The Evaluation of Cause report** (prepared by a subset of the Team, with input from SMEs): This overall report summarizes the findings of the SME reports and further considers interactions between stressors (Overarching Hypothesis #2). It describes the reasons that most likely account for the decline in the Westslope Cutthroat Trout population in the upper Fording River.

Participation, Engagement & Transparency

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

Ktunaxa Nation Council

BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development

BC Ministry Environment & Climate Change Strategy

Ministry of Energy, Mines and Low Carbon Innovation

Environmental Assessment Office

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[4] These are the conditions that would need to have occurred for the impact hypothesis to have resulted in the observed decline of Westslope Cutthroat Trout population in the upper Fording River.

Citation for the Evaluation of Cause Report

When citing the Evaluation of Cause Report use:

Evaluation of Cause Team, (2021). *Evaluation of Cause — Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Evaluation of Cause Team.

Citations for Subject Matter Expert Reports

Focus	Citation for Subject Matter Expert Reports
Climate, temperature, and streamflow	Wright, N., Greenacre, D., & Hatfield, T. (2021). *Subject Matter Expert Report: Climate, Water Temperature, Streamflow and Water Use Trends. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Ice	Hatfield, T., & Whelan, C. (2021). *Subject Matter Expert Report: Ice. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. Report Prepared by Ecofish Research Ltd.
Habitat availability (instream flow)	Healey, K., Little, P., & Hatfield, T. (2021). *Subject Matter Expert Report: Habitat availability. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Ecofish Research Ltd.
Stranding – ramping	Faulkner, S., Carter, J., Sparling, M., Hatfield, T., & Nicholl, S. (2021). *Subject Matter Expert Report: Ramping and stranding. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Ecofish Research Ltd.

Focus	Citation for Subject Matter Expert Reports
Stranding – channel dewatering	Hatfield, T., Ammerlaan, J., Regehr, H., Carter, J., & Faulkner, S. (2021). *Subject Matter Expert Report: Channel dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Ecofish Research Ltd.
Stranding – mainstem dewatering	Hocking M., Ammerlaan, J., Healey, K., Akaoka, K., & Hatfield T. (2021). *Subject Matter Expert Report: Mainstem dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd. and Lotic Environmental Ltd. Zathey, N., & Robinson, M.D. (2021). *Summary of ephemeral conditions in the upper Fording River Watershed. In Hocking et al. (2021). Subject Matter Expert Report: Mainstem dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd. and Lotic Environmental Ltd.
Calcite	Hocking, M., Tamminga, A., Arnett, T., Robinson M., Larratt, H., & Hatfield, T. (2021). *Subject Matter Expert Report: Calcite. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd., Lotic Environmental Ltd., and Larratt Aquatic Consulting Ltd.
Total suspended solids	Durston, D., Greenacre, D., Ganshorn, K & Hatfield, T. (2021). *Subject Matter Expert Report: Total suspended solids. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Fish passage (habitat connectivity)	Harwood, A., Suzanne, C., Whelan, C., & Hatfield, T. (2021). *Subject Matter Expert Report: Fish passage. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd. Akaoka, K., & Hatfield, T. (2021). Telemetry Movement Analysis. In Harwood et al. (2021). *Subject Matter Expert Report: Fish passage. Evaluation of Cause – Decline in upper*

Focus	Citation for Subject Matter Expert Reports
	Fording River Westslope Cutthroat Trout population. Report prepared for Teck Coal Ltd. by Ecofish Research Ltd.
Cyanobacteria	Larratt, H., & Self, J. (2021). *Subject Matter Expert Report: Cyanobacteria, periphyton and aquatic macrophytes. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Larratt Aquatic Consulting Ltd.
Algae / macrophytes	
Water quality (all parameters except water temperature and TSS [Ecofish])	Costa, EJ., & de Bruyn, A. (2021). *Subject Matter Expert Report: Water quality. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd. Healey, K., & Hatfield, T. (2021). *Calculator to assess Potential for cryoconcentration in upper Fording River.* In Costa, EJ., & de Bruyn, A. (2021). *Subject Matter Expert Report: Water quality. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd.
Industrial chemicals, spills and unauthorized releases	Van Geest, J., Hart, V., Costa, EJ., & de Bruyn, A. (2021). *Subject Matter Expert Report: Industrial chemicals, spills and unauthorized releases. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd. Branton, M., & Power, B. (2021). *Stressor Evaluation – Sewage.* In Van Geest et al. (2021). *Industrial chemicals, spills and unauthorized releases. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd.
Wildlife predators	Dean, D. (2021). *Subject Matter Expert Report: Wildlife predation. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by VAST Resource Solutions Inc.

Focus	**Citation for Subject Matter Expert Reports**
Poaching	Dean, D. (2021). *Subject Matter Expert Report: Poaching. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by VAST Resource Solutions Inc.
Food availability	Orr, P., & Ings, J. (2021). *Subject Matter Expert Report: Food availability. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Minnow Environmental Inc.
Fish handling	Cope, S. (2020). *Subject Matter Expert Report: Fish handling. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Westslope Fisheries Ltd.
	Korman, J., & Branton, M. (2021). *Effects of capture and handling on Westslope Cutthroat Trout in the upper Fording River: A brief review of Cope (2020) and additional calculations.* Report prepared for Teck Coal Limited. Prepared by Ecometric Research and Azimuth Consulting Group.
Infectious disease	Bollinger, T. (2021). *Subject Matter Expert Report: Infectious disease. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by TKB Ecosystem Health Services Ltd.
Pathophysiology	Bollinger, T. (2021). *Subject Matter Expert Report: Pathophysiology of stressors on fish. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by TKB Ecosystem Health Services Ltd.
Coal dust and sediment quality	DiMauro, M., Branton, M., & Franz, E. (2021). *Subject Matter Expert Report: Coal dust and sediment quality. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Azimuth Consulting Group Inc.

Focus	Citation for Subject Matter Expert Reports
Groundwater quality and quantity	Henry, C., & Humphries, S. (2021). *Subject Matter Expert Report: Hydrogeological stressors. Evaluation of Cause - Decline in upper Fording River Westslope Cutthroat Trout population.* Report Prepared for Teck Coal Limited. Prepared by SNC-Lavalin Inc.

1. INTRODUCTION

Abundances of adult and juvenile life stages of Westslope Cutthroat Trout (Oncorhynchus clarkii lewisi) (WCT) in the upper Fording River (UFR) have been estimated since 2012 using high-effort snorkel and electrofishing surveys, supported by radio-telemetry and redd surveys (Cope et al. 2016). Annual snorkel and electrofishing surveys were conducted in the autumns of 2012-2014, 2017, and 2019. Abundances of both juvenile and adult life stages were substantively lower in 2019 than 2017, indicating a large decline during the two-year period between September 2017 and September 2019 (Westslope Cutthroat Trout Population Decline Window, hereafter referred to as Decline Window; Cope 2020). The magnitude of the decline as well as refinements in the timing of decline are reviewed in detail by Cope (2020).

Teck Coal Limited (Teck Coal) initiated the "Evaluation of Cause" (EoC) to assess factors responsible for the population decline. The EoC evaluates numerous impact hypotheses to determine whether and to what extent various stressors and conditions played a role in the decline of WCT. Given that the primary objective is to evaluate the cause of the sudden decline over a short time period (from 2017 to 2019), it is important to identify stressors or conditions that changed or were different from normal during the Decline Window. However, it is equally important to identify all potential stressors or conditions that did not change during the Decline Window but nevertheless may be important constraints on the population. Finally, interactions among stressors are also considered in the EoC. Where an impact hypothesis depends on interactions among stressors or conditions, or where the impact may be exacerbated by particular interactions, the mechanisms of interaction are considered as part of the evaluation of specific impact hypotheses.

A project team is evaluating the cause of WCT decline in abundance and is investigating two "overarching" hypotheses:

- Overarching Hypothesis #1: The significant decline in the UFR WCT population was a result of a single acute stressor[5] or a single chronic stressor[6].
- Overarching Hypothesis #2: The significant decline in the UFR WCT population was a result of a combination of acute and/or chronic stressors, which individually may not account for reduced WCT numbers, but cumulatively caused the decline.

Ecofish Research Ltd. (Ecofish) was asked to provide support as Subject Matter Expert (SME) for an evaluation of stressors. This report investigates loss of stream connectivity due to low water levels, which can represent a stressor on WCT in the UFR during the Decline Window; low water levels can limit fish access to overwintering habitat and can cause confinement within suboptimal habitat, which can in turn result in fish mortality.

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[5] Implies the single acute stressor acted between September 2017 and September 2019.

[6] Implies a chronic slow change in the stressor (using 2011-2019 timeframe, data dependent).

1.1. Background

1.1.1. Overall Background

This document is one of a series of SME reports that supports the overall EoC of the UFR WCT population decline (EoC Team 2021). For general information, see the preceding Readers Note.

1.1.2. Report-specific Background

As water temperature decreases in autumn, conservation of energy becomes a priority for fish and they move into overwintering areas that favour reduced energy use (Cunjak 1996). This shift to overwintering habitat, which may be local (e.g., movements to nearby suitable habitat) or long-distance (e.g., if suitable habitats are not adjacent to rearing habitat) in scale (Bjornn 1971, Huusko et al. 2007), is an important event for fish in their annual life cycle. When water level is reduced to the extent that fish passage is precluded, fish may be prevented from reaching suitable habitat for overwintering and they may become confined to sub-optimal habitats, resulting in increased mortality. Changes in stream connectivity due to water level reductions may directly affect fish movement; however, mortality of fish is not expected unless connectivity loss interacts with other stressors. For example, confinement of fish to sub-optimal habitats can increase risks of dewatering, freezing, predation, or hypoxia. Further, conditions under which connectivity is lost can be exacerbated by environmental factors. For example, rapid ice formation during the overwintering period can cause reduced flow (discharge depression) and blockages (e.g., when anchor ice forms on the substrate or creates dams), which may cause mortality or prevent fish moving to other potentially more suitable habitat. Loss of connectivity can result from flow changes caused by operational (e.g., water use) or natural (e.g., weather) factors and is most likely to occur at locations where water is shallow (e.g., riffles) or at known partial barriers (e.g., Henretta culvert).

Figure 1 provides a pathway of effect conceptual model for the cause-effect linkages between low water levels in streams (due to natural or operational causes) and reduced fish abundance considered in this investigation. Within the UFR, reduced water levels that could lead to loss of connectivity may be due to Teck Coal water uses or natural factors. Locations where low flows may create barriers to migration were identified in the UFR in previous studies (Cope et al. 2016, Johnson et al. 2019). The sections below describe the migration behaviour and overwintering habitat of WCT in the UFR and the potential impacts that loss of connectivity may have.

Figure 1. Pathway of effect relevant to potential effects to fish from low water levels that impact access to overwintering habitats.

1.1.2.1. Migration Behaviour and Overwintering Habitat

For stream-dwelling fish with migratory life histories, stream connectivity is critical for seasonal access to habitats located in different parts of the watershed. Based on a study of WCT populations in the UFR by Cope et al. (2016), individuals in the UFR vary in the extent to which they move during their annual life history. Cope et al. (2016) classified WCT as resident if movements were <8.0 km and migratory if movements were >8.0 km. Of the radio tagged WCT in the UFR between 2012 and 2015, 23% were categorized as Upper and Mid-Watershed Migratory and 28% were categorized as Mid and Lower Watershed Migratory. Cope et al. (2016) demonstrated that WCT may range from 2 to 35 km within the UFR in a year. Additional analysis of the telemetry data collected by Cope et al. (2016), including an assessment of home range size, is appended to this report (Appendix A). These movements allow WCT to access different habitats for each season or life stage; the habitats may be separated by several kilometres. Interruptions of connectivity may force individuals to rely on habitat with lower suitability, leaving those individuals vulnerable to dewatering, freezing, predation, hypoxia or other stressors.

The radio-telemetry study conducted by Cope et al. (2016) identified temporal and spatial patterns of overwintering WCT adults in the UFR from 2013-2015. The study reported that migratory fish predominantly overwintered in S6 (59%) and Henretta Pit Lake (16%), and the remaining 25% overwintered in a diversity of locations ranging from log jams in S2 to UFR headwaters in S10 (see Map 2 for river segment breaks). A total of 247 overwintering locations (where an individual fish spent most of its time) were identified in the UFR, which were grouped into four areas comprising roughly 20% of the total available habitat in the UFR. The overwintering areas, in upstream order, are: 1) log jams and bedrock pools in segments S1 through lower segment S3; 2) river segment S6 oxbows; 3) river segments S7, S8 and S9 in the Clode Flats area, including the Multi-plate culvert pool; and 4) Henretta Pit Lake (Map 2). Cope et al. (2016) found groundwater to be a confounding factor: fish were not observed to overwinter immediately adjacent to major sources of groundwater inflow, but rather downstream several kilometers where groundwater had become better mixed with surface water. Within the four overwintering areas, seven finer scale sites were identified as important overwintering habitat; portions of S6 known as the S6 oxbow pools were used by the greatest percentage of tagged fish (~42% of tagged population), followed by Henretta Pit Lake (~22%), the S7-S9 sections (~15%), and the S2 logjams (10%). Roughly 11% of the radio-tagged WCT overwintered in the remaining three locations of the S3-S5 logjams, S10-S11 sections, and Chauncey Creek confluence. The Multi-plate culvert pool was identified as the most important location in sections S7-S9 and was the only deep-water habitat in a 6 km stretch of the UFR; however, it has little cover and no groundwater inflow.

In the UFR, migratory fish would access overwintering areas from the following rearing habitats: 11 km of channel between Henretta Pit Lake, Clode Flats and STP; 6.6 km in S6; and large log jams in S2 through S5. Cope et al. (2016) also identified migrations of WCT that occurred in opposite directions. For example, some fish from S6 migrated upstream to spawn in Clode Flats, then returned to overwinter in S6; whereas, other fish that overwinter in Henretta or the Multi-plate culvert pool migrated downstream to spawn in S6 and log jams in S2 through S5, then returned to Henretta or S6 oxbows to overwinter. Migratory fish demonstrated a propensity for site fidelity with 65% returning to the same locations in their 2nd winter of the study (Cope et al. 2016).

This report evaluates passage conditions and movements past "critical riffles" (California Department of Fish and Game (CDFG), 2017), the Multi-plate and Henretta culverts, habitat rehabilitation works, and log jams to determine whether conditions at these locations may have contributed to the observed decline of WCT. Based on the Cope et al. (2016) assessment of WCT migratory life histories, it is apparent that some life history strategies require both upstream and downstream movement past critical riffles and the Multi-plate and Henretta culverts to move from rearing to overwintering habitats.

1.1.3. Author Qualifications

Todd Hatfield, Ph.D., R.P.Bio., Senior Environmental Scientist

This project is being led by Todd Hatfield, Ph.D., a registered Professional Biologist and Principal at Ecofish Research Ltd. Todd has been a practising biological consultant since 1996 and he has focused his professional career on three core areas: environmental impact assessment of aquatic resources, environmental assessment of flow regime changes in regulated rivers, and conservation biology of freshwater fishes. Since 2012, Todd has provided expertise to a wide array of projects for Teck Coal: third party review of reports and studies, instream flow studies, environmental flow needs assessments, aquatic technical input to structured decision making processes and other decision support, environmental impact assessments, water licensing support, fish community baseline studies, calcite effects studies, habitat offsetting review and prioritizations, aquatic habitat management plans, streamflow ramping assessments, development of effectiveness and biological response monitoring programs, population modelling, and environmental incident investigations.

Todd has facilitated technical committees as part of multi-stakeholder structured decision making processes for water allocation in the Lower Athabasca, Campbell, Quinsam, Salmon, Peace, Capilano, Seymour and Fording rivers; he has been involved in detailed studies and evaluation of environmental flows needs and effects of river regulation for Lois River, China Creek, Tamihi Creek, Fording River, Duck Creek, Chemainus River, Sooke River, Nicola valley streams, Okanagan valley streams, and Dry Creek. Todd was the lead author or co-author on guidelines related to water diversion and allocation for the BC provincial government and industry, particularly as related to the determination of instream flow for the protection of valued ecosystem components in BC. He has worked on numerous projects related to water management, fisheries conservation, and impact assessments, and developed management plans and guidelines for industry and government related to many different development types. Todd is currently in his third 4-year term with COSEWIC (Committee on the Status of Endangered Wildlife in Canada) on the Freshwater Fishes Subcommittee.

Andrew Harwood, Ph.D., R.P.Bio., Senior Fisheries Scientist

The Technical Lead for this project is Andrew Harwood, Ph.D., a registered Professional Biologist and Senior Fisheries Scientist at Ecofish Research Ltd. Andrew has 20 years of experience as a researcher and consultant, whose expertise is in the field of fish ecology, aquatic ecosystem health, and environmental flows. Andrew has worked on stream, wetland and lake ecosystems from the tropics to the Arctic Circle and has international experience in: setting environmental flows and monitoring the effects following implementation; environmental impact assessment; baseline, compliance and operational monitoring; and designing fish habitat restoration projects. Since 2016, Andrew has provided expertise to a wide array of projects for Teck Coal: third party review of reports and studies, instream flow studies, environmental flow needs assessments, environmental impact assessments, water licensing support, fish community baseline studies, DFO requests for review, streamflow ramping assessments, development of biological response monitoring programs, trigger action response plans, and environmental incident investigations.

Andrew has contributed to over 10 impact assessments evaluating the consequences of water withdrawal, including the development of environmental flow needs, associated with hydropower and mining projects. He is currently the Technical Lead responsible for assessing the impacts on environmental flow needs on four streams and a wetland ecosystem associated with Teck Coal mining projects in the Elk Valley. Andrew has also published in the primary science literature on environmental flows, fish passage, and fish ecology. Most recently, Andrew was lead author on a policy brief published in Frontiers in Environmental Science outlining the critical factors needed to enable effective environmental flow implementation. Andrew was lead author in developing long-term monitoring guidelines for new and upgraded hydropower projects in British Columbia and the Yukon for Fisheries and Oceans Canada that was published in 2013, and was also a major contributor to recent guidance prepared for the British Columbia Ministry of Environment on the implementation of their Environmental Flow Needs policy under the Water Sustainability Act. Andrew has been Technical Lead on eight longitudinal connectivity studies associated with hydropower projects in BC and has testified as an Expert Witness before an Environmental Appeal Board regarding environmental flows and the impacts of water withdrawal on aquatic and fisheries resources, including the potential effects of changes in longitudinal connectivity.

1.2. Objective

The objective of this report is to review the available information for fish passage within the UFR and assess potential effects to fish abundance from loss of stream connectivity due to low water levels or other factors (e.g., culverts, construction works, log jams) during the fall migration period. The potential impacts to fish from loss of connectivity are restricted access to overwintering habitat and confinement within suboptimal habitat, which can lead to death if other stressors are severe within the ensuing overwintering period; this may, in turn, result in a population decline if a large proportion of the population is affected.

Thus, the specific impact hypothesis evaluated was:

- Did restricted fish passage within the UFR during the fall migration period contribute to the observed WCT population decline?

1.3. Approach

Our evaluation of potential restrictions to fish movement during the fall WCT migration period (September 1 to October 15 2017-2019; Table 1) focused on a critical riffle analysis (CRA) that involves examination of conditions at riffles that may act as barriers to movement at low flows[7]. This evaluation was supported by:

- Summarizing passive integrated transponder (PIT) data collected at two arrays in the UFR installed at the Multi-plate and Henretta culverts;
- Completing additional analyses on radio telemetry data collected by Cope et al. (2016);
- Documenting the recent habitat rehabilitation work that has occurred on the Fording River mainstem and the potential for impacts on migration; and
- Evaluating the occurrence of large log jams on the upper Fording River mainstem.

Although our focal period for investigation was the fall migration period, we also evaluated conditions from August 1 to October 30 to characterize variability in conditions among years and assess whether conditions in the Decline Window may have been more restrictive than years prior. Results from the surveys of seasonal drying reaches for the FRO Local Aquatics Effects Monitoring Program (LAEMP) were also reviewed to provide additional context to the results of our analyses.

For the CRA method (Section 2.1), we built on field work completed for Year 1 of the FRO Operational Environmental Monitoring Plan (OEMP) in 2018, for which Ecofish assessed the potential for delayed or impeded WCT migration between summer rearing habitat and overwintering habitat within the UFR (Johnson et al. 2019). The assessment for the OEMP followed the CRA approach described in CDFG, (2017[8]) and evaluated fish passage at five potentially restrictive locations during the fall fish migration period using hydraulic measurements in relation to fish passage criteria. The five sites were selected as the most sensitive sites within ~500 m sections and although other sensitive critical riffles exist within the UFR between Chauncey Creek and Henretta Pit Lake they are not commonplace.

The WCT fall migration period is defined as September 1 to October 15 in the FRO consumptive water licences Orders (BC Water Act 2017). During this period, minimum flows in the UFR are

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[7] Referred to as critical riffles, which are riffles that are "particularly shallow and sensitive to changes in stream flow" (CDFG 2017).

[8] This method has been used, and approved by the Ministry of Forests, Lands, Natural Resources and Rural Development, to assess longitudinal connectivity within the diversion reaches of a number of run-of-river hydropower facilities in the lower mainland of British Columbia.

specified in BC Water Licences and Orders C133241, C133242, and C133243 as 0.26 m^3/s at Measuring Point B (FR_FRNTP) and 0.45 m^3/s at Measuring Point C (FR_FRABCHF) (Map 1). When flows are less than these levels, then diversions are not allowed. Building on the FRO OEMP 2018 study, we evaluated whether flow conditions in the UFR impeded WCT movement between summer and winter habitats; for the evaluation we used the most recent hydrology data for the UFR and the thresholds for passage derived using empirical measurements at the critical riffles (Map 1). To interpret comparison of results among years it was necessary to assume that there have been no substantial changes to the bed profile of the riffles from year to year. Further discussion of this assumption and other uncertainties associated with the study is provided in Section 4.6.

To date, Ecofish has evaluated passage conditions at five shallow riffles located on the UFR between the confluences with Henretta Creek and Chauncey Creek from September 25 to October 30, 2018 (i.e., the dates when stage was recorded continuously at the critical riffles). Thresholds for passage were defined for each site based on empirical measurement of physical attributes of the riffles; however, during the period analyzed for the original assessment there were not strong relationships between stage at the critical riffles and discharge at Measuring Points B (FR_FRNTP) and C (FR_FRABCHF) (Map 1). The lack of strong stage-discharge relationships makes it difficult to relate passage conditions at the riffles to flow at the Measuring Points. Nevertheless, it is possible to compare the thresholds for passage derived using empirical measurements at the critical riffles in 2018 to make inferences about when passage may have been restricted in other years. We also examined the extent to which fish passage at critical riffles is sensitive to inter- and intra-annual variability in flow and water use during the overwintering migration period (September 1 to October 15).

The PIT tag analysis (Section 2.2) focussed on PIT tag detections in 2017 through early 2020 at arrays installed by Lotic Environmental (Lotic) at the Multi-plate and Henretta culverts. The analysis assessed whether detections declined over the period by examining the number of PIT tag detections both in absolute and relative terms (# of tagged fish as a proportion of an estimate of total # of tagged fish) to evaluate whether timing of the decline could be refined using trends in the number of detections. We also assessed the number of migrants during the fall migration period (September 1 to October 15) to identify the dates of peak movement in the fall migration period in different years. Finally, we assessed trends in the number of fish successfully moving past the Multi-plate array and Henretta culvert.

Results from the CRA were used to determine whether loss of connectivity during the fall migration window was associated with the observed WCT decline (Section 2.5). Specifically, we identified requisite conditions that would have to be met for there to be a cause-effect relationship between low water levels (causing loss of stream connectivity and preventing fish passage) and reduced access to known overwintering habitats, which could act in combination with other stressors and lead to reduced WCT abundance. The results of the PIT tag analyses were used to evaluate possible timing of the decline, the timing of fish movement during the late summer and early fall, and to support the CRA in determining whether fish movement was impeded.

Table 1. **Periodicity of WCT in the UFR watershed. The migration to overwintering habitat, the focal period for this assessment, is highlighted in green.**

Life Stage	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 migration													■	■	■	■	■	■	■	■																												
Spawning																			■	■	■	■	■	■	■	■																						
Incubation (egg & alevin)																			■	■	■	■	■	■	■	■	■	■	■	■	■	■																
Summer Rearing (≥7° C)																											■	■	■	■	■	■	■	■	■	■												
Over-wintering migration																																	🟩	🟩	🟩	🟩	🟩	🟩										
Over-wintering	■	■	■	■	■	■	■	■	■	■	■	■																											■	■	■	■	■	■	■	■	■	■
Juvenile migration[1]																																																

[1] No defined periodicity

2. METHODS

2.1. Critical Riffle Analysis

2.1.1. OEMP 2018 Methods

In the OEMP 2018 analysis (Johnson et al. 2019), the CRA method described by the California Department of Fish and Game (CDFG 2017) was used to assess stream connectivity and fish passage in the UFR at low flows at potentially restrictive shallow riffles. Five sensitive shallow riffles were selected in 2018 within the ~22 km stream length from the Chauncey Creek confluence to Henretta Pit Lake (Map 1). Cope et al. (2016) identified the S7, S8 and S9 segments as those where increased width:depth ratios and shallow water depths may contribute to the development of fish migration barriers and hence these were the segments where critical riffles were identified. Critical riffle site selection also considered input from the FRO Environment Team on potential at-risk areas, on-site reconnaissance surveys, and a desire to install transects at riffles that represent potential migration barriers throughout the ~22 km reach from Chauncey Creek to Henretta Lake (i.e., we wanted to avoid placing all transects within a short reach and neglect potential riffle barriers in other areas). Areas identified in the OEMP and by the FRO Environment Team as potentially having passage challenges at riffles included three general areas: 1) near the Turnbull Bridge; 2) downstream of the South Tailings Pond; and 3) near the southern seasonally drying reach by Swift and Cataract creeks. Field crews walked each of these three areas, as well as a section upstream of the confluence with Chauncey Creek, to identify riffles that posed the highest risk for passage. Once all sensitive areas had been assessed, the riffles deemed to be the most likely to impede fish passage (i.e., widest channel width, shallowest depth) within each area based on conditions observed on September 19, 2018 were selected for surveying.

CRA field work commenced on September 25, 2018 with the installation of level loggers at five CRA sites (FRD-CRA01 to FRD-CRA05; Map 1). Water level data were recorded by the loggers from September 25 to October 30, except for FRD-CRA02 where data were available only from October 10 onwards due to equipment failure. At each CRA site, two transects were set up across the stream. The purpose of the transects were to record water depth across the channel, which could then be compared to fish passage criteria. Two kinds of transects were installed at each site. 'Non-linear' transects extended from left bank to right bank along the shallowest section of the riffle according to methods in CDFG (2017); as such, these transects were not always perpendicular to the stream channel, but often "zig-zagged" across it (Figure 2). The non-linear transects at FRD-CRA03 and FRD-CRA04 were ended at the river right wetted edge rather than the bank because of long lengths of dry riverbed between the wetted edge and the right banks at the time of surveys. 'Linear' transects extended from left bank to right bank perpendicular across the stream in the location where it intersected the shallowest section of the non-linear transect. Transects were marked by attaching transect tape to permanent pins placed on each stream bank and at rebar stakes secured in the substrate (CDFG 2017). A level logger was installed at each perpendicular transect to monitor water level during the monitoring period. Along each transect, depths were measured at a minimum of 20 verticals following methods in CDFG (2017). Water level profiles and linear and non-linear transect surveys were conducted during three field visits between September 25, 2018 and October 30, 2018 to provide CRA results for a range of low flow conditions.

UFR streamflow measurements were obtained from active hydrometric gauging stations in the UFR (Map 1). Methods from the OEMP 2018 study relevant to this report are detailed below.

Figure 2. Non-linear transect at FRD-CRA01 on September 26, 2018.

Both non-linear and linear transects were established at each CRA site to compare passability determinations under the two transect setups. Non-linear transects are prescribed in the CRA method (CDFG 2017), whereas linear transects are commonly used in instream flow studies (IFS) for the purpose of hydraulic modelling. Additionally, the linear transects allowed for potential development of stage-discharge relationships between the critical riffles and hydrometric gauges, which would potentially allow prediction of passability at the CRA transects using flows measured at the UFR hydrometric gauges.

Fish passage at the shallow riffle sites, and relationships between passage and flow, were evaluated using the following steps and criteria in the 2018 OEMP (Johnson et al. 2019):

- Across the observed range of water levels and corresponding flows at each CRA site from September 25 to October 30, 2018, water depth was measured at each vertical for each transect to allow estimation of the portion of the wetted width of the channel that satisfies minimum depth criteria. The CDFG (2017) minimum depth criterion for adult trout is 12 cm. However, since the depth criterion applies to adult trout in general and is not species-specific or population-specific there is uncertainty in whether the passage depth criterion is appropriate for WCT in the UFR. Therefore, for the OEMP 2018 analysis we completed a sensitivity analysis using other water depth criteria, described below.
- R2 Resource Consultants (2008a, b) provide the key supporting information used to develop the CDFG (2017) methods. Factors that influence fish passage include: water depth; lane width; longitudinal distance of the barrier; cumulative number of barriers; target body size (body length and body depth); distance between belly of the fish and substrate; and other factors such as water temperature, cover, water velocity, and fish condition. R2 Resource Consultants (2008a) provides a concise review of relevant literature for upstream passage suitability criteria. This includes the minimum passage water depth criteria for adults of three anadromous species, in consideration of the above factors influencing passage in a two foot (61 cm) wide cell. Orsborn and Powers (1985; cited in R2 Resource Consultants 2008a) reported a general body length to body depth ratio of five and used empirical measures of mean length for steelhead (32 inches) in one of their reference streams as a target body size. They also used an assumption of 0.1 feet (3 cm) for distance between belly of the fish and substrate to avoid abrasion during passage. These factors were key in providing a table of depth criteria for the three species highlighted in CDFG (2017).
- CDFG (2017) does not discuss how water depth criteria were established for trout (adult, including 1-2+ juvenile steelhead) and salmonids (young of year juvenile), but we assumed the criteria were developed using a similar approach in combination with professional judgement. Back-calculating using the above approach gives a target body length of 45 cm for an adult trout ((12 cm – 3 cm) x 5), and 30 cm for a juvenile salmonid ((9 cm – 3 cm) x 5). Since juveniles are typically less than 30 cm, we assumed this criterion is meant to apply to fish up to 30 cm. The full suite of depth criteria used in the sensitivity analysis for the OEMP 2018 analysis were back-calculated to body dimensions in Table 2. Therefore, water depths of 6 cm, 8 cm, 9 cm, and 10 cm were also evaluated. Linear and non-linear transects were evaluated using the same passage criteria.

The CDFG CRA assumes that passage is possible if the following two criteria are met:

- Criterion 1: A minimum 25% of the maximum transect wetted width satisfies the minimum depth criterion; and
- Criterion 2: A contiguous section at least 10% of the maximum transect wetted width satisfies the minimum depth criterion.

To assess the sensitivity to these criteria, each site was assessed for passage using CRA Criterion 1 and 2 separately and in combination (Table 3), and the CRA passage criteria were assessed for each site at each of the five passage depths (Table 2).

Results of field surveys were used to create a model (SEFA software; Aquatic Habitat Analysts 2012) to predict passage at the range of water surface elevations recorded by the level loggers. A time series of fish passage suitability was then created for each transect using the modelled results from SEFA and the level logger data.

The relationship between flow and passage was determined for each transect by comparing the passage suitability time series to flow estimates during the time period the level loggers were installed. Flow estimates were taken from the hydrometric gauges Measuring Point B (FR_FRNTP) and Measuring Point C (FR_FRABCHF) (Map 1). The passage-flow relationships documented through this approach were used to determine the flows that would allow fish to pass at each of the CRA sites.

Table 2. Water depth criterion calculated for salmonids for the 2018 OEMP CRA (Johnson et al. 2019).

Water Depth Criterion (cm)	Body Depth (cm)	Body Length (cm)
6	3	15
8	5	25
9	6	30
10	7	35
12	9	45

Table 3. CRA passage assessment methods summary for the 2018 OEMP CRA (Johnson et al. 2019).

Assessment Method	Passage Criteria
1	Criterion 1 + Criterion 2
2	Criterion 1
3	Criterion 2

2.1.2. Analysis for the Evaluation of Cause

Evaluation of critical riffles for the EoC followed methods in the OEMP 2018 study (Johnson et al. 2019), described above (Section 2.1.1). However, in 2018 it was not possible to develop accurate relationships between stage at the riffles and stage at the Measuring Points, given the distance and the small range in flows during the period when loggers were installed at the riffles. Thus, it was not possible to use the linear transects to model passability across a wider range of flows than those observed in the 2018 study. Hence, for this evaluation we exclusively focus on the results from the non-linear transects; these transects are also the most representative of conditions that fish encounter during migrations to overwintering habitat.

Our analysis also primarily focused on the passability of riffles according to the CDFG (2017) Criterion 2; i.e., a contiguous section of 10% of wetted width that satisfies the minimum depth criterion. We consider Criterion 2 to be the key criterion for fish passage because as long as there is one location that is wide enough and deep enough for fish to pass, conditions elsewhere along the transect are less relevant (and therefore it may not matter whether sufficient depth is present over 25% of the wetted width). To support this contention, illustrations of hypothetical linear and non-linear transects are depicted in Figure 3 and Figure 4. These images illustrate why linear transects may have sections of deeper water than non-linear transects, and also why 10% of contiguous width of sufficient depth is the more relevant criterion for successful passage. Note that depending on the wetted width of the transect, the requirement for 10% of contiguous width of sufficient depth may still be conservative as fish may only require a narrow channel of sufficient depth in order to successfully pass a riffle.

For the minimum depth criteria, we focus on the results generated using 9 cm and 12 cm as these are the criteria suggested for juvenile and adult trout, respectively (CDFG 2017). As noted in Section 2.1.1, a sensitivity analysis of minimum depth criteria is presented in the 2018 OEMP (Johnson et al. 2019).

For the EoC we did not survey the UFR for critical riffles beyond those assessed in the field in 2018 (depicted in Map 1). We extended the analysis completed in the 2018 OEMP to evaluate likely passage conditions at FRD-CRA01, 02 and 03 from 2017 to 2019 using the available flow data from Measuring Point C, and at FRD-CRA04 and 05 from 1997 to 2019 using the available flow data from Measuring Point B. Measuring Point B was the only relevant gauge with flow data available outside the 2017-2019 time period. Although there are other sensitive critical riffles within the UFR between Chauncey Creek and Henretta Pit Lake, and an additional three riffles between FRD-CRA03 and Henretta Pit Lake have been identified for further study in 2020, they are not commonplace and FRD-CRA01 through 05 were selected to be the most sensitive in the areas in which they are located (~500 m long sections).

To evaluate the extent to which fish passage at critical riffles is sensitive to inter- and intra-annual variability in flow and water use during the overwintering migration period, specifically during the Decline Window, we added 5%, 10% and 15% to actual flows (i.e., gauged streamflow) recorded at Measuring Point B and C from September 1 to October 15 in 2017 and 2018. The selection of 5%, 10% and 15% for the sensitivity analysis was based in part on total water withdrawal as a % of total water available at FR_FRNTP, excluding Shandley Pit stored water (Table 4), reported in the EoC report on Climate, Temperature and Streamflow Trends (Wright et al. 2021). Table 4 illustrates that water use in the overwintering migration period from 2015 through 2019 varied from 4.4% to 9.2%.

Figure 3. Difference between linear (white line) and non-linear (orange line) transects. A non-linear transect best represents conditions encountered by fish migrating upstream. Photo taken at a critical riffle upstream of the southern drying reach on the upper Fording River on September 19, 2018 when average daily flow at Measuring Point C was 0.98 m^3/s (40% MAD).

Figure 4. **Difference between linear (white line) and non-linear (orange line) transects and an illustration of why Criterion 2 (10% contiguous passable) is considered the key criterion for fish passage: as long as there is one location that is wide enough and deep enough for fish to pass, sufficient depth over 25% of the wetted width may not be required. Photo taken upstream of the Turnbull Bridge over the upper Fording River on September 19, 2018 when average daily flow at Measuring Point B was 0.73 m^3/s (41% MAD).**

Table 4. Total water withdrawal per WCT life stage period expressed as % of total water available (daily average observed flow plus total daily water use) at FR_FRNTP for the FR_POTWELLS and PODs associated with the FR_FRNTP compliance monitoring point, excluding Shandley Pit stored water (reproduced from Wright et al. 2021).

Year	Westslope Cutthroat Trout Life Stages					
	Spawning Migration	Spawning	Incubation	Summer Rearing	Over-wintering migration	Over-wintering
	April 1 to May 31	May 15 to July 15	May 15 to August 31	July 15 to September 30	September 1 to October 15	October 15 to March 31
2015	1.9%	2.5%	3.5%	7.7%	6.1%	11.5%
2016	2.1%	3.0%	3.3%	4.9%	8.2%	9.6%
2017	1.6%	1.1%	1.3%	3.3%	9.2%	12.4%
2018	1.0%	1.0%	1.4%	3.6%	4.9%	8.9%
2019	1.8%	0.9%	1.1%	2.0%	4.4%	

For the overwintering period, the year reflects the start of the period; e.g., 2015 is the 2015-2016 winter. The over-wintering period is subject to gaps in the continuous and manual flow measurements; therefore, the % of water use to total available water may be an overestimate, paticularly during the overwintering periods. Similarly, the 2017 over-wintering migration period has a gap in the streamflow record of 14 days, which likely results in an overestimation of the % of water use relative to total water available.

2.2. PIT Tag Analysis

2.2.1. PIT Tag Detection Arrays

A PIT tag detection array was installed at the Multi-plate culvert in July 2017 and consisted of two antennas upstream of the culvert. A second array was installed at the Henretta culvert, with one antenna installed downstream of the culvert in July 2017, and a second antenna installed upstream of the culvert (180 m apart) in October 2017. The arrays logged detections of PIT tags from installation up to April 30, 2020, except for periods when one or more antennae were intermittent or non-functional (these blackout periods are illustrated in result plots). The arrays were installed for the purpose of effectiveness monitoring to assess juvenile WCT passage past these two locations following implementation of fish habitat offsetting measures to improve passage at these sites (Lotic 2017, 2018). The arrays also detected any WCT tagged during other programs in the UFR since 2016 (Table 1 in Appendix B).

The detection arrays had several periods of interrupted operation due to technical problems (Table 5). Generally, these periods were attributed to problems with the battery systems that ran the arrays, and the solar panels that charged them. In some cases, the arrays were non-functional, and had no ability to detect passing tags (grey panels in the figures), but at other times the array's operation was intermittent, and the array was likely operating when sun hit the solar panels; therefore, some detections occurred, but some tagged fish may have passed undetected (blue panels in the figures).

2.2.2. PIT Tag Deployments

PIT tag detection data were compiled by Lotic in preparation for analysis by Ecofish. A roster of PIT tags deployed in the UFR since 2016 was provided to Ecofish by Teck Coal. The data were evaluated to ascertain the timing of fish movements from July 2017 to March 2020 and used to provide insight into the timing of the WCT population decline. Fish detections were also analyzed spatially based on the geographic area each fish was tagged, to assess patterns of movement (Map 2, Map 3). Due to limitations in the data (e.g., limited number of PIT array locations, array non-functioning periods, and relatively few PIT tag deployments in adult fish) we did not attempt to distinguish migration from movement in the PIT tag analyses. Migration is a seasonal movement from one area or habitat to another, usually in association with a life history requirement (e.g., spawning, overwintering). Instead, analyses of PIT tag data focussed on detections at each array, which indicate movement over shorter distances or time periods. For further discussion of migration timing, please see the telemetry memo (Appendix A).

Detection data were reviewed to evaluate whether the timing of the fall peak movement aligned with the overwintering migration period of September 1 to October 15 (Table 1, Cope et al. 2016). Plots were generated for both the count of array detections and the proportion of the cumulative tags deployed and detected. WCT tagged south of the Fording-Kilmarnock confluence (462 of the 1,191 tagged WCT, mostly tagged in Greenhills Creek, n=346) were substantially less likely to be detected at the arrays (Map 2; Map 3; Table 3 in Appendix B), due to the distance of travel required to reach the arrays. These tagged WCT were excluded from proportional analyses, leaving a total of 729 tagged WCT for analysis. Life stage-specific results were examined using size-at-tagging to categorize the detections and analyze the different life stages separately. The datasets were subdivided into adults (≥200 mm) and juveniles (60-200 mm) as per life stage classifications in Cope et al. (2016).

When a tagged fish remained stationary within range of the array an inflated detection count occurred; therefore, a rule was implemented where each fish could only have one detection per day. Passage of tagged fish across the Henretta culvert was determined between October 2017 and October 2019 by examination of occurrences where a fish had one detection at the array's downstream antenna and the next detection at the upstream antenna, or vice versa. For the purposes of examining culvert passage a fish was allowed more than one detection per day, if the detections occurred at different antennae. Passage success as a function of individual passage attempts at the Multi-plate culvert could not be determined in the same manner because both antennae of the array are upstream of the culvert.

A sizeable proportion of the PIT tag detections (1,574 of 7,090 or 56 of 198 unique fish detected) were not present in the roster of PIT tags deployed. A number of these are likely from an unknown number of tags that were deployed in the UFR by Environment Canada from 2012 to 2016. We were unable to acquire the fish data associated with these tags and they could therefore not be included in our analysis. Fish not in the roster had an unknown tagging date or unknown size-at-tagging. Fish not in the roster were included in plots of count and proportion of array detections; however, any analyses that incorporated fish length (e.g., to evaluate movement by different life stages) or PIT tag deployment location included only those detections with a corresponding PIT tag in the deployment roster.

Caution should be used when interpreting the Henretta results from July 20 (array installation) to September 15, 2017. During this period, 55 fish were PIT tagged within 300 m of the Henretta array as part of effectiveness monitoring for modifications to the Henretta culvert (Lotic 2017). These fish were disproportionately detected by the array and led to an inflated detection rate for the early part of the study period. Releases of tagged fish were also completed in August 2017 (n = 146) and on July 12 and 13, and August 17, 2018 at the Multi-plate culvert (n = 70) to test the effectiveness of passage improvements (Lotic 2018). However, these releases did not have the same effect on proportional detections as observed at the Henretta array (Section 3.2.2.2).

Fish that were tagged in the earlier years of the study would have grown, and some likely transitioned from the juvenile to adult life stage over the course of the study[9]. We did not attempt to account for growth over the period of the study and did not adjust life stage categories over time. Similarly, the analysis did not account for fish mortality or tag shedding, which means the true number of functional tags is smaller than the cumulative number of fish tagged. However, past research on PIT tags in Cutthroat Trout has demonstrated that the invasiveness of PIT tags is low, 100% retention is possible, and survivorship did not differ significantly from the control group over a six-month period (Ostrand et al. 2011). Therefore, we do not expect that fish are regularly shedding inserted tags, nor that the tag insertion itself was a substantial source of mortality. Nevertheless, the cumulative number of fish tagged will decrease over time as a result of ongoing mortality. (As a guide, Cope et al. (2016) used an annual population loss rate of 10% when estimating the amount of stream required to maintain a population.)

2.2.3. PIT Tag Recaptures

A separate analysis was completed to identify movements of recaptured individuals during the Decline Window. The deployment roster was examined for PIT tag codes that were listed more than once. The locations where these individuals were initially tagged were then compared to locations where they were recaptured to identify if there had been changes in location.

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[9] Since PIT tags are passive, lack of detection is not related to functioning of the tag itself.

Table 5. Array locations and periods of non-functionality

Array	Antenna	Location			Non-Functional Periods
		UTM Zone	Easting	Northing	
Henretta	Upstream	11U	652245	5566463	July 20, 2017 - Oct 1, 2017 [1] Oct 17, 2017 - Apr 1, 2018 Jan 2018 - June 28, 2018 [2] Mar 7, 2019 - Aug 8, 2019
	Downstream	11U	652057	5566388	Oct 17, 2017 - Apr 1, 2018 Jan 2018 - June 28, 2018
Multi-Plate	Upstream	11U	651199	5562802	Dec 22, 2017 - May 8, 2018 Dec 18, 2018 - June 20, 2019
	Downstream	11U	651213	5562793	Dec 22, 2017 - May 8, 2018 Dec 18, 2018 - June 20, 2019

[1] These dates indicate the period where the downstream antenna at Henretta was functional, but the upstream antenna had not yet been installed

[2] These dates indicate a period where the upstream antenna at Henretta was intermittent and may have missed passing tagged WCT

2.3. Evaluation of Offsetting Habitat Construction

During the period leading up to and including parts of the Decline Window, Teck Coal implemented habitat rehabilitation at several sites (Table 13) in the UFR. The intent of the projects was to increase fish habitat suitability; however, the rehabilitation included activities that could impede fish passage, or discourage fish presence in the vicinity of the construction. Activities during these projects included the placement of large woody debris (LWD) or boulders within streams, bank realignment, the alteration of streambed morphology (e.g., smoothing plunged drops) and bridge construction. The heavy equipment used for these activities can create noise, vibration, movement and/or turbidity, which can deter fish from passing or approaching construction areas. For this report, we qualitatively evaluated each habitat offsetting construction location for its potential to affect fish behaviour, and those projects with possible effects are described in the results (Section 3.3).

2.4. Evaluation of Log Jam Occurrence in the UFR

Log jam formation and associated channel changes were hypothesized to influence migration of WCT in the UFR. As a first test of this hypothesis, the occurrence of log jams was quantified by analyzing orthophotos. Orthophotos are available dating back to the late 1970s; however, only the orthophotos from 2007 to 2019 were deemed high enough resolution, and captured a sufficient portion of the UFR, to be useful for this analysis. We analyzed orthophotos from 2007, 2012, 2013, 2016, 2017, 2018 and 2019. Log jams were enumerated if they spanned the width of the UFR and had more than approximately 30 logs; these criteria were considered sufficient to influence fish passage or result in channel changes. Log jams that met these requirements were enumerated for each segment of river (S1-9).

2.5. Evaluation of Requisite Conditions to Contribute to the Decline

As noted in Section 1, loss of connectivity to preferred overwintering habitats is expected to play an influencing role, interacting with other potential WCT stressors and factors (e.g., climate, predation, water quality), rather than directly causing fish mortality. Accordingly, we used results of the CRA to assess whether requisite conditions to contribute to the decline of WCT were met (Overarching Hypothesis #2), and used the PIT tag analysis to provide supplemental information on timing of migration and potential timing of the decline. Requisite conditions (Table 6) were based on spatial (extent and location) and temporal (timing and duration) aspects of low water levels and connectivity loss and on the intensity (magnitude) of the water depth reductions relative to passability criteria for fish.

Table 6. Requisite conditions required for a loss of connectivity to contribute to the decline.

Factors	Requisite Conditions to Contribute
Spatial Extent	Loss of connectivity prevented access to preferred overwintering habitat within much of the UFR mainstem (confluence of Chauncey Creek to confluence with Henretta Creek [S6 through S9])
Duration	Loss of connectivity was maintained for long enough to prevent access to preferred overwintering habitat (e.g., weeks)
Location	Low water levels occurred in locations sensitive to loss of connectivity (riffles located in S6, S7, S8 and S9)
Timing	Loss of connectivity occurred in the Decline Window during the fall migration period (September 1 to October 15)
Intensity	Water depth in critical connectivity locations (e.g., riffles) was shallow enough to restrict fish movement (assessed in relation to minimum depth criterion for fish passability)

3. RESULTS

3.1. Critical Riffle Analysis

3.1.1. OEMP 2018 Results

An initial comparison between non-linear and linear transect bed profiles was conducted for one CRA transect (FRD-CRA01) to demonstrate why non-linear transects are more representative of conditions for migrating fish in the UFR (Figure 5). Figure 5 illustrates that the linear bed profile has two deep sections that are deeper than any part of the non-linear transect. These two sections imply deep migration corridors that would overestimate the passability of the riffle during analysis compared to results obtained using the non-linear transect.

Wetted widths along the zig-zag path of non-linear transects during three site visits from September 25 to October 30, 2018 are shown in Figure 6. This illustrates that wetted width clearly declined at the transects in the drying reach (FRD-CRA02 and FRD-CRA03; see Minnow and Lotic 2018, 2019 for further description of the southern drying reach); however, wetted widths were more similar among the survey dates at the other three transects. The wetted widths (Figure 6), and passability of critical riffles (Figures 7 through 11), at flows observed in 2018 are used to evaluate passage conditions in other years in Section 3.1.2.

Figure 5. Comparison of non-linear and linear bed profiles at FRD-CRA01. The top plot shows water surface elevation averaged across the transect, whereas the bottom plot shows the water surface elevation measured at each station.

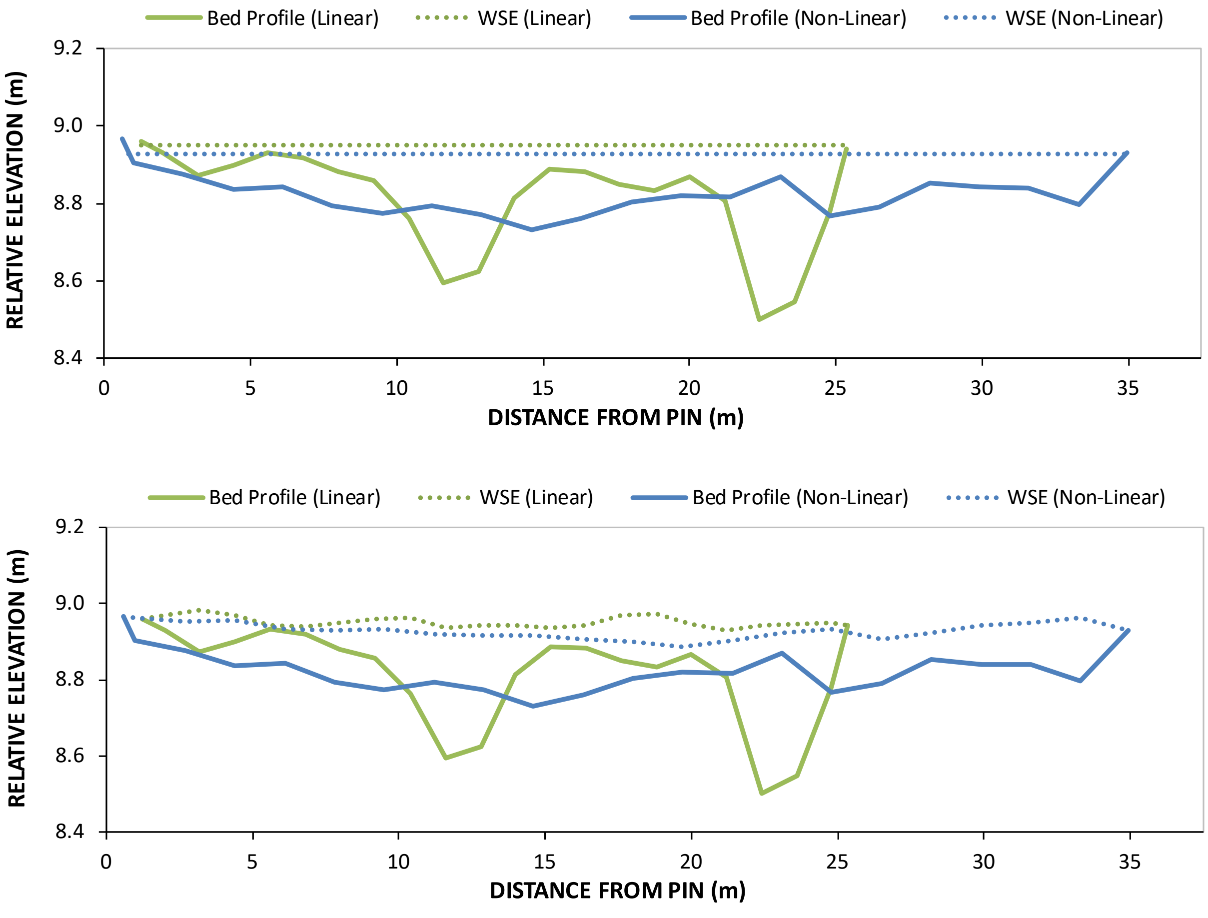
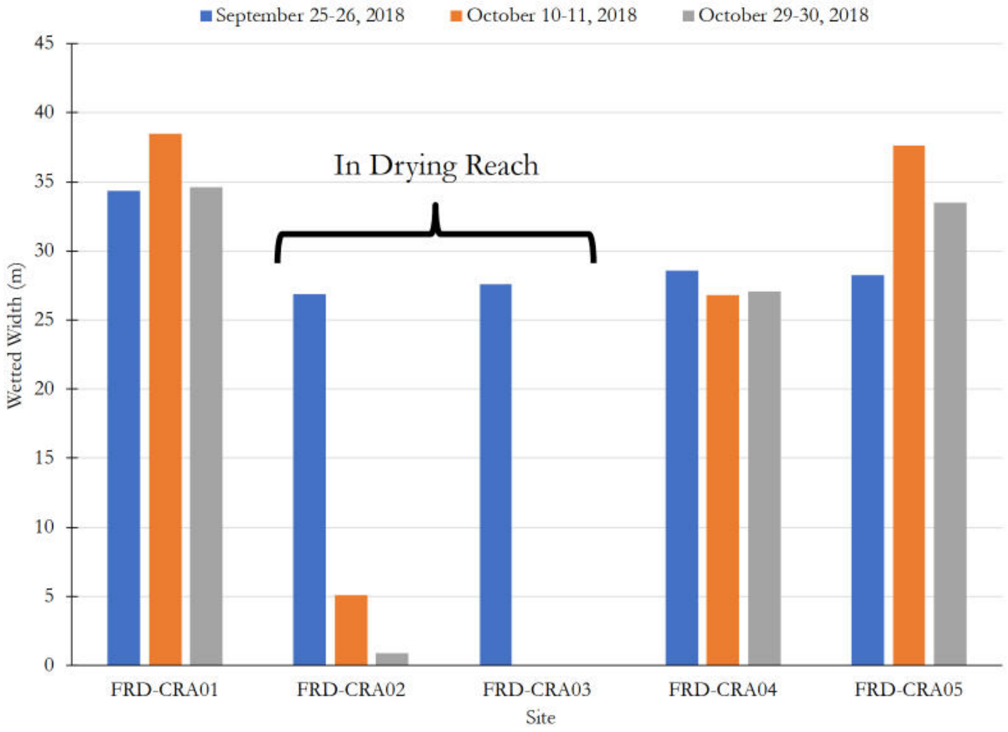


Figure 6. **Wetted widths at non-linear transects during 2018 survey dates relative to the fall migration period (September 1 to October 15).**



To illustrate the relationship between wetted width and the percentage of the transect width that meets minimum depth criteria, Figure 7 to Figure 11 show results for the non-linear transects and the two minimum depth criteria, 9 cm (juveniles) and 12 cm (adults), on September 25-26, 2018. In each figure, the first bar is the total wetted width across the zig-zag non-linear transect on that 2018 survey date. The second bar is the amount of wetted width across the non-linear transect that meets the minimum depth criterion of 9 cm or 12 cm (black line is 25% wetted width threshold). The third bar is the contiguous wetted width across the non-linear transect that meets the minimum depth criterion of 9 cm or 12 cm (black line is 10% wetted width threshold).

- FRD-CRA01 was passable at the minimum depth criterion of 9 cm and 12 cm based on the 10% and 25% wetted width thresholds on September 26, 2018 (Figure 7). In Figure 7a, the comparison between the second and third bars indicates that much of the transect that is ≥9 cm deep was in one contiguous section. The comparison between Figure 7a and Figure 7b shows the difference between use of the 9 cm and 12 cm minimum depth criterion. There was less wetted width of ≥12 cm depth than of ≥9 cm.

- FRD-CRA02 was not passable at the minimum depth criterion of 9 cm based on either the 10% or 25% wetted width thresholds on September 26, 2018 (Figure 8). A plot showing wetted width using the 12 cm depth criterion was not shown because there was 0 m passable. Passage at this riffle was therefore impeded by insufficient water depth even though wetted width was >25 m on September 26 (Figure 6).

- FRD-CRA03 was passable at the depth criterion of 9 cm based on the 10% wetted width threshold, but did not meet the 25% wetted width threshold on September 26, 2018 (Figure 9a). FRD-CRA03 was not passable at the minimum depth criterion of 12 cm for either the 10% or 25% wetted width threshold (Figure 9b). In Figure 9a, a comparison of the second and third bars indicates that all of the transect that was ≥ 9 cm deep was in one contiguous section. Adult passage at this riffle was therefore impeded by insufficient water depth even though wetted width was >25 m on September 26 (Figure 6).
- FRD-CRA04 was passable at the minimum depth criteria of 9 cm and 12 cm based on the 10% and 25% wetted width thresholds on September 25, 2018 (Figure 10). Comparison of Figure 10a and Figure 10b shows the difference between using the 9 cm and 12 cm minimum depth criterion. There was slightly less wetted width ≥12 cm deep than of ≥9 cm deep.
- FRD-CRA05 was passable at the minimum depth criteria of 9 cm based on the 10% and 25% wetted width thresholds on September 25, 2018 (Figure 11a). FRD-CRA05 was passable at the minimum depth criterion of 12 cm based on the 10% wetted width threshold, but the 25% wetted width threshold was not met (Figure 11b). Comparison of Figure 11a and Figure 11b shows the difference between using the 9 cm and 12 cm minimum depth criterion. There was less wetted width of ≥12 cm deep than of ≥9 cm deep.

Evaluation of passability on September 25-26, 2018 demonstrated that determination of passage is dependent on the depth criteria and width thresholds used. Most of the critical riffles assessed were passable at the 9 cm (juvenile) and 12 cm (adult) minimum depth criteria for either the 10% wetted width or 25% wetted width threshold, or both. FRD-CRA02, in the southern drying reach, was the only critical riffle that was not passable on that day at either the 9 cm or 12 cm minimum depth criterion. FRD-CRA01 and FRD-CRA04 were both passable at the 9 cm and 12 cm minimum depth criteria and for the 10% wetted width and 25% wetted width thresholds. FRD-CRA03 was only passable at the 9 cm minimum depth criterion and 10% wetted width threshold; FRD-CRA05 was not passable at the 12 cm minimum depth criterion and 25% wetted width threshold.

Figure 7. Passability on September 26, 2018 at FRD-CRA01 for non-linear transect at (a) 9 cm and (b) 12 cm minimum depth criteria.

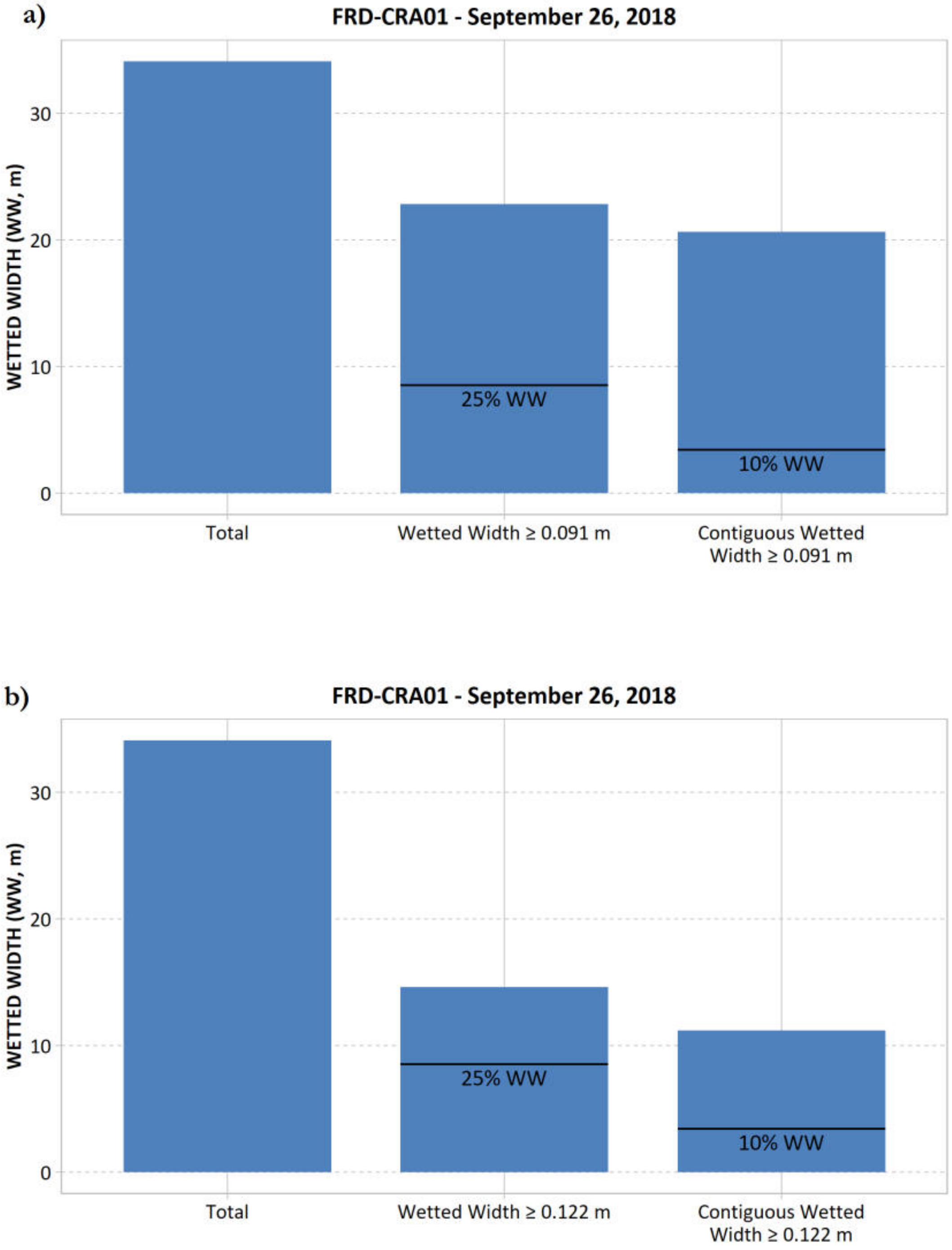


Figure 8. Passability on September 26, 2018 at FRD-CRA02 for non-linear transect at 9 cm minimum depth criteria. A plot showing wetted width using the 12 cm depth criterion is not shown because there was 0 m passable.

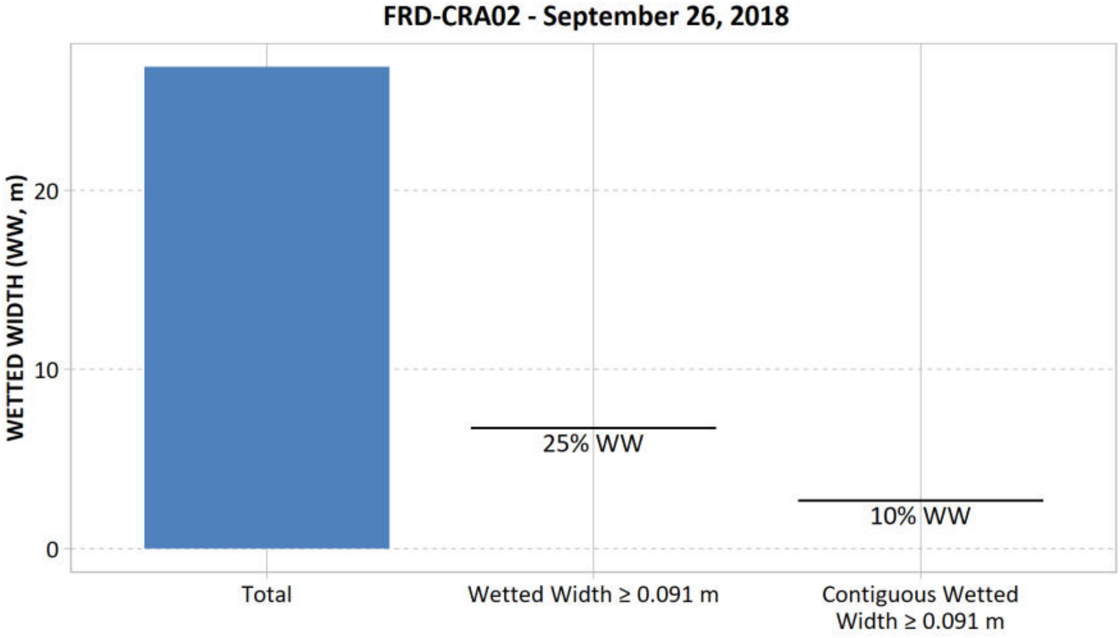


Figure 9. Passability on September 26, 2018 at FRD-CRA03 for non-linear transect at (a) 9 cm and (b) 12 cm minimum depth criteria.

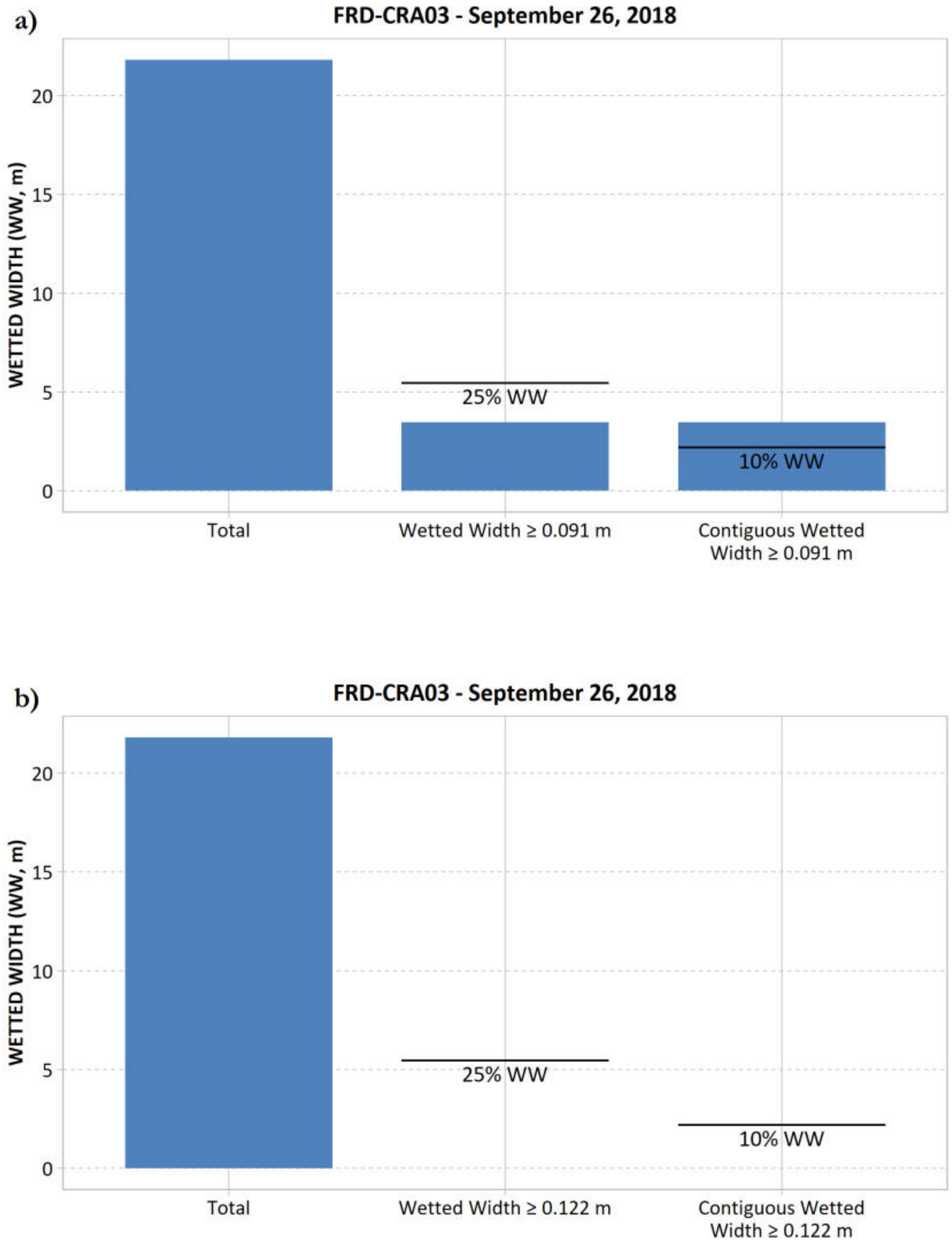


Figure 10. Passability on September 25, 2018 at FRD-CRA04 for non-linear transect at (a) 9 cm and (b) 12 cm minimum depth criteria.

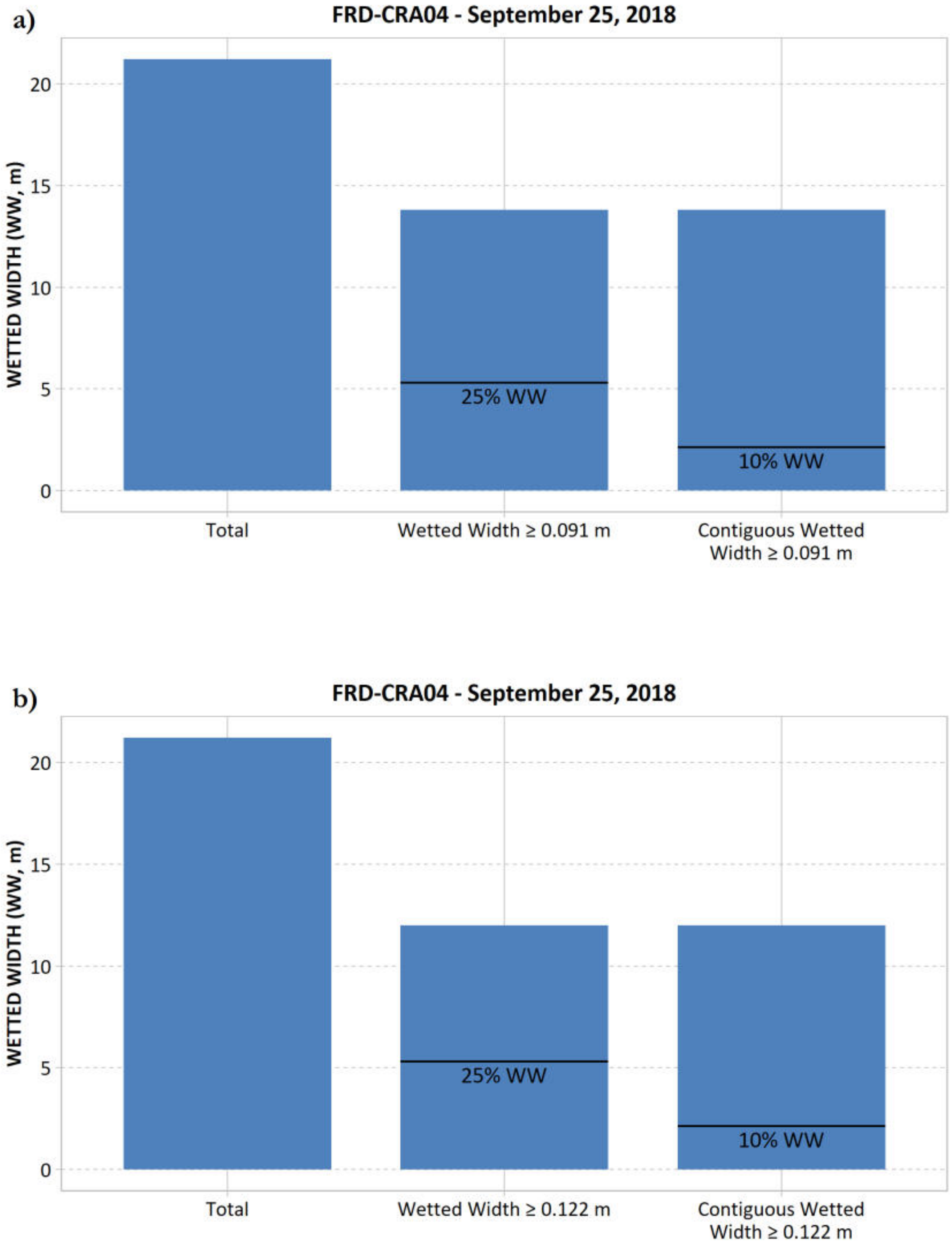
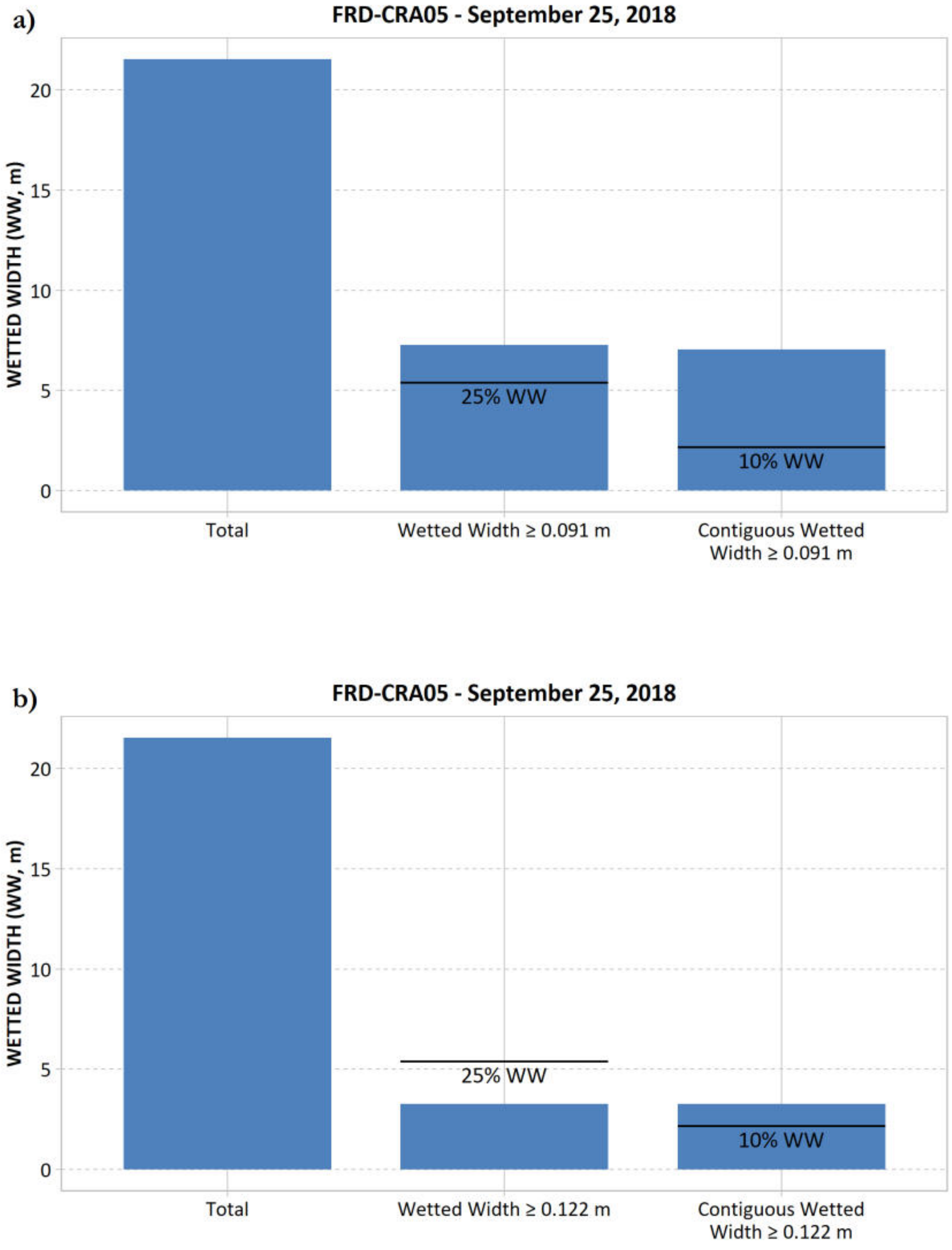


Figure 11. Passability on September 25, 2018 at FRD-CRA05 for non-linear transect at (a) 9 cm and (b) 12 cm minimum depth criteria.



3.1.2. Analysis for the Evaluation of Cause

Passability in 2018 was measured directly at CRA transects, as described above in Section 3.1.1. Passability at each critical riffle was predicted for years other than 2018 using historical flow data at the relevant Measuring Point (i.e., Measuring Point B or Measuring Point C).

The following sub-sections present hydrographs during the August 1 to October 31 period for each year based on records available at the Measuring Point nearest to each critical riffle. Based on these flow data, the potential for fish passage was predicted for non-linear transects at the two minimum depth criteria, 9 cm (juveniles) and 12 cm (adults), based on the 10% contiguous passable criterion (Criterion 2). Additional hydrographs are presented showing the addition of 5%, 10% and 15% to actual flows to illustrate the extent to which fish passage at critical riffles is sensitive to variability in flow and water use.

3.1.2.1. FRD-CRA01

The non-linear transect at FRD-CRA01 is passable by juveniles and adults when discharge at Measuring Point C is greater than 0.887 m^3/s (green dashed line, Figure 12). The green colour of the line indicates that the transect is passable above this flow; the dashed pattern of the line indicates that we do not know the discharge below 0.887 m^3/s at which the transect is not passable (i.e., we would need to measure at lower flows). There were missing flow data for 2017 (light blue line), but the passage threshold and available hydrology data suggest that passage across FRD-CRA01 would not have been problematic in 2017 through 2019.

Furthermore, fish passage at FRD-CRA01 was not sensitive to inter- and intra-annual variability in flow and water use in 2017 and 2018. Based on the passage threshold derived from empirical measurements in 2018, passage for juveniles and adults was possible throughout the overwintering migration period in 2018 because actual flows were >0.887 m^3/s (Figure 13, Table 7). Similarly, although flow data are only available for 9 days at the end of the overwintering migration period in 2017, actual flows on these 9 days were >0.887 m^3/s. Since flows are typically higher earlier in the migration period, it is unlikely that FRD-CRA01 impeded fish movement during the 2017 overwintering migration period.

Figure 12. **Passage threshold for the FRD-CRA01 non-linear transect and continuous flow data at Measuring Point C from 2017 to 2019. The green colour of the line indicates that the transect is passable above this flow; the dashed pattern of line indicates that we do not know the discharge below 0.887 m^3/s at which the transect is not passable (i.e., we would need to measure at lower flows). The riffle is passable to both juveniles and adults at flows ≥0.887 m^3/s, but the threshold at which the riffle is not passable may be different for juveniles and adults.**

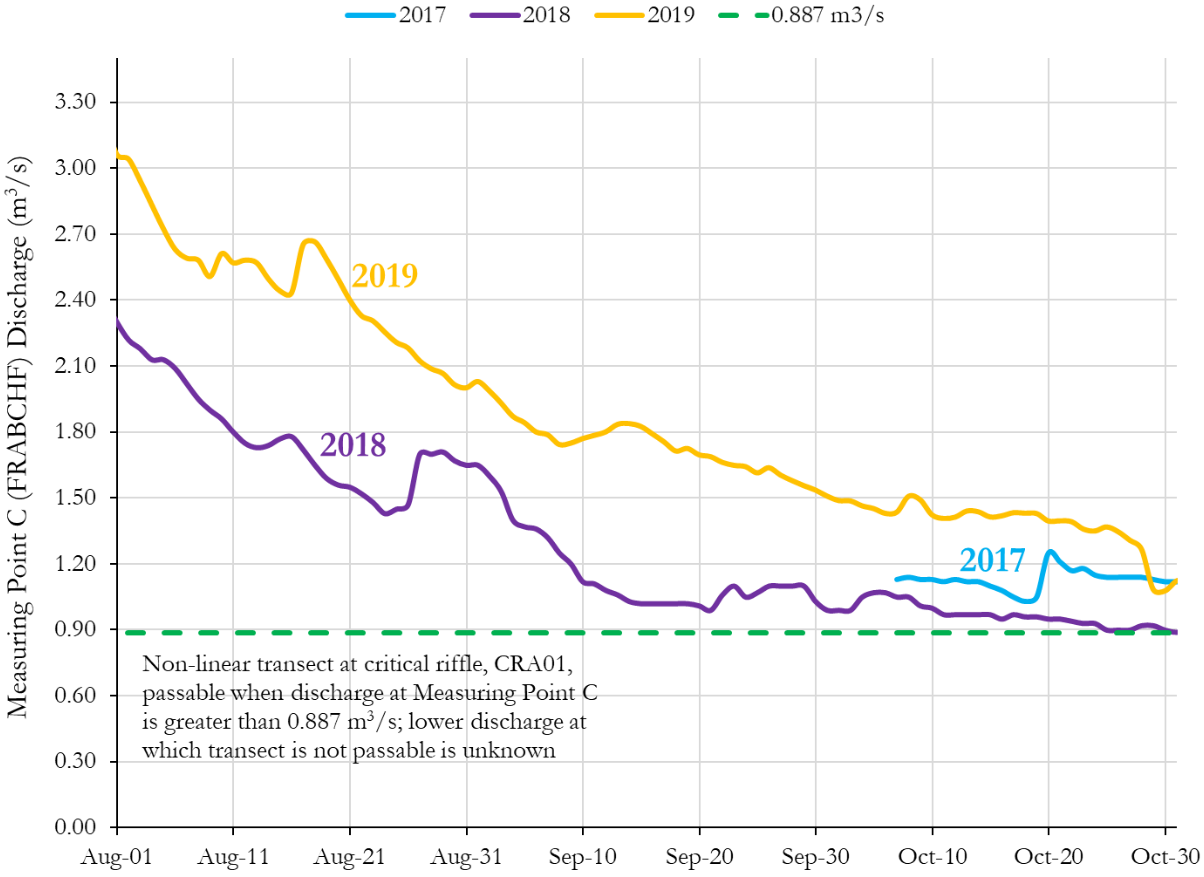


Figure 13. **Passage threshold for the FRD-CRA01 non-linear transect (green dashed line) and continuous flow data at Measuring Point C from 2017 and 2018 (solid blue and purple lines). Also shown are actual flows in 2017 and 2018 plus 5%, 10% and 15% to enable an evaluation of the sensitivity of fish passage at the transect to different flows and levels of water use. The green dashed line indicates that the transect is passable above this flow; the dashed pattern of the line indicates that we do not know the discharge below 0.887 m^3/s at which the transect is not passable (i.e., we would need to measure at lower flows). The riffle is passable to both juveniles and adults at flows ≥0.887 m^3/s, but the threshold at which the riffle is not passable may be different for juveniles and adults.**

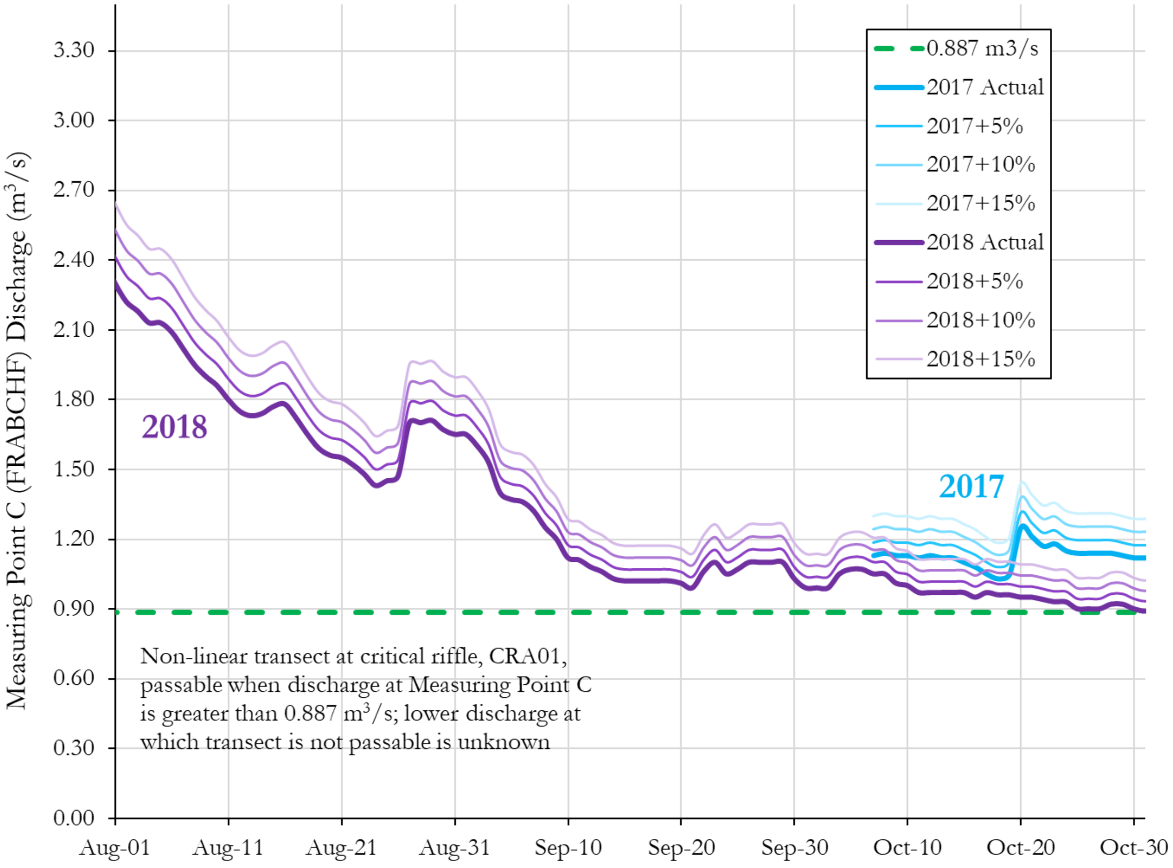


Table 7. Number and percentage of days between September 1 and October 15 in 2017 and 2018 with flows >0.887 m^3/s at Measuring Point C. Based on empirical measurements at FRD CRA01 in 2018, the transect is passable by juveniles and adults at flows >0.887 m^3/s.

Flow Metric	2017[a]		2018[b]	
	# of days	%	# of days	%
Actual Flow	9	100%	45	100%
Actual +5%	9	100%	45	100%
Actual +10%	9	100%	45	100%
Actual +15%	9	100%	45	100%

[a] 9 days of flow data were available at Measuring Point C between Sep 1 and Oct 15, 2017

[b] 45 days of flow data were available at Measuring Point C between Sep 1 and Oct 15, 2018

3.1.2.2. FRD-CRA02 and FRD-CRA03

The non-linear transects at FRD-CRA02 and FRD-CRA03 are not passable by juveniles and adults when discharge at Measuring Point C is less than 1.13 m^3/s (red dashed lines, Figure 14 and Figure 15). The red colour of the lines indicates that the transects are not passable below this flow; the dashed pattern of the lines indicate that we do not know the discharge above 1.13 m^3/s at which the transects are passable. There were missing flow data for 2017 (light blue lines), but the passage threshold and available hydrology data suggest that passage across FRD-CRA02 and FRD-CRA03 may have been problematic in fall 2018, particularly after early September. Based on the available data, juveniles and adults would have been impeded at FRD-CRA02 and FRD-CRA03 from September 10, 2018 to the end of the migration period (October 15), and hence for 80% of the 45-day migration period.

Fish passage at FRD-CRA02 and CRA03 was therefore sensitive to inter- and intra-annual variability in flow and water use in 2017 and 2018. Based on the passage threshold derived from empirical measurements in 2018, passage for juveniles and adults was <u>not</u> possible for 36 of 45 days (80%) within the overwintering migration period in 2018 because actual flows were <1.13 m^3/s (Figure 16, Figure 17, Table 8). The addition of 5% of daily average flow during the 2018 overwintering migration period (which is similar to the 4.9% actual use, Table 4) would have reduced the number of days that the transects were <u>not</u> passable for juveniles and adults to 28 of 45 days (62%; Table 8). The addition of 10% and 15% of daily average flow would have further reduced the number of days that the transects were <u>not</u> passable to 17 of 45 days (38%) and 5 of 45 days (11%), respectively (Table 8). It is not possible with the current data to determine how many days the transects were passable during the overwintering migration period, because the discharge at which the transect becomes passable is not known. That is, we know that the passage threshold is >1.13 m^3/s, but we don't know the actual passage threshold for either juveniles or adults.

There are only 9 days of flow data available for Measuring Point C in 2017; however, these data also illustrate the sensitivity of these two transects to water use. Using actual flows, the transects were <u>not</u> passable for juveniles or adults on 4 of 9 days (44%) in the middle of October, but by adding 5% of flow to account for water use, all 9 days were passable (Table 8).

Figure 14. Passage threshold for the FRD-CRA02 non-linear transect and continuous flow data at Measuring Point C from 2017 to 2019. The red colour of the line indicates that the transect is not passable below this flow; the dashed pattern of the line indicates that we do not know the discharge above 1.13 m^3/s at which the transect is passable. The riffle is not passable to juveniles or adults at flows ≤1.13 m^3/s, but the threshold at which the riffle is passable may be different for juveniles and adults.

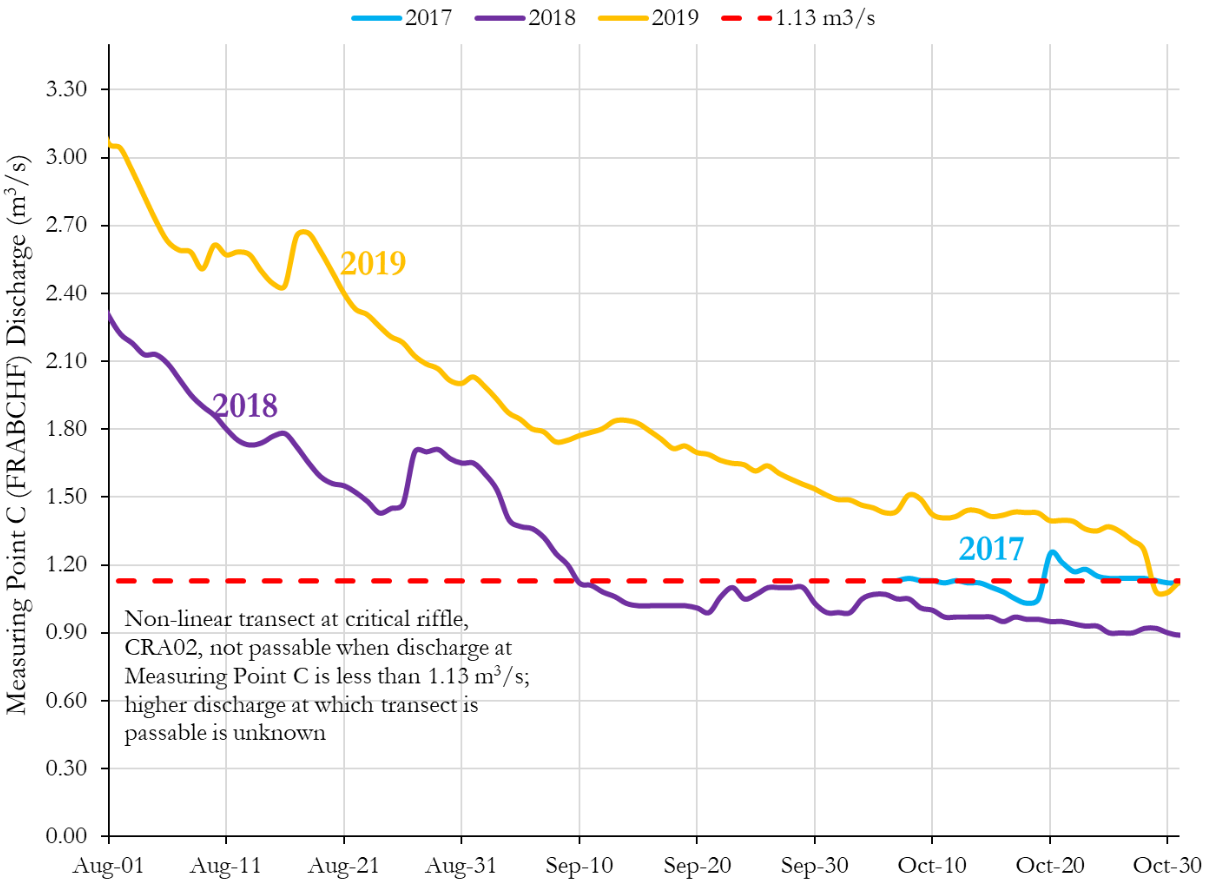


Figure 15. **Passage threshold for the FRD-CRA03 non-linear transect and continuous flow data at Measuring Point C from 2017 to 2019. The red colour of the line indicates that the transect is not passable below this flow; the dashed pattern of the line indicates that we do not know the discharge above 1.13 m^3/s at which the transect is passable. The riffle is not passable to juveniles or adults at flows ≤1.13 m^3/s, but the threshold at which the riffle is passable may be different for juveniles and adults.**

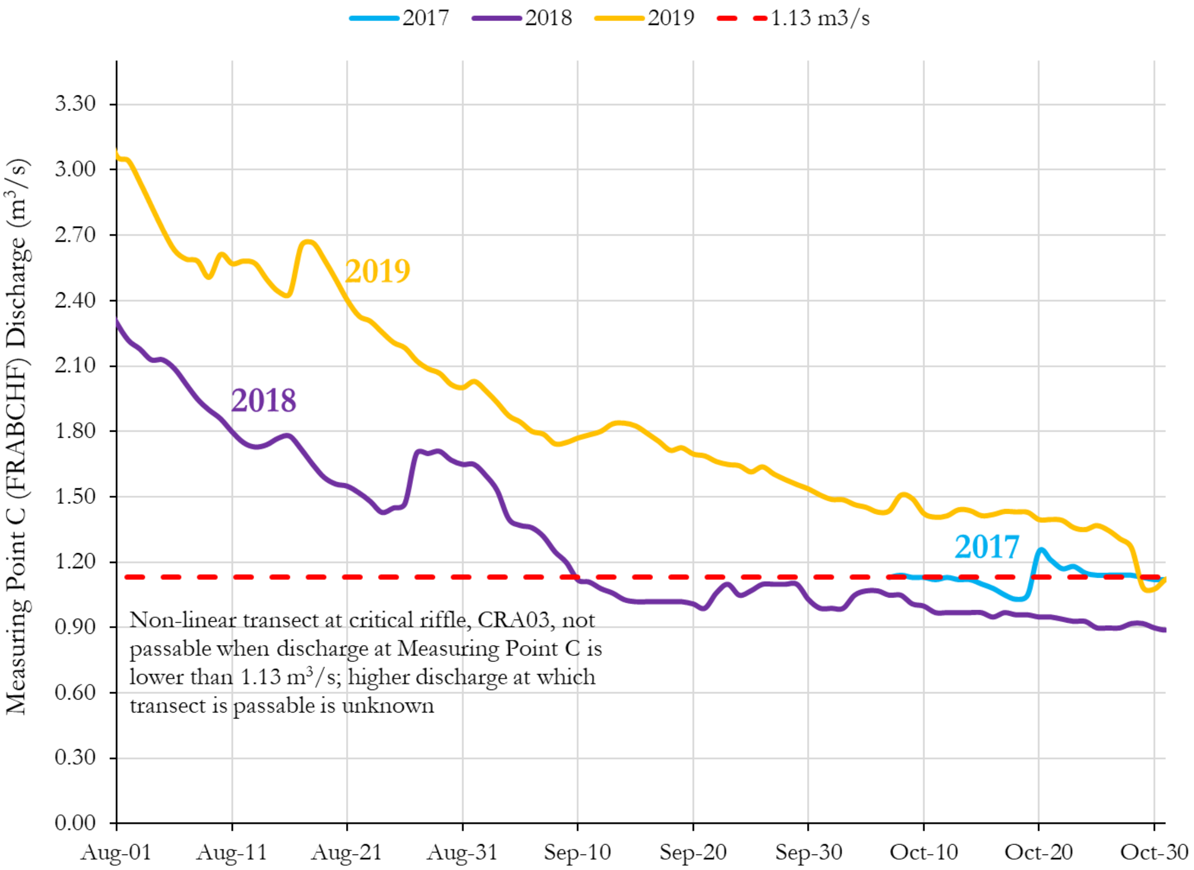


Figure 16. **Passage threshold for the FRD-CRA02 non-linear transect (dashed red line) and continuous flow data at Measuring Point C from 2017 to 2018 (solid blue and purple lines). Also shown are actual flows in 2017 and 2018 plus 5%, 10% and 15% to enable an evaluation of the sensitivity of fish passage at the transect to different flows and levels of water use. The red dashed line indicates that the transect is not passable below this flow; the dashed pattern of the line indicates that we do not know the discharge above 1.13 m^3/s at which the transect is passable. The riffle is not passable to juveniles or adults at flows ≤1.13 m^3/s, but the threshold at which the riffle is passable may be different for juveniles and adults.**

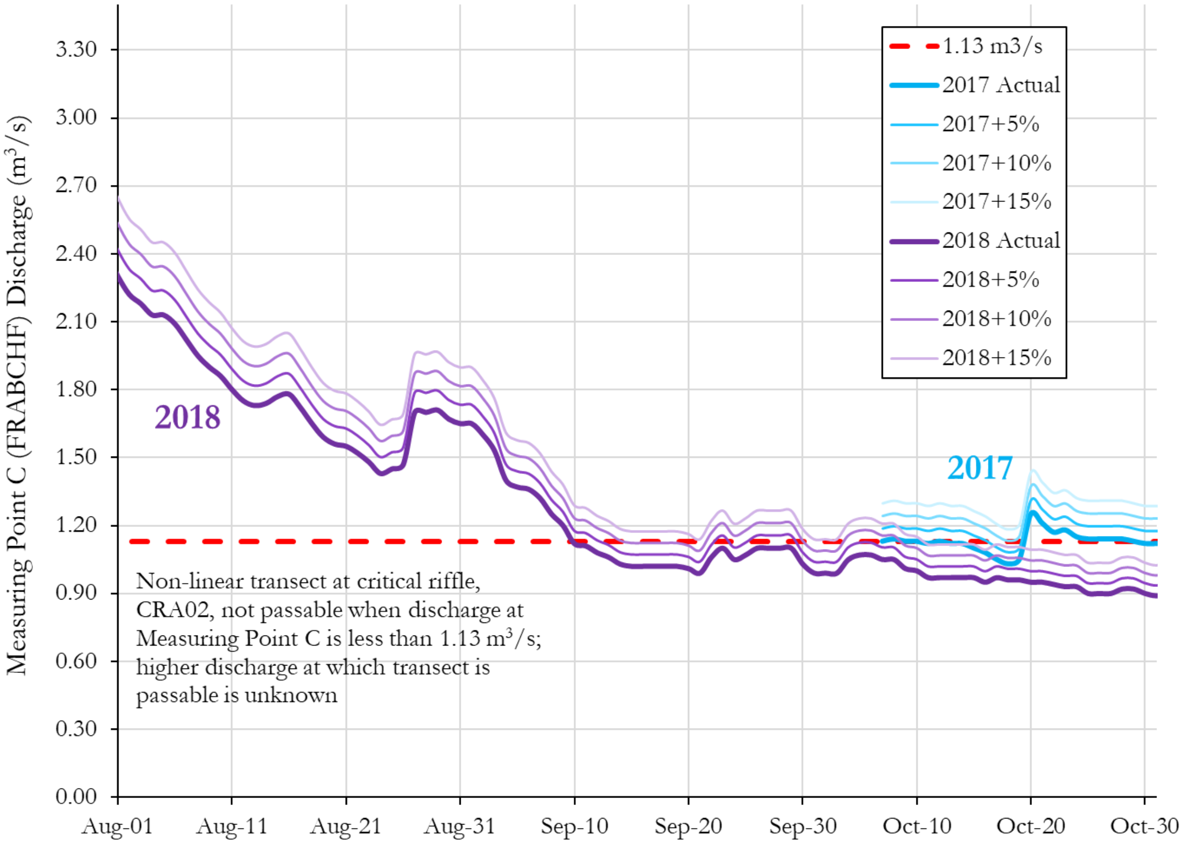
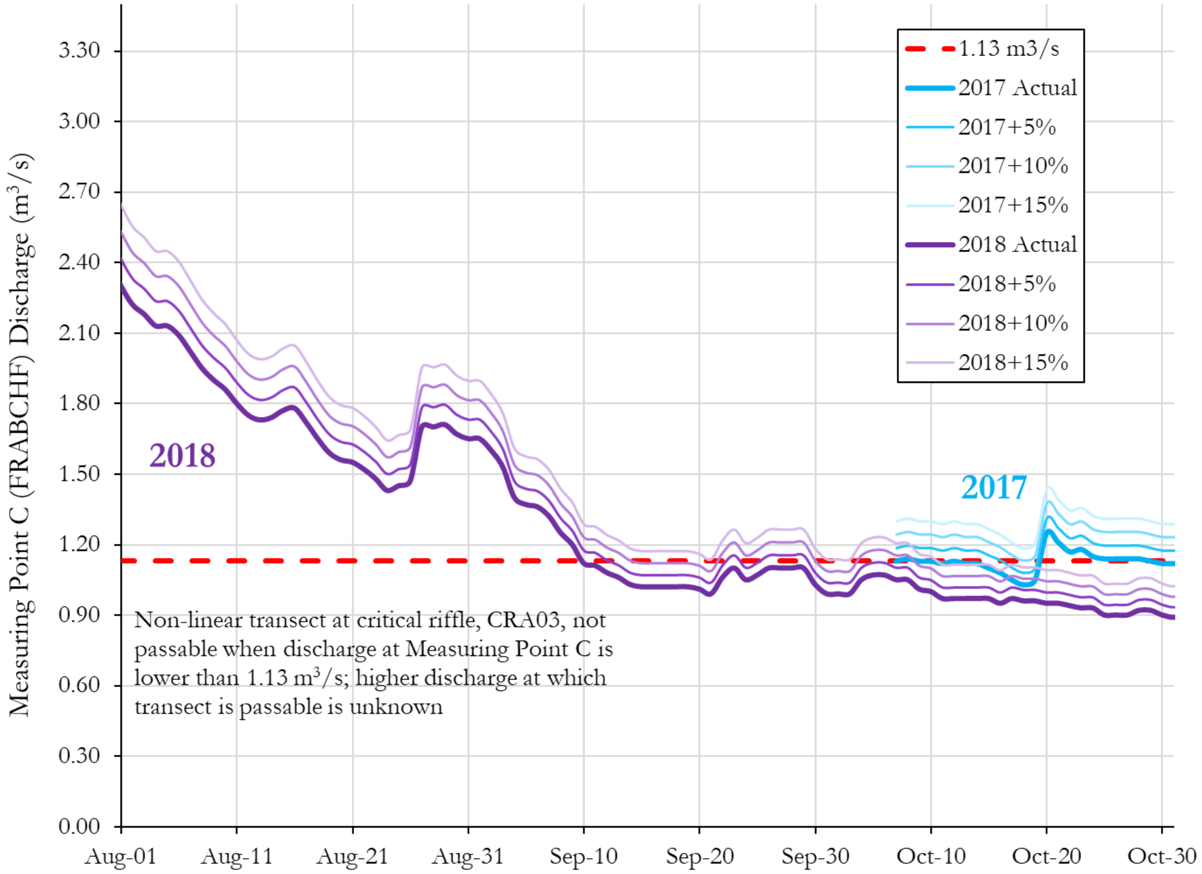


Figure 17. Passage threshold for the FRD-CRA03 non-linear transect (dashed red line) and continuous flow data at Measuring Point C from 2017 to 2018 (solid blue and purple lines). Also shown are actual flows in 2017 and 2018 plus 5%, 10% and 15% to enable an evaluation of the sensitivity of fish passage at the transect to different flows and levels of water use. The red dashed line indicates that the transect is not passable below this flow; the dashed pattern of the line indicates that we do not know the discharge above 1.13 m^3/s at which the transect is passable. The riffle is not passable to juveniles or adults at flows ≤1.13 m^3/s, but the threshold at which the riffle is passable may be different for juveniles and adults.



Non-linear transect at critical riffle, CRA03, not passable when discharge at Measuring Point C is lower than 1.13 m^3/s; higher discharge at which transect is passable is unknown

Table 8. **Number and percentage of days between September 1 and October 15 in 2017 and 2018 with flows <1.13 m^3/s at Measuring Point C. Based on empirical measurements at FRD CRA02 and FRD-CRA03 in 2018, the transects are not passable by juveniles and adults at flows <1.13 m^3/s.**

Flow Metric	2017[a]		2018[b]	
	# of days	%	# of days	%
Actual Flow	4	44%	36	80%
Actual +5%	0	0%	28	62%
Actual +10%	0	0%	17	38%
Actual +15%	0	0%	5	11%

[a] 9 days of flow data were available at Measuring Point C between Sep 1 and Oct 15, 2017

[b] 45 days of flow data were available at Measuring Point C between Sep 1 and Oct 15, 2018

3.1.2.3. FRD-CRA04

The non-linear transect at FRD-CRA04 is passable by juveniles and adults when discharge at Measuring Point B is greater than 0.60 m^3/s (green dashed line, Figure 18). The green colour of the line indicates that the transect is passable above this flow; the dashed pattern of line indicates that we do not know the discharge below 0.60 m^3/s at which the transect is not passable (i.e., we would need to measure at lower flows). There were missing flow data for 2017 (light blue line) and 2019 (yellow line); however, the passage threshold and available hydrology data suggest that passage across FRD-CRA04 may have been problematic in fall 2017, particularly after mid-September. Flows between mid-September and the end of the migration period in 2017 were the lowest in the flow data available (1997-2019).

Fish passage at FRD-CRA04 was not sensitive to intra-annual variability in flow and water use in 2018 as actual flows at Measuring Point B throughout the overwintering migration period were >0.60 m3/s, which is the passage threshold for juveniles and adults derived from empirical measurements in 2018 (Figure 19, Table 9). However, flows at Measuring Point B were lower in 2017 than in 2018, and fish passage at CRA04 was slightly sensitive to water use. Under actual flows, and actual flows plus 5% of daily average flow, the transect was passable for juveniles and adults on 6 of 29 days (21%). The addition of 10% of daily average flow during the 2017 overwintering migration period (compared to 9.2% actual use in 2017, Table 4), increased the number of days the transect was passable for juveniles and adults to 7 of 29 days (24%; Table 9). The addition of 15% of daily average flow would increase the number of days the transect was passable for juveniles and adults to 8 of 29 days (28%).

Figure 18. **Passage threshold for the FRD-CRA04 non-linear transect and continuous flow data at Measuring Point B from 2017 to 2019. Historical flow data are also presented (grey). The green colour of the line indicates that the transect is passable above this flow; the dashed pattern of line indicates that we do not know the discharge below 0.60 m^3/s at which the transect is not passable (i.e., we would need to measure at lower flows). The riffle is passable to both juveniles and adults at flows ≥0.60 m^3/s, but the threshold at which the riffle is not passable may be different for juveniles and adults.**

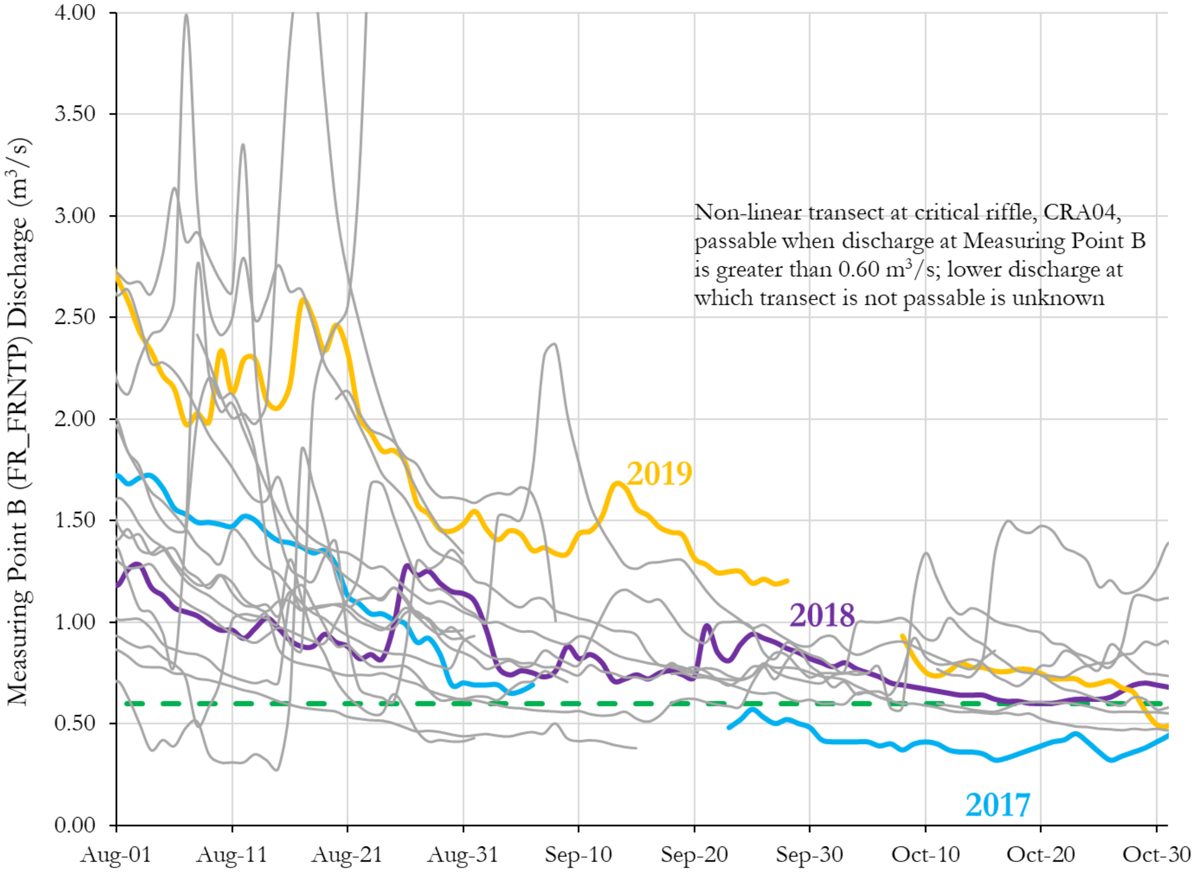


Figure 19. **Passage threshold for the FRD-CRA04 non-linear transect (dashed green line) and continuous flow data at Measuring Point B from 2017 to 2018 (solid blue and purple lines). Also shown are actual flows in 2017 and 2018 plus 5%, 10% and 15% to enable an evaluation of the sensitivity of fish passage at the transect to different flows and levels of water use. The green dashed line indicates that the transect is passable above this flow; the dashed pattern of line indicates that we do not know the discharge below 0.60 m^3/s at which the transect is not passable (i.e., we would need to measure at lower flows). The riffle is passable to both juveniles and adults at flows ≥0.60 m^3/s, but the threshold at which the riffle is not passable may be different for juveniles and adults.**

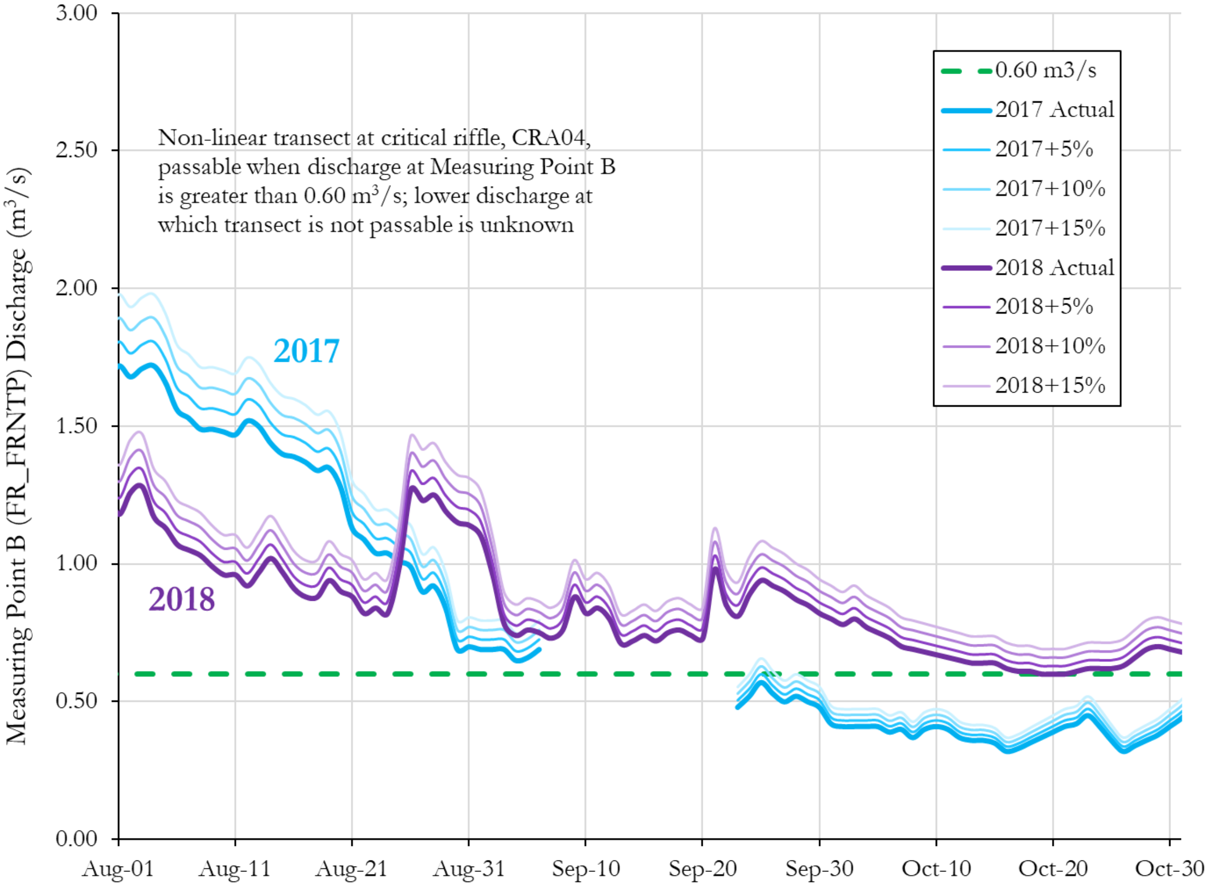


Table 9. Number and percentage of days between September 1 and October 15 in 2017 and 2018 with flows >0.60 m^3/s at Measuring Point B. Based on empirical measurements at FRD-CRA04 in 2018, the transect is passable by juveniles and adults at flows >0.60 m^3/s.

Flow Metric	2017[a]		2018[b]	
	# of days	%	# of days	%
Actual Flow	6	21%	45	100%
Actual +5%	6	21%	45	100%
Actual +10%	7	24%	45	100%
Actual +15%	8	28%	45	100%

[a] 29 days of flow data were available at Measuring Point B between Sep 1 and Oct 15, 2017

[b] 45 days of flow data were available at Measuring Point B between Sep 1 and Oct 15, 2018

3.1.2.4. FRD-CRA05

The non-linear transect at FRD-CRA05 is passable by adults when discharge at Measuring Point B is greater than 0.797 m^3/s and is passable by juveniles when discharge at Measuring Point B is greater than 0.636 m^3/s (green solid lines, Figure 20). The green colour of the line indicates that the transect is passable above this flow; the solid line pattern indicates that we know the discharge at which the transect switches from passable to not passable. There were missing flow data for 2017 (light blue line) and 2019 (yellow line); however, the passage threshold and available hydrology data suggest that passage across FRD-CRA05 may have been problematic for both juveniles and adults in fall 2017 when flows were the lowest in the data record (1997-2019), and adults in fall 2018.

The fish passage threshold for juveniles derived from empirical measurements in 2018 (0.636 m^3/s) indicates that juvenile fish passage at CRA05 was not sensitive to intra-annual variability in flow and water use in 2018 because actual flows were >0.636 m^3/s throughout the overwintering migration period (Figure 21, Table 10). However, adult fish passage at CRA05 was sensitive to intra-annual variability in flow and water use in 2018 as the passage threshold for adults (0.797 m^3/s) is higher than that for juveniles. Based on actual flows, the transect was passable for adults for 18 of 45 days (40%) in the 2018 overwintering migration period. The addition of 5% of daily average flow during the 2018 overwintering migration period (which is similar to the 4.9% actual use, Table 4), increased the number of days the transect was passable for adults to 24 of 45 days (53%; Table 10). The addition of 10% and 15% of daily average flow would have further increased the number of days that the transect was passable for adults to 33 of 45 days (73%) and 37 of 45 days (82%), respectively (Table 10).

Fish passage at FRD-CRA05 was restricted for juveniles and adults during low flows measured at Measuring Point B in the overwintering migration period in 2017. The number of days the transect was passable to juveniles in the overwintering migration period based on actual measured flows in 2017 was 6 of 29 days (21%) as flows were >0.636 m^3/s (Figure 21, Table 10). Actual flows were not above the adult passage threshold of 0.797 m^3/s in the 2017 overwintering migration period, at least for the 29 days for which data are available. Given how low the flows were compared to the passage thresholds, fish passage at CRA05 was not sensitive to water use in 2017; addition of 5% and 10% of daily average flow did not change the number of days that the transect was passable for juveniles or adults (Table 10). The addition of 15% of daily average flow increased the number of days the transect was passable for juveniles from 6 to 7 days, but did not change the number of days the transect was passable for adults (Table 10).

Figure 20. Passage threshold for the FRD-CRA05 non-linear transect and continuous flow data at Measuring Point B from 2017 to 2019. Historical flow data are also presented (grey). The green colour of the line indicates that the transect is passable above this flow; the solid line pattern indicates that we know the discharge at which the transect switches from passable to not passable. The riffle is passable to juveniles at flows ≥0.636 m^3/s and adults at flows ≥0.797 m^3/s.

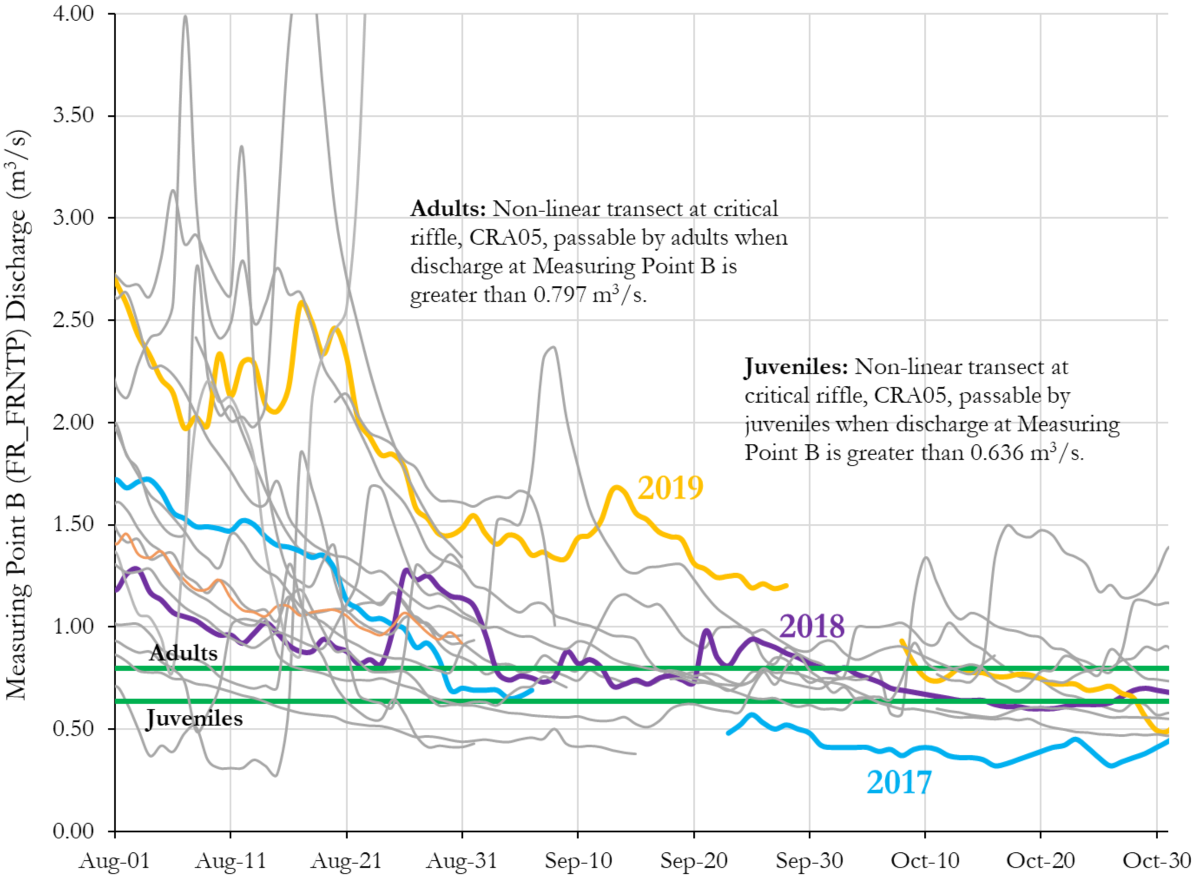


Figure 21. Passage thresholds for the FRD-CRA05 non-linear transect (solid green lines) and continuous flow data at Measuring Point B from 2015 to 2018 (solid blue and purple lines). Also shown are actual flows in 2017 and 2018 plus 5%, 10% and 15% to enable an evaluation of the sensitivity of fish passage at the transect to different flows and levels of water use. The green lines indicate the flows that the transect is passable for juveniles (lower) and adults (upper); the solid line pattern indicates that we know the discharge at which the transect switches from passable to not passable. The riffle is passable to juveniles at flows ≥0.636 m^3/s and adults at flows ≥0.797 m^3/s.

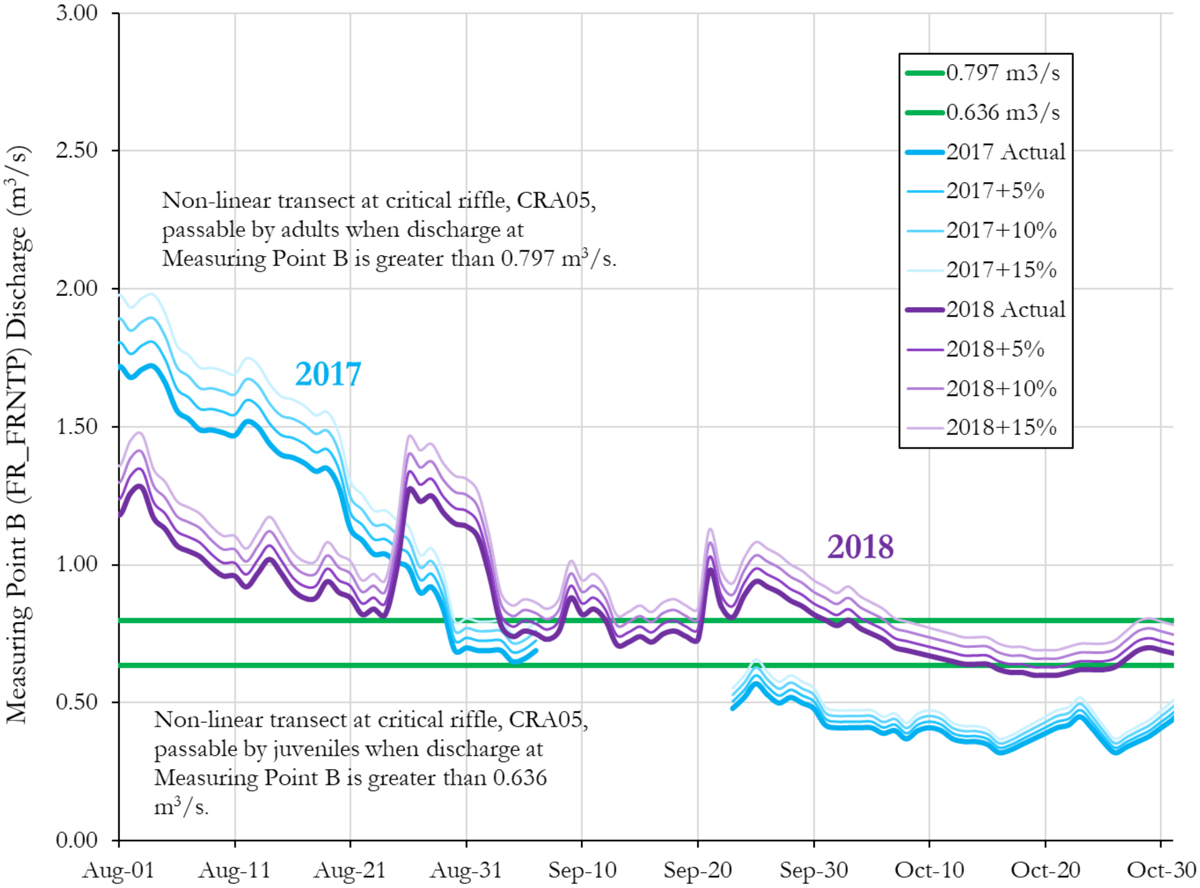


Table 10. Number and percentage of days between September 1 and October 15 in 2017 and 2018 with flows >0.636 m³/s and >0.797 m³/s at Measuring Point B. Based on empirical measurements at FRD-CRA05 in 2018, the transect is passable by juveniles at flows >0.636 m³/s and passable by adults at flows >0.797 m³/s.

Flow Metric	Passable by Juveniles				Passable by Adults			
	2017[a]		2018[b]		2017[a]		2018[b]	
	# of days	%	# of days	%	# of days	%	# of days	%
Actual Flow	6	21%	45	100%	0	0%	18	40%
Actual +5%	6	21%	45	100%	0	0%	24	53%
Actual +10%	6	21%	45	100%	0	0%	33	73%
Actual +15%	7	24%	45	100%	0	0%	37	82%

[a] 29 days of flow data were available at Measuring Point B between Sep 1 and Oct 15, 2017

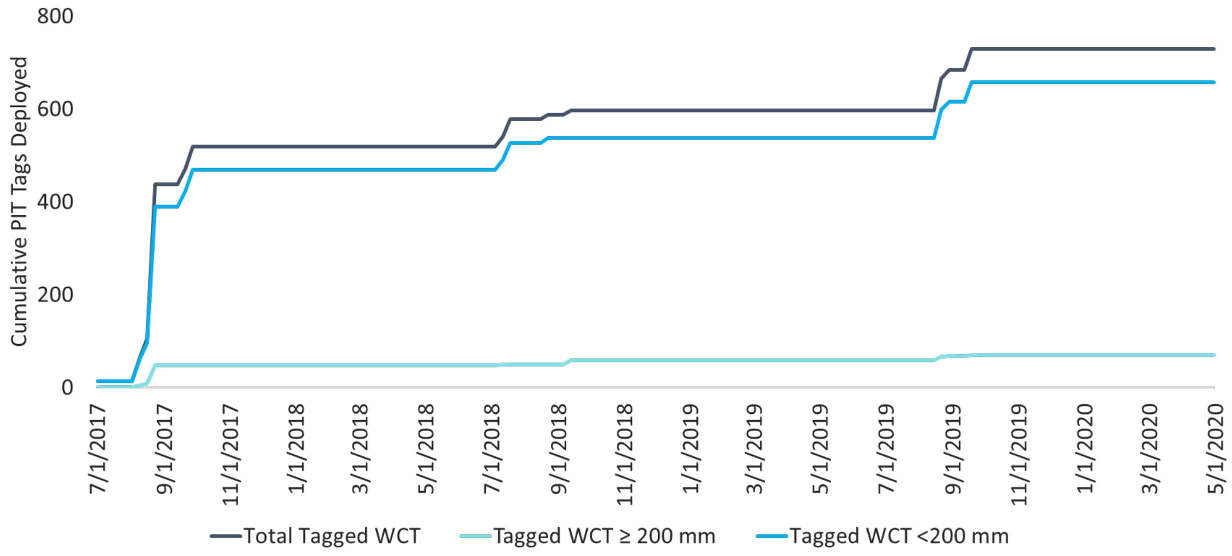
[b] 45 days of flow data were available at Measuring Point B between Sep 1 and Oct 15, 2018

3.2. PIT Tag Analysis

3.2.1. PIT Tag Deployments

The deployment of PIT tags into WCT in the UFR watershed began in the summer of 2016; however, the largest deployment occurred during the summer of 2017 (Figure 22). The summers of 2018 and 2019 also saw substantial PIT tags deployed in the watershed. An unknown number of PIT tags were deployed in the UFR by Environment Canada from 2012 to 2016. We were unable to acquire the fish data associated with such tags and acknowledge that they could make up the group of detections that could not be attributed to fish in the roster provided by Teck Coal.

Figure 22. The cumulative total of PIT tags deployed in the UFR watershed (north of confluence with Kilmarnock Creek) across the duration of the study period (20 July 2017 to 30 April 2020).



3.2.2. PIT Tag Detections over Entire Decline Window

3.2.2.1. Mapping of Detection Outcomes by Location of Tagging

Most tags deployed in the UFR study area were not detected at either the Henretta or Multi-plate arrays (Map 2; Map 3; Table 3 in Appendix B). There was variation among detection success by location of deployment; the closer a fish was to an array when it was tagged, the more likely it was to be detected. Fish were most likely to be detected if they were tagged between the two arrays, especially in the vicinity of Henretta array; however, both Chauncey and Greenhills creeks had fish detected at the Multi-plate array. Most fish that were detected only passed one of the arrays, but there were instances where individual fish were detected at both arrays (Table 3 and 8 in Appendix B)

3.2.2.2. Multi-plate

The number of detections at the Multi-plate array was greatest in the summer of 2018 and dropped off by summer of 2019 (Figure 23). The detections were also low in 2017; however, this was possibly due to the lower number of tags deployed at this time. The peak of detections at the Multi-plate array for 2018 occurred in late August. When examining the proportion of deployed tags that were detected, the results of 2017 and 2018 were comparable; however, the proportion of tags detected in 2019 was smaller (Figure 24). Overall, the proportion of the deployed tags detected was low, and only reached a maximum of 3.0% of deployed tags detected.

Figure 23. **Counts of PIT tagged WCT detections at the Multi-plate array summarized by week, and cumulative tags deployed in WCT in the UFR watershed north of Kilmarnock. The grey boxes indicate time periods when the array was intermittent or non-functional.**

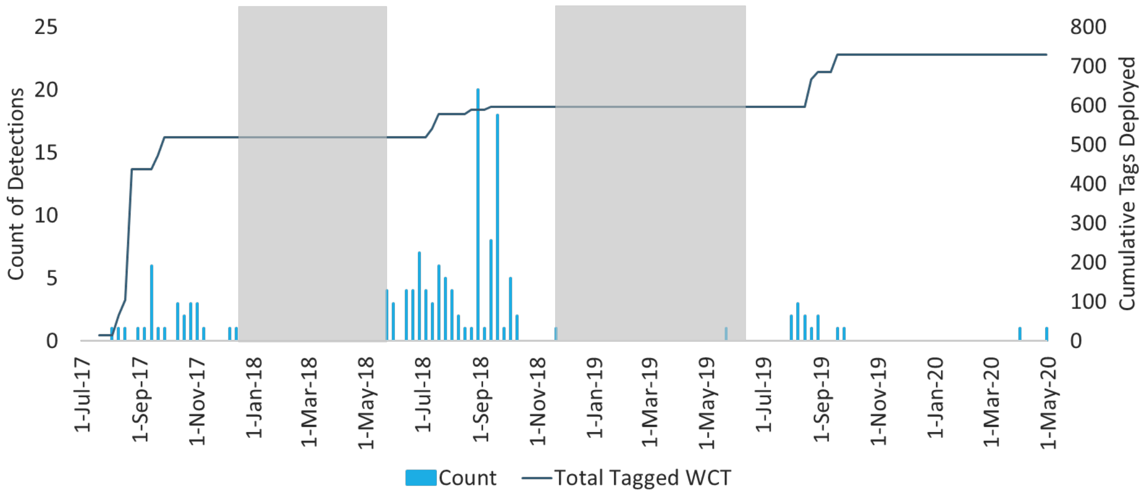
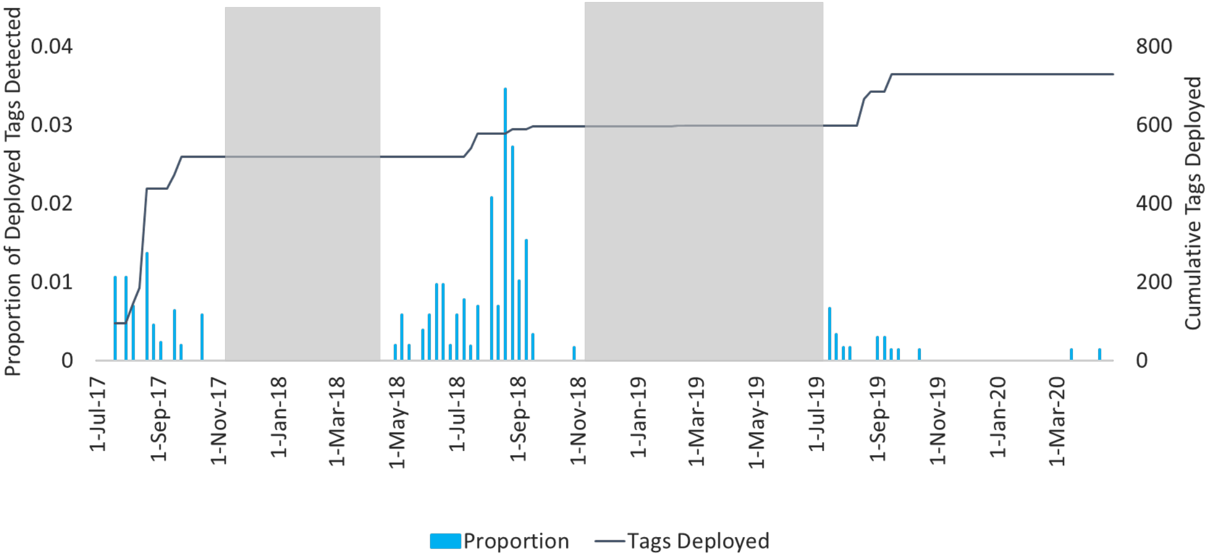


Figure 24. **Multi-plate array proportional detection of tags from PIT tag deployment roster by week, and cumulative tags deployed in WCT in the UFR watershed north of Kilmarnock. Grey boxes indicate time periods when the array was intermittent or non-functional.**



3.2.2.3. Henretta

The number of detections at the Henretta array was higher than at the Multi-plate array, but still low (<10% of all tagged fish). Similar trends in detections across years were observed at both Henretta and Multi-plate. Overall, the 2017 Henretta array counts were slightly higher than 2018, but 2019 had many fewer detections (Figure 25). The trend of low proportional detections displayed at Multi-plate is repeated at Henretta (Figure 26). Due to the large group of tagged fish released near the Henretta array in July 2017, the exact date of peak detection in 2017 is uncertain; however, in 2018 peak detection of tagged fish occurred in early July.

Figure 25. Counts of PIT tagged fish detections at Henretta culvert array summarized by weekly counts, with the cumulative count of tags in the UFR watershed north of Kilmarnock. The green box indicates the time period before installation of the upstream portion of the paired antenna, the grey boxes indicate periods when the array was intermittent or non-functional, and the blue box indicates the period when only the upstream antenna was intermittent.

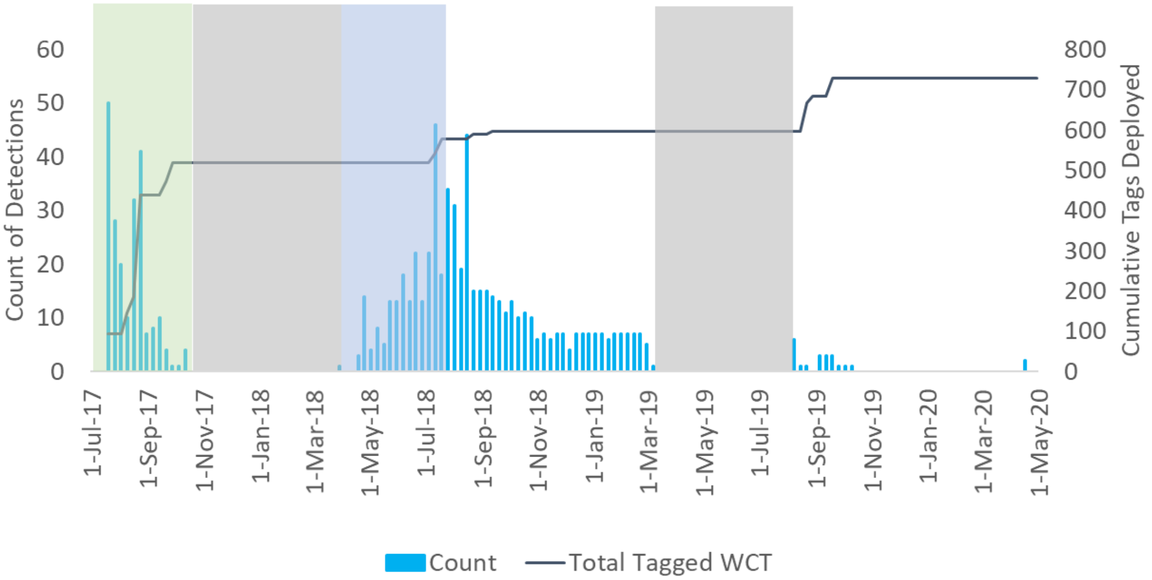
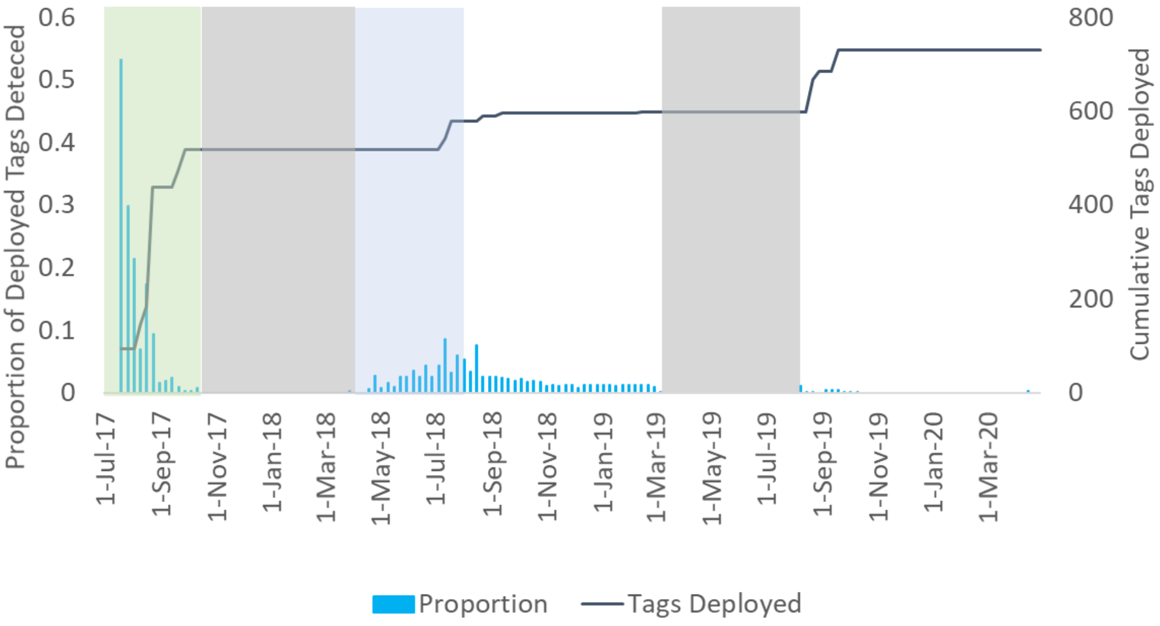


Figure 26. **Proportion of tags deployed, detected at Henretta array summarized by week, with lines representing cumulative tags deployed in the UFR watershed north of Kilmarnock. The green box indicates the time period before installation of the upstream portion of the paired antenna, the grey boxes indicate periods when the array was intermittent or non-functional, and the blue box indicates the period when only the upstream antenna was intermittent. The frequent detections in 2017 are in part due to the release of tagged WCT near the array as part of an effectiveness monitoring project.**



3.2.3. PIT Tag Detections in Late Summer / Early Fall

Detections that could be attributed to a fish from the deployment roster were broken down into adult (≥200 mm) and juvenile (<200 mm) life stages to assess whether there was a difference in detection for adult and juvenile fish during the fall migration period (September 1 to October 15) and a window on either side to evaluate earlier or later activity (plots denote the period from August 1 to November 30). At both arrays the detections of each life stage were proportional to the number of tags deployed in that life stage, with approximately 80% of the tags deployed in juveniles (Figure 22). When considering only adult fish (≥200 mm) it was difficult to draw conclusions due to the low number of detections (Figure 27, Figure 29). It is evident that detections are lower in 2019 compared to previous years, especially among juveniles (Figure 28, Figure 30). Additionally, by mid-September detections decreased from their peak and continued to decline through October. Except for adult detections at the Multi-plate culvert (Figure 27), there was a trend for more detections in August than the defined migration period of September 1 to October 15 (Cope et al. 2016). However, this may simply reflect a higher level of activity in the rearing period (May 15 to August 31) compared to the overwintering migration period (see Figure 7 in Appendix A), rather than evidence of earlier than assumed directed movement to overwintering habitat (see also Section 3.6 in Appendix A). For example, although juveniles continued to be detected at the Henretta culvert in October through November 2018 (Figure 30), there was not a corresponding number of successful upstream passage attempts (Figure 34, Section 3.2.4.2).

Figure 27. Multi-plate adult WCT (≥200 mm) detections from August 1 to November 30 across all years of the study by week; no fish were detected in 2019.

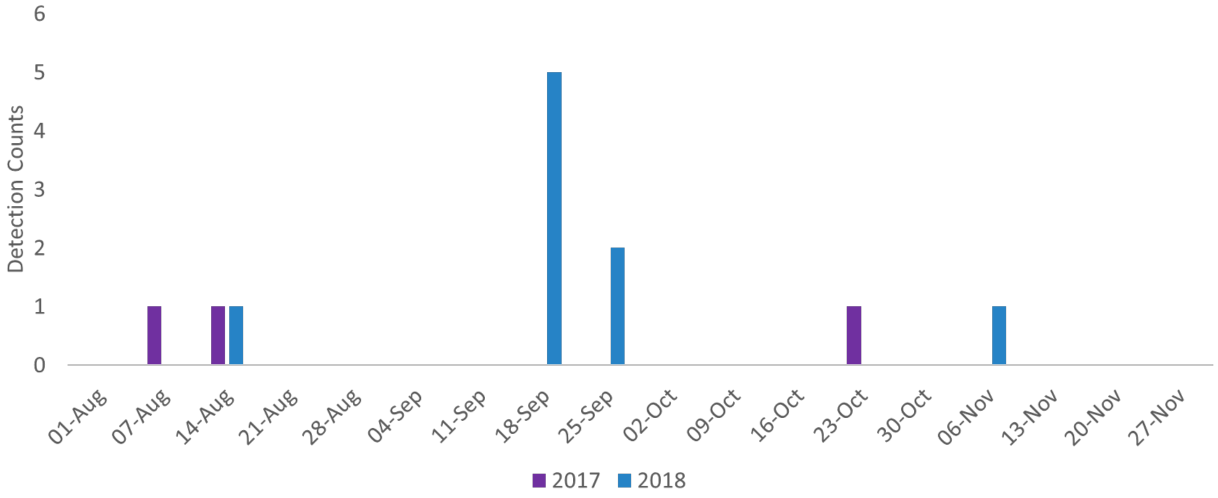


Figure 28. Multi-plate juvenile WCT (<200 mm) detections from August 1 to November 30 across all years of the study by week.

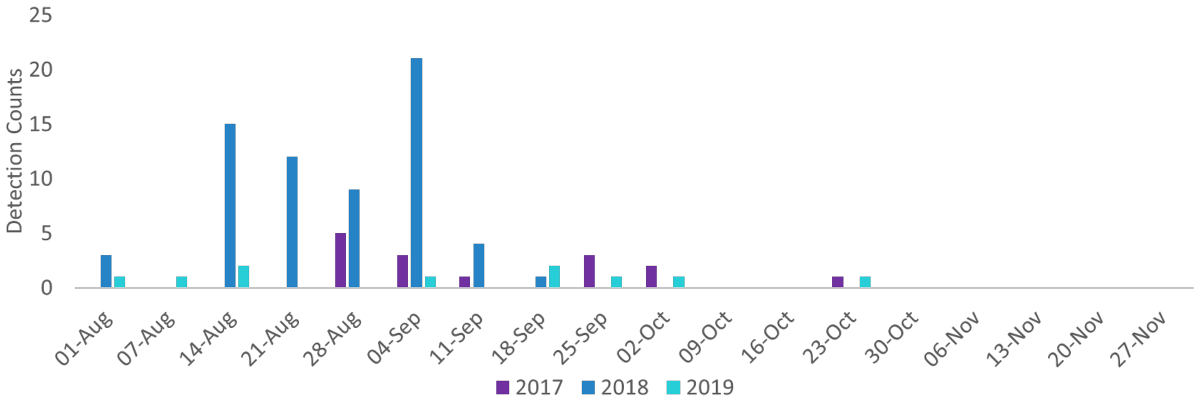


Figure 29. Henretta adult WCT (≥200 mm) detections from August 1 to November 30 across all years of the study by week; the green box indicates the time period in 2017 when the upstream antenna had not yet been installed, the blue box indicates the period in 2017 when the upstream antenna was intermittent or non-functional; however, the downstream antenna was functioning during this period.

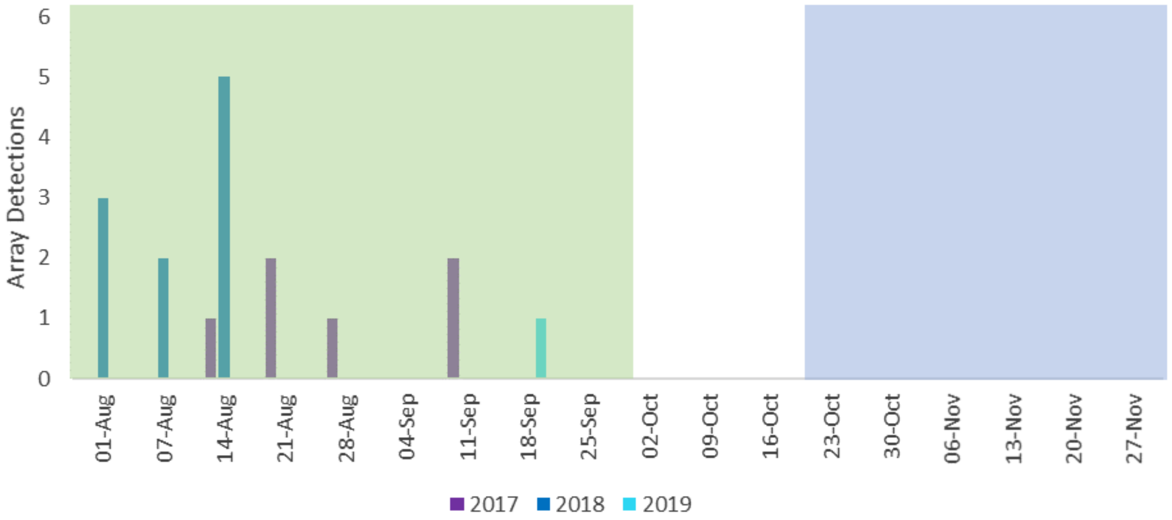
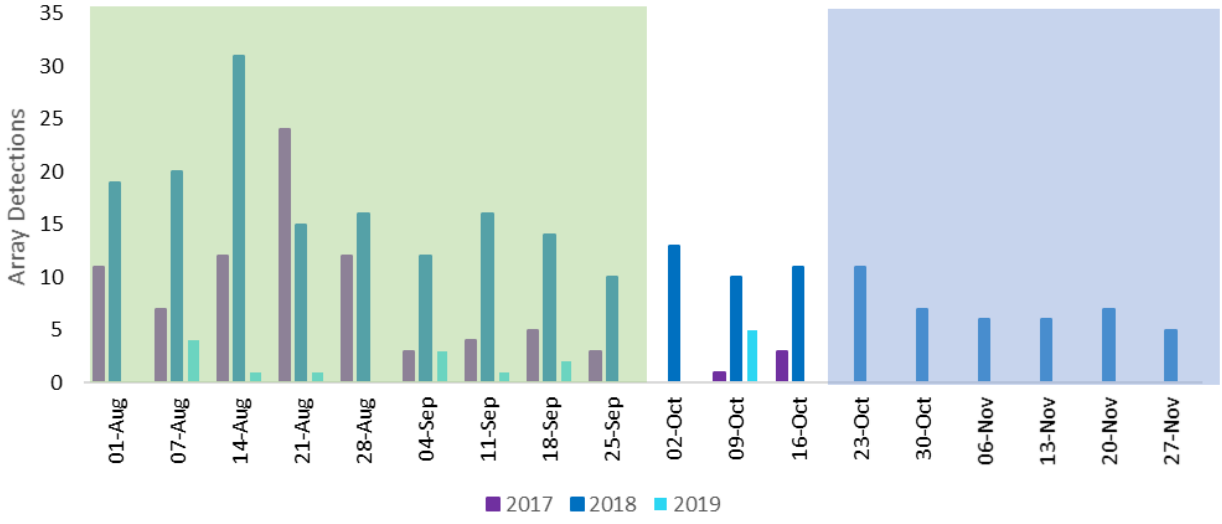


Figure 30. **Henretta juvenile WCT (<200 mm) detections from August 1 to November 30, for all years of the study by week; the green box indicates the time period in 2017 when the upstream antenna had not yet been installed, the blue box indicates the period in 2017 when the upstream antenna was intermittent or non-functional; however, the downstream antenna was functioning during this period.**



3.2.4. Movement as Determined from PIT Tag Data

3.2.4.1. Multi-plate

The directional movement data followed a similar trend to the detection data—movement was highest in 2018, marginally lower in 2017 and much lower in 2019. There was a defined peak in both directions of movement in 2018, with the downstream peak in early July and the upstream peak in early August (Figure 31). This trend is not visible in 2017 or 2019. In 2017, movement upstream and downstream from August 1 to November 30 took place over a longer time period than in 2018 (Figure 32, Figure 33), and there were no obvious peaks. Detection of movement in 2019 was insufficient to examine trends.

Culvert passage success as a function of individual passage attempts at the Multi-plate culvert could not be determined in the same manner as for Henretta (Section 3.2.4.2) because both antennae of the array are upstream of the culvert.

Figure 31. **WCT directional movement across the Multi-plate array by daily count. The grey boxes indicate time periods when the array was intermittent or non-functional.**

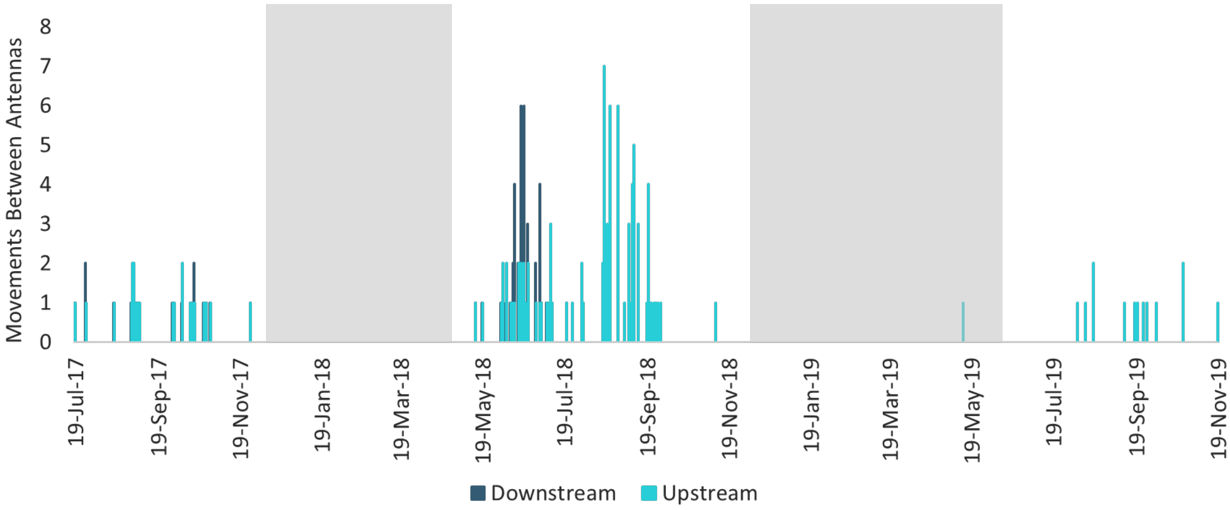


Figure 32. **Movement of fish in the upstream direction past the Multi-plate array antennae from August 1 to November 30 by weekly count.**

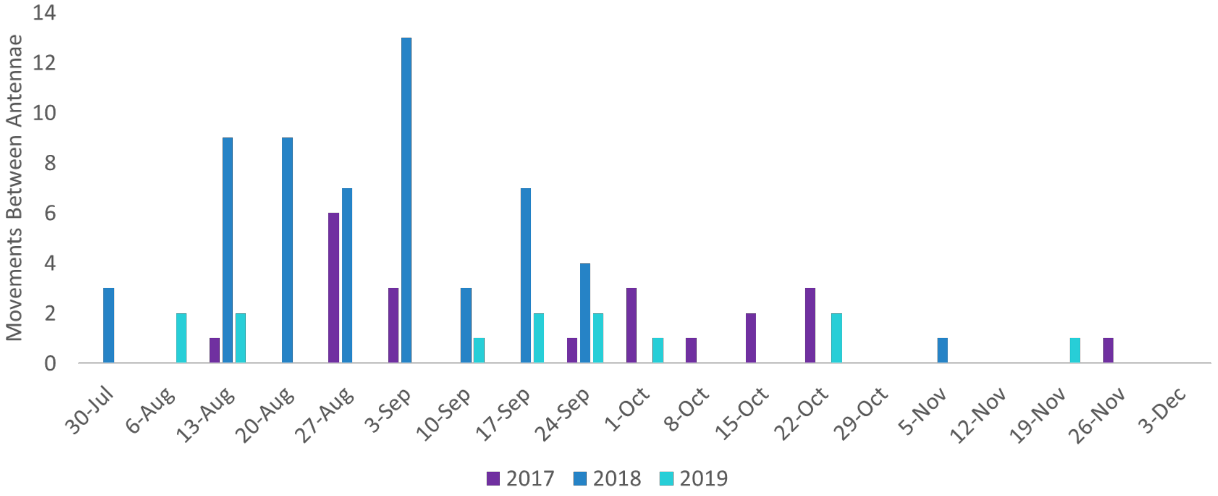
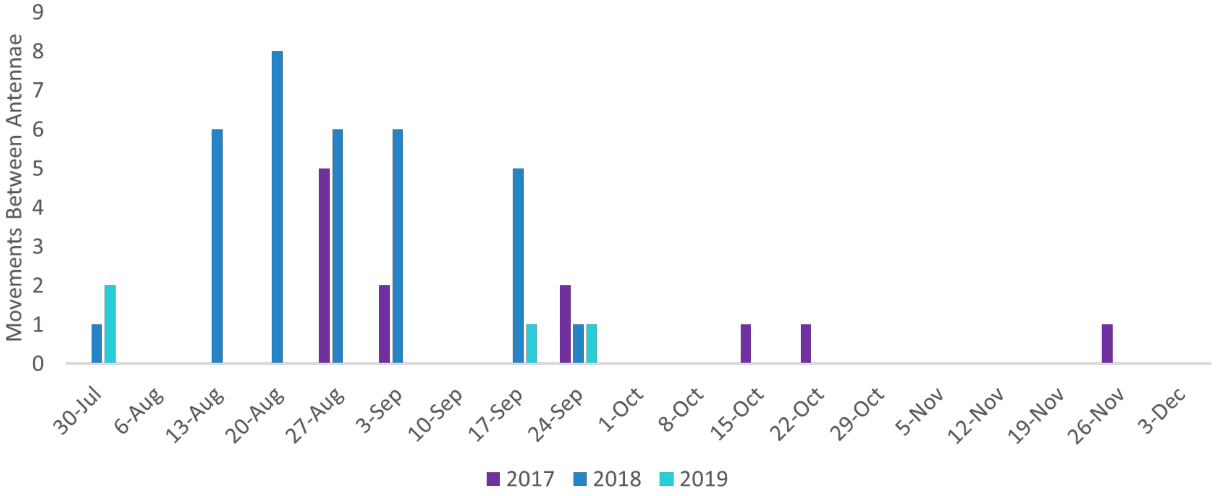


Figure 33. **Movement of fish in the downstream direction past the Multi-plate array antennae from August 1 to November 30 by weekly count.**



3.2.4.2. Henretta

Few occurrences of fish passage through the Henretta culvert were observed, though periods where both antennae were operating is limited to 2018 onward. The majority of passage was upstream in direction and took place during the summer (Figure 34) rather than the period associated with overwintering migration (Table 1; 1-Sep – 15-Oct, Cope et al. 2016). There was a pronounced lack of downstream movement; only a single occurrence was detected in the period of August 1 to November 30, and that was on August 20, 2018. Only three upstream movements across the array between August 1 and November 30 were observed, two in 2018 and one in 2019, and no movements downstream. From March 2018 to November 2019, the number of unsuccessful attempts by PIT tagged juveniles to cross the Henretta culvert far exceeds successful attempts for both upstream and downstream movement (Table 11). There were no successful attempts by PIT tagged adults to pass the Henretta culvert between March 2018 to November 2019, in either direction, although there were also very few attempts (Table 12).

Figure 34. Passage of fish in both directions across the Henretta culvert for all years in the study period by weekly count. The grey box indicates a time period when both antennae were intermittent or non-functional, and the blue box indicates a period when only the upstream antenna was intermittent. The period examined begins when both antennae were installed and functioning.

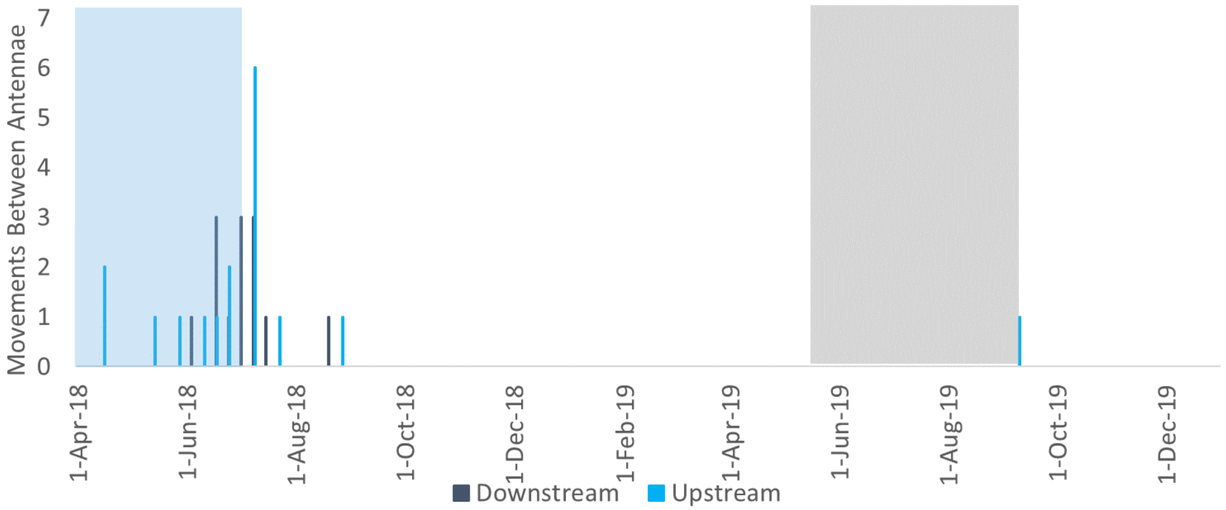


Table 11. Outcomes of attempted passage of the Henretta culvert by PIT tagged juvenile WCT from March 2018 to November 2019.

Culvert Passage Direction	Outcome	Number of Attempts	Percentage
Upstream	Successful[1]	12	14%
	Unsuccessful[2]	73	86%
	Total	85	100%
Downstream	Successful	8	2%
	Unsuccessful	418	98%
	Total	426	100%

[1] Successful culvert passage was defined as instances where a fish was detected at an antenna on one side of the culvert, and the next detection was on the other side of the culvert, regardless of dates.

[2] Unsuccessful movement was defined as instances where a fish was detected on one side of the culvert, and then detected again on the same side of the culvert on a subsequent day, without detection at any other antenna in between. This was an attempt to filter out excessive detections that occured when a fish remained stationary over an antenna; however, 289 of the 418 "unsuccessful" downstream attempts were made by one fish resident upstream of the culvert, inflating the % of unsuccessful attempts at downstream passage.

Table 12. Outcomes of attempted passage of the Henretta culvert by PIT tagged adult WCT from March 2018 to November 2019.

Culvert Passage Direction	Outcome	Number of Attempts	Percentage
Upstream	Successful[1]	0	-
	Unsuccessful[2]	0	-
	Total	0	-
Downstream	Successful	0	0%
	Unsuccessful	22	100%
	Total	22	100%

[1] Successful culvert passage was defined as instances where a fish was detected at an antenna on one side of the culvert, and the next detection was on the otherside of the culvert, regardless of dates

[2] Unsuccessful movement was defined as instances where a fish was detected on one side of the culvert, and then detected again on the same side of the culvert on a subsequent day, without detection at any other antenna in between. This was to filter out excessive detections that occured when a fish remained stationary over an antenna.

3.2.5. Recaptures of PIT Tagged Individuals

The results of the analysis of PIT tag recaptures were inconclusive. In the period where tagged fish were at large, a total of 45 were recaptured, but only five had moved. All five movements were identified as likely errors, due to size discrepancies in the recaptures (>50 mm smaller on recapture) or because the distance travelled was covered in an unrealistically short time (Table 4 in Appendix B).

3.3. Habitat Offsetting Construction Effects

The nine habitat offsetting construction projects (Map 4; Table 13) that had the potential to affect fish migration or behaviour are briefly described below along with descriptions of potential effects on fish behaviour. The timing of each project was limited to between August 10 and November 2 in the year of construction (Table 14). Each project was carried out with full approval of DFO, and under BC Water License (#C133870). Where fish salvages were necessary, they were carried out with a fish collection permit issued under the BC Wildlife Act (Bransfield and Robinson 2018a).

Table 13. Locations of rehabilitation sites that involved instream construction activities during the period leading up to or during the Decline Window.

Project	Rehabilitation Site	Upstream Boundary			Downstream Boundary		
		Zone	Easting	Northing	Zone	Easting	Northing
LCO Phase 2 Offsetting	Henretta Culvert Outlet Riffle Construction	11U	652060	5566388	11U	652067	5566320
	Fording River at the Concrete Arch	11U	650757	5564278	11U	651017	5563477
	Multi-plate Culvert Outlet	11U	651291	5562536	11U	651130	5562348
	Fording River near the North Tailing Ponds	11U	651123	5562348	11U	651128	5561686
Swift Fish Habitat Offsetting	Henretta Lake Outlet	11U	653288	5566797	11U	652182	5566463
	Fish Pond Creek	11U	651179	5565027	11U	650833	5564678
	Henretta Lake Inlet	11U	653281	5566811	11U	652572	5566378
	Fording River near Swift Creek	11U	651796	5559508	11U	652305	5558387
FRO S-AWTF	Fording River near Swift Creek Extension	11U	652294	5558387	11U	652301	5558269

Table 14. Dates of offsetting and rehabilitation construction that occurred preceding or during the Decline Window.

Project	Rehabilitation Site	Construction Year	Dates of construction
LCO Phase 2 Offsetting	Henretta Culvert Outlet Riffle Construction	2016	October 11 - 17
	Fording River at the Concrete Arch	2016	August 23 - October 28
	Multi-plate Culvert Outlet	2016	September 1-9, September 21 and October 27
	Fording River near the North Tailing Ponds	2016	August 25-31, September 12 - October 7
Swift Fish Habitat Offsetting	Henretta Lake Outlet	2017	September 19 - October 17
	Fish Pond Creek	2017	August 22 - October 13
	Henretta Lake Inlet	2018	August 2 - October 3
	Fording River near Swift Creek	2018	August 10 - October 15
FRO S-AWTF	Fording River near Swift Creek Extension	2018	August 10 - October 3

Further details of the rehabilitation projects and activities are provided in Bransfield and Robinson (2018a and 2018b) and Roulston and Robinson (2018). Mitigation planning (e.g., work windows for project implementation) took place prior to commencement and onsite construction monitoring was carried out for the duration of each project (Bransfield and Robinson 2018a, Roulston and Robinson 2018, Bransfield and Robinson 2018b).

- Henretta Culvert Outlet Riffle Construction (2016): Two riffles were created downstream of the grouted weirs below Henretta Culvert. The construction of these riffles required instream placement of the bed materials for the riffles.
- Fording River Rehabilitation near the Concrete Arch (2016): ~1,200 m of the Fording River was rehabilitated with LWD placement along banks and within the stream. Riffles were added in three locations within the reach.

- Multi-Plate Culvert Outlet Rehabilitation (2016): Six riffles were constructed downstream of the Multi-Plate culvert to backwater the pool beneath the outlet of the culvert and increase fish passage success. Boulder and LWD was placed within the stream to create the riffles.
- Fording River Rehabilitation near North Tailings Ponds (2016): Fourteen riffles were constructed in the vicinity of the North Tailings Pond to restore channel form and function. They were constructed of boulders and cobble substrate.
- Henretta Lake Inlet/Outlet Rehabilitation (2017/18): Henretta Lake was deepened by the creation of a riffle at the lake outlet, and inlet and outlet stream habitats were improved by the placement of boulders to create a riffle-pool morphology. LWD structures were placed along lake edges, and within the newly created pools.
- Fish Pond Creek Rehabilitation (2017): Overwintering habitat was improved by deepening in-line ponds to sufficient depth for WCT overwintering. A riffle-pool morphology was constructed below each pond with introduced boulders/cobble/gravel. LWD (comprised of groups of five trees with root wads) was introduced to each pool for cover.
- Fording River Rehabilitation Near Swift Creek and Extension (2018): ~1,500 m of the Fording River was rehabilitated with large woody debris placement along banks and within the stream. Some sections had the channel realigned and riffles were enhanced with LWD. A channel plug was constructed of large boulders to prevent channel migration and increase sinuosity.

All of these activities involve the placement or movement of boulders, LWD, and in some cases bank realignments. To carry out these processes heavy equipment was utilized near streambanks. The placement of heavy structures can cause vibration, turbidity and displacement of fish. To mitigate these effects heavy machinery was kept out of streams and limited to stream banks, substrate was sieved to remove fine sediment, and turbidity was actively monitored. Fish salvages were conducted in locations where fish were at risk from material placement. When it was necessary for heavy machinery to make creek crossings, temporary culverts were installed and crossed (Bransfield and Robinson 2018a).

3.4. Assessment of Orthophotos for Log Jam Accumulation

A summary of the logjams as interpreted from orthophotos in 2007, 2012, 2013, 2016, 2017, 2018 and 2019 is presented in Table 15. 2013 was the year with the most log jams (17 log jams); the remaining years varied between 10 and 14 (excluding 2007, which was missing coverage of the lower segments of the UFR). Smaller log jams appeared to be intermittent (Figure 35); whereas, the larger log jams were present during the entire period analyzed.

Figure 35. Examples of two large sized log jams (left brackets) and a small sized log jam (all located in S3/S4) captured during the 2016 orthophoto flight.

Table 15. Count of log jams present in each section of the UFR as determined from analysis of orthophotos.

Section	Orthophoto Year						
	2007[1]	2012	2013	2016[2]	2017[2]	2018[2]	2019
S1	n/a	0	0	0	0	1	1
S2	n/a	3	6	5	5	4	4
S3	n/a	1	2	1	2	1	1
S4	n/a	2	1	1	1	1	1
S5	n/a	1	2	1	1	1	2
S6	4	3	4	2	3	1	4
S7	0	1	1	0	1	1	0
S8	0	0	0	0	0	0	0
S9	1	0	1	0	0	0	1
Total	**5**	**11**	**17**	**10**	**13**	**10**	**14**

[1] Imagery is not available for S1-S5 in 2007

[2] Years 2016-2018 are missing a portion of the of imagery from S4 due to the flight path taken, therefore those years may have a low log jam count

4. DISCUSSION

4.1. Critical Riffle Analysis

Results from the critical riffle analysis indicate that flows at some critical riffles may have impeded WCT movement in late September 2018 (FRD-CRA02, 03, 05). Further, we can infer potential passage issues for a longer duration in the 2018 season by using flow data and passage thresholds. Based on the available data, juveniles and adults would have been impeded at FRD-CRA02 and FRD-CRA03 from September 10, 2018 to the end of the migration period (October 15), and hence for 80% of the 45-day migration period. Similarly, the available data suggest that adults may have been impeded at FRD-CRA05 for 40% of the 45-day migration period. However, it is important to reiterate that the 2018 OEMP study on which this analysis was based was not intended to actually observe fish passing at a certain flow, rather it was to model passability based on bed profile and stage-discharge relationships and assumed depth and width requirements. There remains uncertainty, therefore, in the degree to which fish movement past the riffles was actually impeded.

FRD-CRA02 and FRD-CRA03 are in the reach of the UFR that goes dry seasonally. Minnow and Lotic surveys for the FRO LAEMP indicate that the extent and duration of dewatering can vary substantially between years. For example, surveys of the reach between Chauncey and Kilmarnock creeks indicate that in the winter of 2018/2019, dewatering occurred earlier (October) and was more extensive than in 2017/2018 (Minnow and Lotic 2019). In October 2018, there was a

280 m long dewatered section, whereas in 2017/2018 dewatering wasn't observed until January 2018. In January 2019, approximately 2.8 km of the 12.8 km (22%) of the UFR covered by the FRO LAEMP surveys was dewatered (Minnow and Lotic 2019). This compares to ~1.5 km of the 12.8 km (12%) being dewatered in January 2018 (Minnow and Lotic 2018). These results indicate that in addition to the potential for passage to preferred overwintering habitats to have been impeded in fall 2018, the amount of wetted habitat available to overwintering fish was lower in the winter of 2018/2019 than in 2017/2018.

Evaluation of passability in other years based on flow data demonstrated that most of the critical riffles assessed were passable at the 9 cm (juvenile) and 12 cm (adult) minimum depth criteria and based on the 10% wetted width threshold in August, prior to the fall migration period (September 1 to October 15). The results in the fall migration period vary depending on the year. In 2019, flows were relatively high through September and thus all critical riffles were likely passable, although there is uncertainty for FRD-CRA02 and FRD-CRA03 because the discharge at which the transect is passable is not known. In fall 2017, there is not enough flow data available at Measuring Point C to judge whether FRD-CRA02 and FRD-CRA03 were passable during the migration period; however, FRD-CRA01 was likely passable based on the passage threshold and flows in late October. Flows at Measuring Point B between mid-September and the end of the migration period in 2017 were the lowest in the flow data available (1997-2019), and FRD-CRA05 would not have been passable for juveniles or adults at these flows. However, there is a data gap from September 7 to 22 so passage conditions within this period are unknown. Given the low flows in 2017, CRD-FRA04 may also not have been passable for much of the fall migration period, although there is more uncertainty for this riffle because the discharge at which the transect is not passable is unknown.

The results of the analysis to evaluate the extent to which fish passage at critical riffles is sensitive to inter- and intra-annual variability in flow and water use indicate that fish passage at four of the five critical riffles in the upper Fording River is sensitive to variability in flow and water use during the overwintering migration period. The degree of sensitivity depends on the physical nature of the critical riffle and the natural hydrology during the migration period.

4.2. PIT Tag Analysis

The original purpose of the PIT tag study was to determine the effectiveness of habitat offsetting in the UFR; however, the data enabled an examination of the timing of movement and also supported refinements of the Decline Window. There are several factors that limit the conclusions that can be made about the potential timing of the population decline. These factors include the seasonal nature of fish movement, the low proportion of tags detected by the arrays, and the several periods when the arrays were non-functional. Nevertheless, detections in the summer of 2017 and the summer of 2018 are comparable, whereas detections in the summer of 2019 are much lower; the much lower detections provide evidence that the decline occurred between the summers of 2018 and 2019.

There was variability between months and years in the number of detections at the arrays; however, there were considerably fewer detections in 2019 compared to 2017 and 2018. For example, in the months of August through October there were 69 detections across both arrays in 2017, 65 detections in 2018, but only 21 in 2019 (Table 6 in Appendix B). Similarly, during the spawning migration period of April-May (Table 1), there were 41 detections across both arrays in 2018, but only 1 detection in 2019. Tag-induced mortality and tag shedding may lead to fewer detections, but data are insufficient to assess these factors in detail. However, research on PIT tags in Cutthroat Trout has demonstrated that the invasiveness of PIT tags is low, and retention and survival can be high over a six-month period (Ostrand et al. 2011). Therefore, we do not expect that fish are regularly shedding tags, nor that the tag insertion itself was a substantial source of mortality. The tagged adults (n=201) make up a small proportion (5%) of the WCT population in the UFR based on the estimate of 3,690 WCT greater than 200 mm in 2017 (Cope et al. 2017). It is evident from the maps (Map 2, Map 3) that the low overall detection is in part related to distance between tagging location and the detection arrays, as there is a trend of decreasing detection with distance from the arrays. Our analysis partially corrected for this distance effect by excluding tags deployed downstream of Kilmarnock Creek.

Given that PIT tags are not expected to substantively influence survival of tagged fish, we conclude that detections should have been similar for 2018 and 2019. That the detections declined precipitously provides evidence that the WCT abundance decline occurred between the summers of 2018 and 2019. Recently received data for the winter of 2019/20 suggests that the trend of low numbers of detections persists into 2020. Only four WCT were detected in March-April 2020, compared to two in 2019 and 14 in 2018 (Table 6 in Appendix B). Inconsistent array operations prevented a detailed comparison with 2019.

The PIT tag data indicate that WCT movement in the vicinity of the arrays is highest through the summer and early fall. The analysis of PIT tag detections indicates that for the years of 2017-2019 the peak of fish movements occurred from July to early August at Henretta and peaked by the first week of September at Multi-plate. At both arrays, total detections were in decline by the second week of September and had stabilized at low levels by early October. These findings are supported by the telemetry data collected by Cope et al. (2016) which show greater movement during the summer rearing period than the overwintering migration period (Appendix A). The reasons for an earlier peak in movement are not well understood, but earlier movement may be related to higher activity levels in general or the timing may be in response to a change in environmental conditions.

The second finding was the low number of successful fish passages of the Henretta culvert. Unsuccessful attempts far outnumber the successful attempts for both upstream and downstream movement (Table 11, Table 12). The movement patterns indicate that the culvert or the associated weirs are acting as a partial barrier to migration. Henretta Pit Lake was identified in Cope et al. (2016) as a primary location for WCT overwintering and the Henretta culvert was identified as a contributor to an overall loss of connectivity in the UFR. Instream works were completed in October 2016 to improve passage conditions, and analysis completed by Lotic demonstrated that 55% of fish tagged and released downstream of the culvert successfully moved through the culvert, meeting the target of

10% successful passage (Lotic 2017)[10]. However, the PIT tag results presented here indicate that the culvert still acts as a partial migration barrier. Data were not available to determine whether conditions were less suitable for fish passage within the Decline Window than in previous years; however, based on the instream works completed and the demonstration of improved conditions (Lotic 2017), it is unlikely that passage conditions at the culvert were worse in the Decline Window than prior.

4.3. Habitat Offsetting Construction Activities

From 2016 until 2018 construction took place at nine locations (Table 13; Map 4) to complete habitat offsetting rehabilitation or improvements. Each of these projects was carried out to improve habitat suitability for WCT in the UFR. The most common construction activity was the placement of LWD or boulders into the stream to create cover, or improve the stream morphology. Several projects also involved the creation of riffles to increase backwatering. At times substrate smaller than boulders was placed, but this substrate was sieved to remove fine sediment that could increase turbidity.

All of the offsetting projects have the potential to create conditions that WCT would likely avoid, which could affect fish passage past the construction sites. The placement of large structures within a stream requires heavy machinery that generate vibration, noise and overhead activity. During placement, the movement of structures or equipment would deter fish from entering the immediate area, and potentially create turbidity that would extend downstream. All the construction projects listed would have likely created these conditions to some extent.

There was a limited window for construction each year (August 10 – November 2), construction took place during daylight, and mitigations were in place to control the effects of construction (no heavy machinery in streams, turbidity monitoring and controls, fish salvages etc.). While construction activities stretched out over several months for some projects, much of the work was on shore restoration or preparing structures for placement, and would not have affected fish passage. It is unlikely that as carried out, these presented major impediments to WCT migration in the UFR. We find it more likely that WCT would have temporarily avoided areas of construction, but because the activities were not constant, opportunities for fish passage would have existed.

4.4. Log Jam Accumulations

There is uncertainty with respect to whether log jams in the UFR contribute to fish passage difficulties, and there are likely different hydraulics and challenges at each log jam. Our enumeration of log jams in the UFR between 2007 and 2019 indicated some variation from year to year, from a maximum of

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[10] The target was set at 10% of the sample population of PIT tagged fish, with a recommended sample size of 50-100 juvenile fish (length <100 mm) to show successful passage by juveniles is possible. This value was agreed to by the EVFFHC (KNC, FLNRO, DFO and Teck) and accepted by DFO in the *Fisheries Act* Authorization when developing the offsetting measures and effectiveness monitoring for those offsetting measures in 2015/2016 (L. Watson, Teck Coal Ltd., personal communication)

17 in 2013, to a minimum of 10 in 2016 and 2018, and with most of the log jams occurring in S2 and S6.

The effects of these log jams on fish migration are uncertain; however, there does not seem to have been a large and sudden shift in connectivity due to log jams during the Decline Window relative to the pre-decline period. Further, the log jams appeared similar in nature prior to and during the Decline Window. Overall, we expect that fish passage within the UFR remained fairly constant with respect to log jams, but finer resolution data would be required than are available from analysis of orthophotos to further assess this.

4.5. Evaluation of Requisite Conditions to Contribute to the Decline

In the UFR mainstem, results of the critical riffle analysis indicate that most of the critical riffles assessed were passable at the juvenile and adult minimum depth criteria for either the 10% wetted width or 25% wetted width threshold at some point during the fall migration period of September 1 to October 15, 2018. However, there were instances where flows at some critical riffles may have impeded WCT movement within the period of September 1 to October 15 in 2017 (FRD-CRA04 and 05) and 2018 (FRD-CRA02, 03, 05). Given that potential fish passage impedances were identified at certain riffle barriers during the fall migration period within the Decline Window, some of the requisite conditions to contribute to the decline (Duration, Location, Timing, Intensity) were met. However, requisite conditions for Spatial Extent could not be confidently assessed because passage impedances were identified only at a limited number of locations and the influence of impedance at these locations will depend on the number of fish affected. As noted in Section 1.1.2, although there is evidence that passage may have been impeded at certain riffle barriers, the failure to reach preferred overwintering habitat would not directly result in fish mortality; thus, this pathway cannot be the sole explanation for the observed decline.

4.6. Assumptions, Limitations and Uncertainties

Key assumptions, limitations, and uncertainties related to this assessment are as follows.

- To evaluate the passability of critical riffles in years other than 2018, when empirical measurements were taken, it was necessary to assume that there had been no substantial changes to the bed profile of the riffles from year to year. The validity of this assumption depends on the occurrence of channel forming flows between the months when empirical measurements were taken (Sep/Oct 2018) and pre- and post-periods of interest. Based on the magnitude of peak flows (1-day maximum) during freshet in 2018 (50.0 m^3/s at the Fording River gauge 08NK018, Wright et al. 2021) and 2019 (31.4 m^3/s at the Fording River gauge 08NK018, Wright et al. 2021), there is a lower likelihood of changes to riffle morphology between the 2018 and 2019 fall migration periods than between the 2017 and 2018 fall migration periods. Greater care should therefore be taken when drawing conclusions regarding potential passage conditions at critical riffles in 2017. Nevertheless, we believe that the evaluation of potential impedances at riffle barriers in the upper Fording River in 2017 is still reasonable. Although the morphology of a specific riffle may change following channel forming flows, the cobble and gravel substrate that form sensitive riffles within the upper Fording River will be deposited at other locations within the river as flood flows recede. It is therefore reasonable to assume that although individual riffles may change and become less sensitive following channel forming flows, other sensitive riffles that act as barriers to fish migration under low flows will be formed at other locations with similar slope and channel confinement as flood flows recede.

- Given the distance between the critical riffles and the hydrometric gauges at Measuring Points B and C, and the small range of variability in flows during the period when loggers were installed at the riffles in 2018, it was not possible to develop accurate stage-discharge relationships relating stage at the critical riffles to discharge at the hydrometric gauges. The evaluation of passage conditions in years other than 2018 therefore relies on the riffle-specific passage thresholds derived from empirical measurements in fall 2018, and the corresponding discharge at Measuring Points B or C at the time of the survey, to make inferences about when passage may have been restricted in other years. However, if inflow conditions and/or operational water use between the critical riffles and the hydrometric gauges at Measuring Points B and C were different in 2018 than the other years being assessed, then passage conditions at the critical riffles may have been different even if Measuring Point discharge was the same.

- Due to the narrow range of flows observed during the 2018 critical riffle field assessment, thresholds at which a critical riffle switches from passable to not passable could only be precisely derived for one of five critical riffles. Furthermore, conclusions for the critical riffle analysis are based on depth criteria and wetted width thresholds taken from CDFG (2017), and were not verified for use in the UFR through direct observations of fish. There is therefore uncertainty in the accuracy of the identified flow thresholds for passage.

- Our assessment focused on the UFR upstream of Chauncey Creek (S6 through S9) to Henretta Pit Lake. Cope et al. (2016) identified the S7, S8 and S9 segments as those where increased width:depth ratios and shallow water depths may contribute to an increase in lost connectivity and hence these were the segments where critical riffles were identified. This portion of the watershed also includes the Multi-plate and Henretta culverts that have been identified as partial barriers to migration. The river segments from Chauncey Creek to Henretta Pit Lake are therefore those expected to be most affected by potential losses of connectivity. Since migration through these river segments from rearing habitat to key overwintering areas in Henretta Pit Lake and S6 is required by WCT in the upper and mid-watershed migratory group (23% of the radio-tagged population, Cope et al. (2016)), there is the potential that migration impedance may affect a considerable portion of the UFR WCT population.

- The analysis focused on fish that migrate to overwintering habitat and therefore need to migrate along the stream longitudinally (>8.0 km based on the definition of migratory fish used by Cope et al. (2016)). However, resident fish had home ranges averaging 4.6 km ± 0.6 km (Cope et al. 2016) and may therefore also be susceptible to passage challenges that preclude moving to overwintering habitat. Upper watershed residents (residing around Henretta Pit Lake and Clode Flats) and mid-watershed residents (residing around the important overwintering habitat in S6) made up 24% and 13% of the radio-tagged population in 2012-2015 (Cope et al. 2016), but the extent to which these fish may be affected by passage impedance is uncertain.

- The selection of depth criteria was meant to account for the depth requirements of the majority of fish in the UFR; however, the UFR is known to contain large-bodied WCT (>450 mm) that may require water depths for passage greater than the 12 cm depth criterion used in this analysis. Given that passage impedances were found for a depth criterion of 12 cm, we assume that fish requiring greater water depth are impeded at 12 cm of depth. Additional modelling was not required to test passability for such individuals.
- PIT tag data were largely restricted to the Decline Window since PIT arrays were installed immediately prior to September 2017. Comparisons to previous years was therefore not possible. However, instream works were completed in September and October 2016 to improve fish passage conditions at the Multi-plate and Henretta culverts so it is unlikely that passage conditions at the culverts were worse in the Decline Window than prior.
- The PIT tag analyses relied on assumptions of the timing of migration to overwintering areas based on previous work in the watershed (Cope et al. 2016). The PIT tag results (Section 3.2) and aspects of the telemetry analysis (Section 3.2 in Appendix A) indicated higher levels of activity and movement in the summer rearing period compared to the overwintering migration period. However, evaluation of movement trends using telemetry data (Section 3.6 in Appendix A) found general alignment with the assumed fall migration period of September 1 to October 15. Nevertheless, if migratory patterns differ from those assumed in a given year, this could affect conclusions with respect to the effects of the identified riffles and culverts, since flow and water levels would differ during alternative movement periods.
- If fish are impeded from migrating past critical riffles or through culverts, there is uncertainty as to the fate of these fish, the quality of the overwintering habitat they end up occupying and the stressors they may encounter in these habitats. Nevertheless, Cope et al. (2016) documented high mortality of fish that did not overwinter in select areas, even during winters of average severity, supporting the notion that fish overwintering in suboptimal habitat are at higher risk of overwintering mortality than those in optimal habitat.

5. CONCLUSION

This assessment evaluated the potential for barriers to fish passage in the UFR to have contributed to the observed decline of WCT. A critical riffle analysis was used to identify potential barriers. Fish passability was assessed by comparing hydraulic measurements in relation to fish passage criteria, and PIT tag analysis was used to provide information on timing of WCT movement and potential timing of the population decline. Overall, potential restrictions to WCT movement in the UFR during the fall migration periods in the Decline Window were identified at some locations; thus, requisite conditions to contribute to the decline were identified. The documented seasonal preferences of WCT for different habitats within the UFR (Cope et al. 2016) highlights the importance for fish to be able to access and use habitats that are suitable for different life history functions (e.g., spawning, rearing, overwintering). Cope et al. (2016) documented high mortality for fish that did not overwinter in select areas, even during winters of average severity.

Assuming the critical riffle model results accurately describe realized fish passage, further investigation is required to determine whether the impedance of movement at critical riffles or culverts could have contributed to the observed WCT decline in combination with other stressors (e.g., climate, predation, water quality). To address some of the uncertainties identified (Section 4.6), additional data collection occurred in 2020, which included evaluating more riffles and over a wider range of flow conditions.

Specific and localized barriers to migration were identified that could contribute to the documented WCT decline; however, to result in mortality other stressors would need to interact with the lack of connectivity and resulting confinement of fish to sub-optimal habitats. Other stressors evaluated for the EoC that could have interacted with the fish passage stressor include:

- Weather: Particularly cold temperatures were documented during the Decline Window, especially during the winter of 2018/19 when snow depths were low; thus, ice formation may have been particularly extensive and could have interacted with fish passage restrictions by reducing accessibility to some overwintering areas (Henretta Lake and S6 oxbows). One of the main behavioural strategies for WCT encountering severe frazil ice is to move to better locations; restricted connectivity may have precluded movement to alternate habitats. Ice formation may also have resulted in reduced flows (discharge depression), which would exacerbate potential barriers to movement.
- Predation: Fish confined to sub-optimal habitat may be at greater risk from predation.
- Water quality: Reduced water quality could be a potential consequence of fish being confined to sub-optimal habitat. For example, dissolved oxygen concentrations in less suitable (shallower) overwintering habitats may be lower than can be tolerated by WCT.

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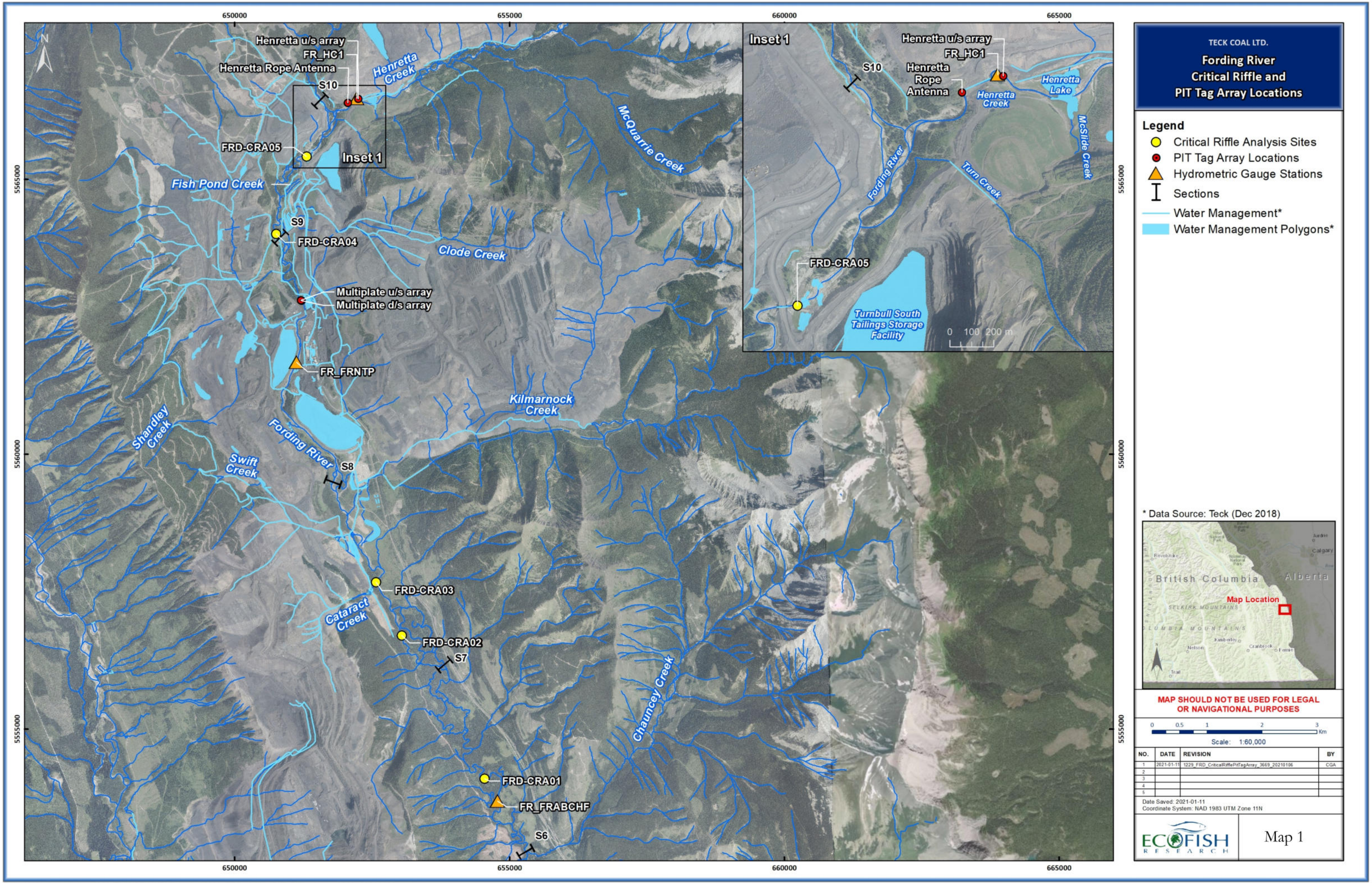
PROJECT MAPS



TECK COAL LTD.

Fording River Critical Riffle and PIT Tag Array Locations

Legend

- ● Critical Riffle Analysis Sites
- ● PIT Tag Array Locations
- ▲ Hydrometric Gauge Stations
- I Sections
- — Water Management*
- ▨ Water Management Polygons*

* Data Source: Teck (Dec 2018)

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 0.5 1 2 3 Km

Scale: 1:60,000

NO.	DATE	REVISION	BY
1	2021-01-11	1229_FRD_CriticalRifflePitTagArray_3669_20210106	CGA
2			
3			
4			
5			

Date Saved: 2021-01-11
Coordinate System: NAD 1983 UTM Zone 11N

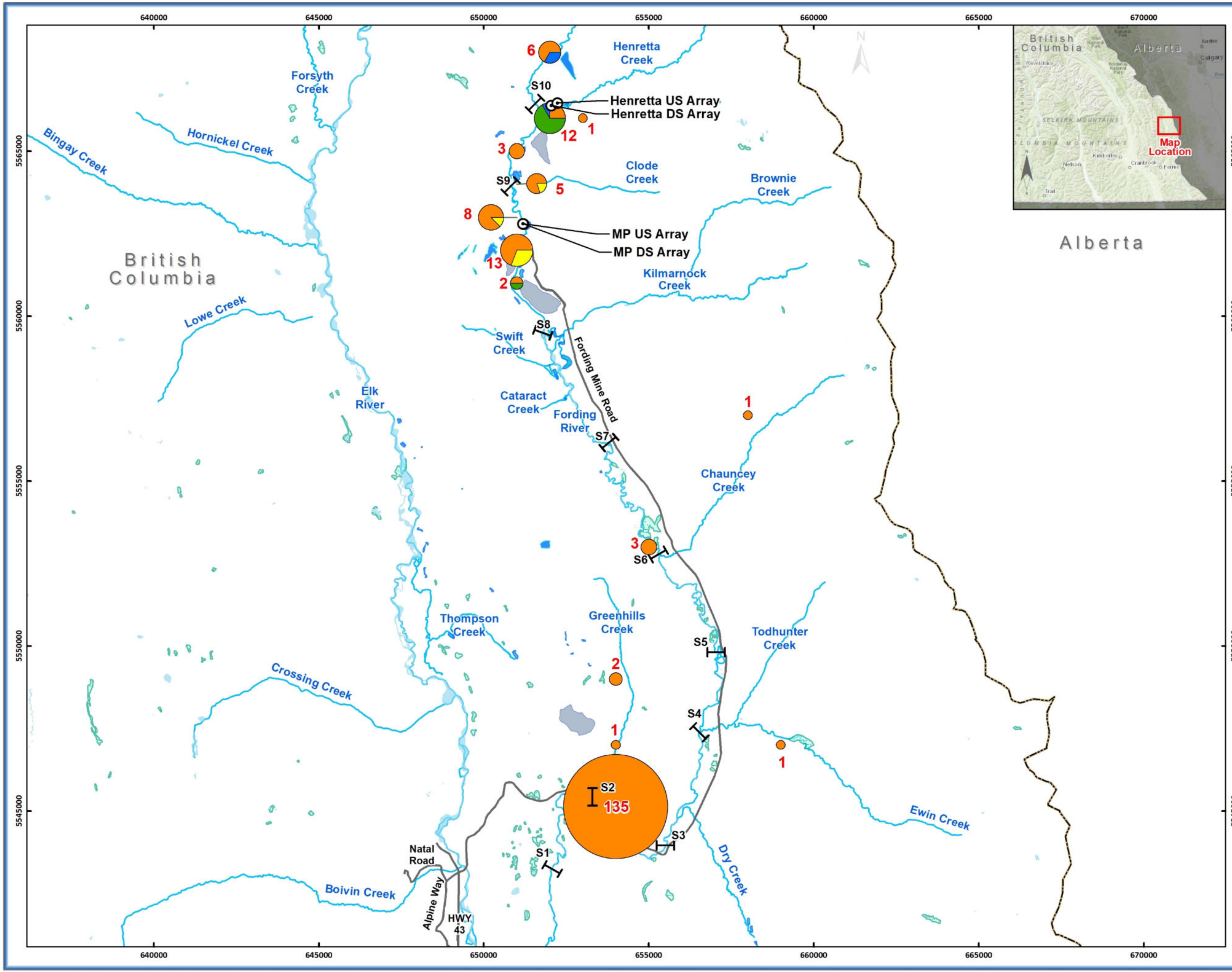
ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_FRD_CriticalRifflePitTagArray_3669_20210106.mxd

TECK COAL LTD.

UFR PIT Tag Deployments/Detections, Fish ≥200mm



Legend

PIT Tag Detections
(circle size represents dectection totals)

- 🟠 Not Detected
- 🟡 Multiplate
- 🟢 Henretta
- 🔵 Henretta and Multiplate
- ⊙ Henretta and Multiplate(MP) Arrays
- I Sections

- ― Paved Surface
- ▬ End Pit Lake
- ▬ Settling Pond
- ▬ Tailings Pond
- ▬ Lake
- ▬ River
- ▨ Wetland

Watercourse

- ― Stream
- ▭ Provincial Border

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 0.5 1 2 3 4 5 Km

Scale: 1:110,000

NO.	DATE	REVISION	BY
1	2021-01-06	1229_50_FRD_PITTagDetections_3693_20200408	guiver
2			
3			
4			
5			

Date Saved: 2021-01-06
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 2

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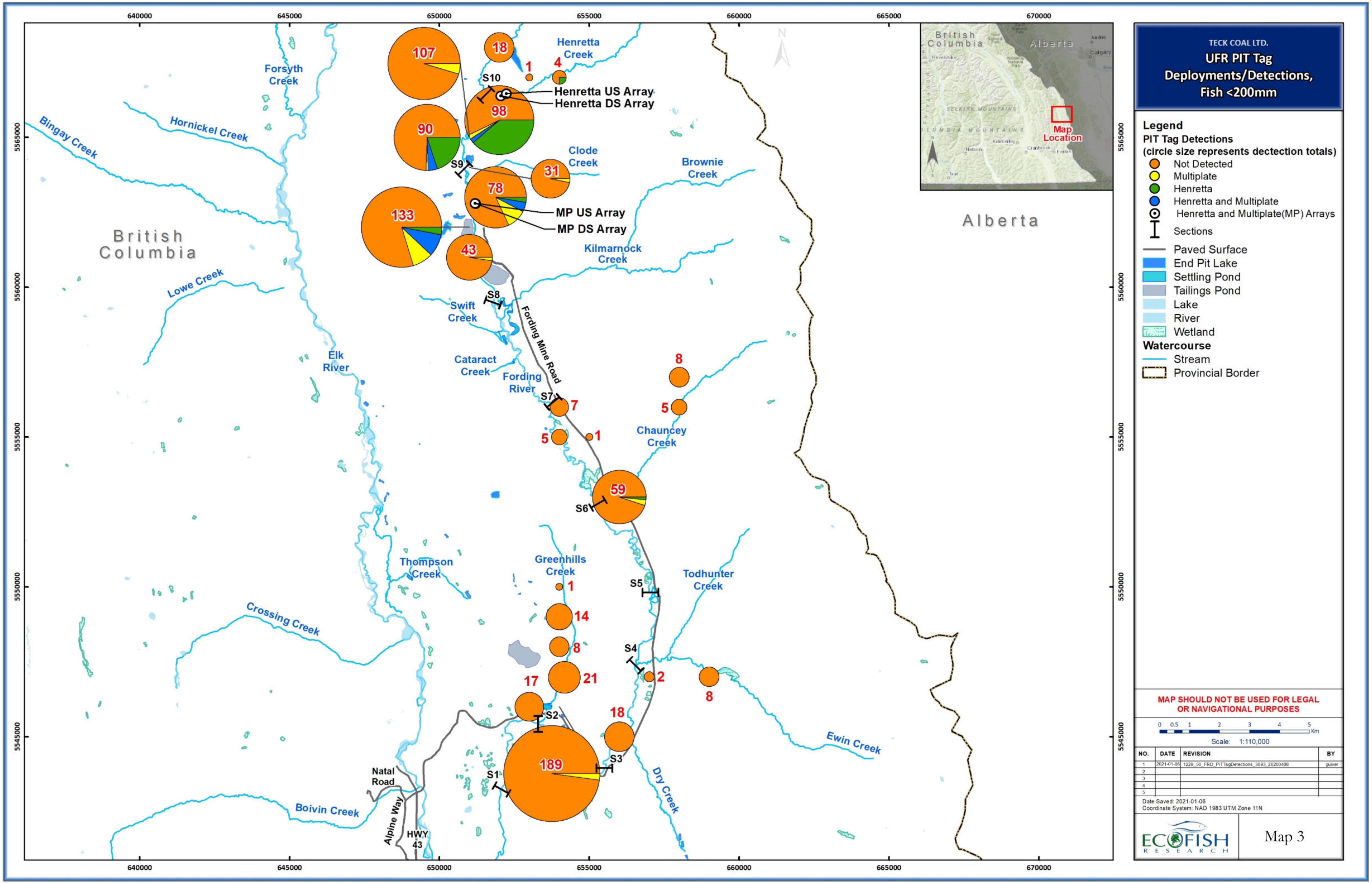

TECK COAL LTD.

UFR PIT Tag Deployments/Detections, Fish <200mm

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

NO.	DATE	REVISION	BY
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2			
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Date Saved: 2021-01-06
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 3

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_50_FRD_PITTagDetections_3693_20200408.mxd

TECK COAL LTD.

Offsetting Construction Locations

Legend

Offsetting Construction Locations (Year)

- 2016
- 2017
- 2018
- Segment Breaks
- Railway

Water Management

- Flooded Pit
- Settling Pond
- Tailings Pond
- Water Management Lines
- Planned Water Management Lines
- Water Network
- Fording River Watershed

0 0.5 1 2 Km

Scale: 1:45,000

NO.	DATE	REVISION	BY
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3			
4			
5			

Date Saved: 2021-01-12
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 4

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APPENDICES

Appendix A. Telemetry Movement Analysis Memorandum

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MEMORANDUM

TO: **Beth Power, Azimuth Consulting Group Partnership, Evaluation of Cause Lead**
FROM: **Kevin Akaoka, M.Sc., and Todd Hatfield, Ph.D., R.P.Bio., Ecofish Research Ltd.**
DATE: **January 15, 2021**
FILE: **1229-50**

RE: **Telemetry Movement Analysis – Draft V4**

1. INTRODUCTION

Abundances of adult and juvenile life stages of Westslope Cutthroat Trout in the upper Fording River have been estimated since 2012 through high-effort snorkel and electrofishing surveys, supported by radio-telemetry and redd surveys (Cope *et al.* 2016). Surveys using similar methods were conducted in the summer/fall of 2012-2014, 2017, and 2019. Abundances of adult and juvenile life stages declined substantively in the two-year period between 2017 and 2019[1] (referred to as the Westslope Cutthroat Trout Population Decline Window, also Decline Window; Cope 2020). The magnitude of the decline as well as refinements in the timing of decline are reviewed in detail by Cope (2020) and Korman (2020).

Teck Coal Ltd. (Teck Coal) initiated the "Evaluation of Cause" to assess factors responsible for the population decline. The Evaluation of Cause (EoC) evaluates numerous impact hypotheses, to determine whether and to what extent various stressors and conditions played a role in the decline of Westslope Cutthroat Trout. As part of the EoC, Ecofish Research Ltd. (Ecofish) was asked to undertake additional analysis of the telemetry data presented in Cope *et al.* (2016) to inform a detailed understanding of fish movements and timing in the upper Fording, and to understand whether the influence of some stressors may be dependent on movements or restrictions to movements. This scenario analysis complements the analyses done for the connectivity assessment (Harwood *et al.* 2021). For example, if fish movements were restricted at a particular location and time, might this have led to more (or fewer) fish being exposed to a given stressor?

This memo summarizes additional analysis conducted on the telemetry data to provide a detailed look at movement patterns within the species annual periodicity of key activities by life stage (see Table 1). As part of the analysis, the potential impact of hypothetical barriers in the upper Fording River was investigated. A key assumption of the analysis we present here is that movement patterns observed in the three-year study completed by Cope *et al.* (2016) are representative of behaviour and movement

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[1] Abundance estimates for adults / sub-adults are based on surveys in September of each year, whereas estimates for juveniles are based on surveys in August.

patterns expressed in the population in other years, and that fish passage conditions in the study area do not significantly change during the entire three-year period.

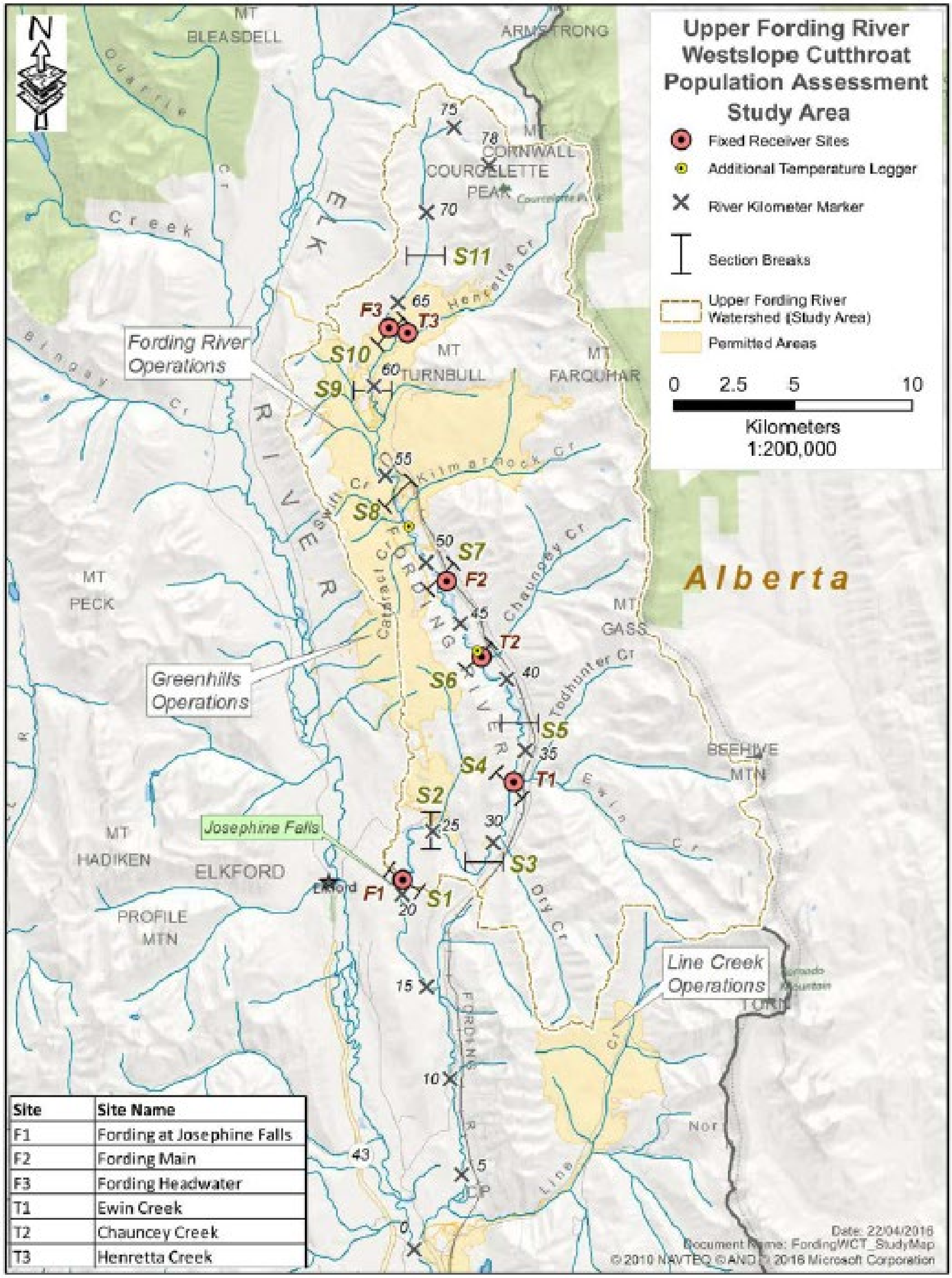
2. METHODS

2.1. Telemetry Data and Periodicity

Cope *et al.* (2016) assessed a variety of study questions related to the Westslope Cutthroat Trout population in the upper Fording River. One of the study questions aimed to describe temporal and spatial patterns of fish movement. Three cohorts of ~60 fish from 2012-2014 (181 in total) were radio-tagged and then tracked in a telemetry study using a combination of fixed-station receivers and mobile tracking from 2012 to 2015 (Figure 1). All radio-tagged fish were adults or sub-adults, with an average length of 320 mm across all radio-tagged individuals. The study area focuses on three sections of the upper Fording River: a lower section (approximately S1 through mid-S5) characterized as a "high sinuosity, low velocity, potential over-wintering area"; a middle section (approximately mid-S5 through mid-S9) corresponding with the Fording River Operations area and in which most of the physical changes to the river have occurred; and an upper section (approximately mid-S9 through S11, including Henretta Creek) characterized by "lower water volume (and) higher gradient headwaters" (Cope *et al.*, 2016). We adhere to the river segment and river kilometre descriptions used in Cope *et al.* (2016).

Empirical data (primarily Cope *et al.* 2016) and professional experience of EoC Subject Matter Experts with respect to species periodicity of Westslope Cutthroat Trout in the upper Fording River were collated, reviewed and agreed on by the SMEs. Information on timing of key activities is presented in Table 1 and is the assumed periodicity for further analysis of the telemetry data. As shown in Table 1, certain periods overlap: spawning migration overlaps with spawning and incubation, spawning overlaps with incubation, incubation overlaps with summer rearing, and summer rearing overlaps with fall migration. For each of these instances, each period was assumed to end/begin in the middle of the overlapping period. For example, in Table 1 summer rearing is defined as July 15-September 30 and fall migration is defined as September 1-October 15. For the purposes of analyses here, our analyses assume summer rearing to be July 15-September 15, and fall migration to be September 15-October 15. This was done to keep each period unique and to avoid issues that may arise from "double counting" observations when comparing results across periods.

Figure 1. Upper Fording River telemetry study area map showing location of fixed receivers (from Cope *et al.* 2016).



Site	Site Name
F1	Fording at Josephine Falls
F2	Fording Main
F3	Fording Headwater
T1	Ewin Creek
T2	Chauncey Creek
T3	Henretta Creek

Table 1. Periodicity table for Westslope Cutthroat Trout in the upper Fording River indicating timing of key activity periods.

		Jan				Feb				Mar				Apr				May				Jun				Jul				Aug				Sep				Oct				Nov				Dec			
Species/Ecosystem	**Life Stage**																																																
Westslope Cutthroat Trout	**Spawning migration**													■	■	■	■	■	■	■	■																												
	Spawning																			■	■	■	■	■	■	■	■																						
	Incubation (egg & alevin)																			■	■	■	■	■	■	■	■	■	■	■	■	■	■																
	Summer Rearing (≥7° C)																											■	■	■	■	■	■	■	■	■	■												
	Over-wintering migration																																	■	■	■	■	■	■										
	Over-wintering	■	■	■	■	■	■	■	■	■	■	■	■																											■	■	■	■	■	■	■	■	■	■
	Juvenile migration																																																
	Icing Days	■	■	■	■	■	■	■	■	■	■	■	■																															■	■	■	■	■	■
	Channel Formation																		■	■	■	■	■	■	■																								
	Off-Channel Connectivity																																																

2.2. Data Organization and Zone Assignments

The study area was divided into zones based on the location of fixed station receivers (Table 2), which required combining segments or portions of segments (Figure 2). Since the majority of detections will be at the fixed telemetry stations, assigning the zones in this manner allows one zone per fixed telemetry station.

The raw telemetry data collected during the Cope *et al.* (2016) study were processed to simplify and more easily identify trends and relationships. 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 assigned a zone based on the detected river km (rkm, Table 2). Fish located in tributaries were assigned to the zone corresponding to the location of the tributary confluence, with the exception of fish detected in Henretta Creek, which were treated as occurring in a separate zone.

Table 2. List of zone assignments by river km.

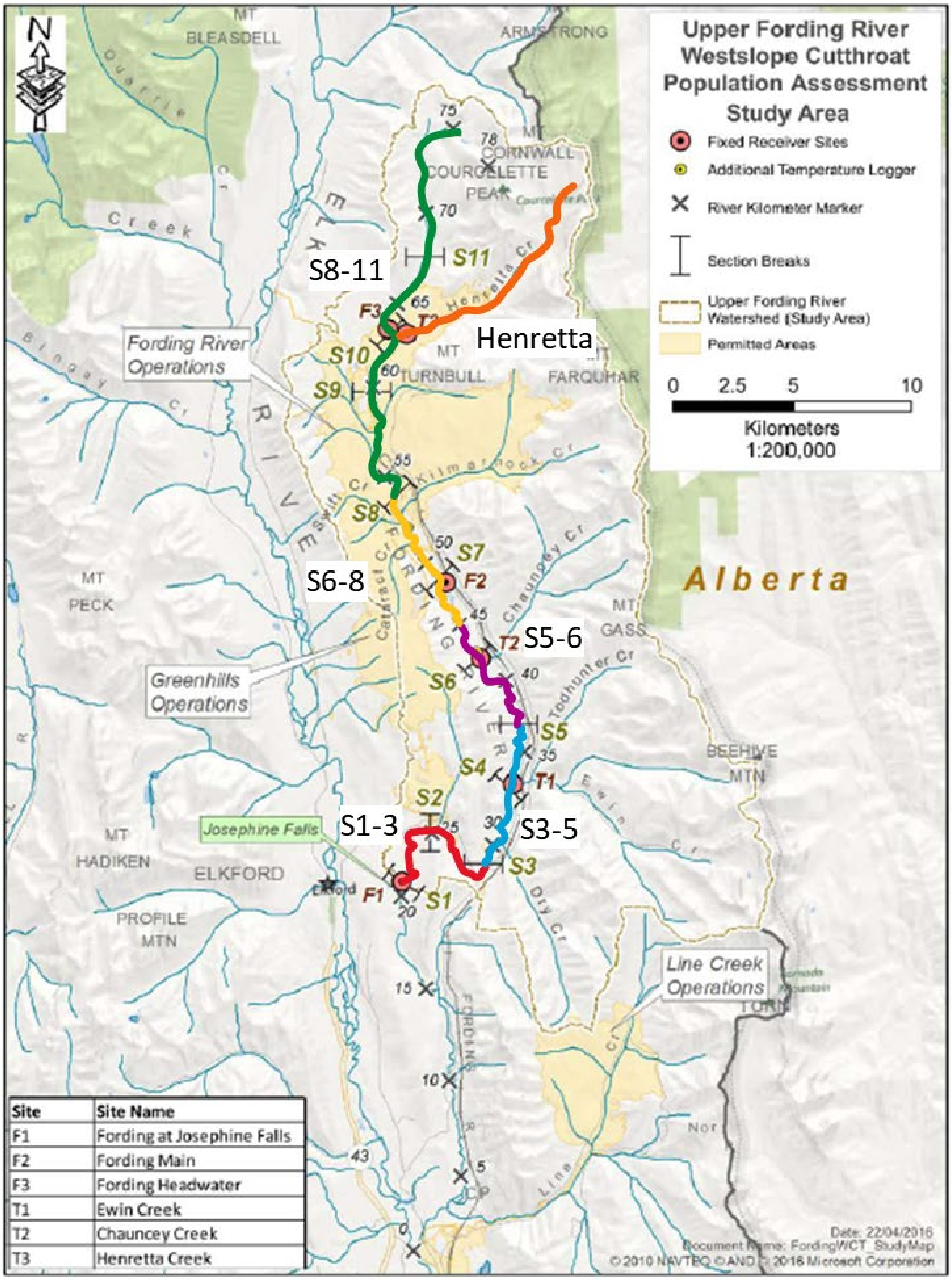
Zone	Section[1]	Fixed Station	Start rkm	End rkm
S1-3	Lower	F1	20.51	29.00
S3-5	Lower	T1	29.00	37.56
S5-6	Middle	T2	37.56	45.28
S6-8	Middle	F2	45.28	54.00
S8-11	Middle/Upper	F3	54.00	78.00
Henretta	Upper	T3	62.90[2]	3.81[3]

[1] Section boundaries do not precisely align with zone boundaries.

[2] rkm in Fording River.

[3] rkm in Henretta Creek.

Figure 2. Upper Fording River telemetry study area map showing zone assignments (from Cope *et al.* 2016).



Site	Site Name
F1	Fording at Josephine Falls
F2	Fording Main
F3	Fording Headwater
T1	Ewin Creek
T2	Chauncey Creek
T3	Henretta Creek

2.3. Overwintering Zone

To provide a reference point for the telemetry data analysis, each individual radio-tagged fish was assigned an overwintering zone. The overwintering zone was determined by examining the zone in which the most detections were observed during the overwintering period (defined as October 15 - March 31, Table 1). Overwintering was used as the reference period due to the observation of reduced fish movement during this time, and for its importance for "survival and recovery of Westslope Cutthroat Trout populations in general" (Cleator *et al.* 2009). This overwintering zone is representative of the expected area of the river where fish are expected to move from for spawning, and return to after rearing. Of the total 181 tags, 16 tagged fish were not detected at any point during overwintering and were therefore excluded from this analysis.

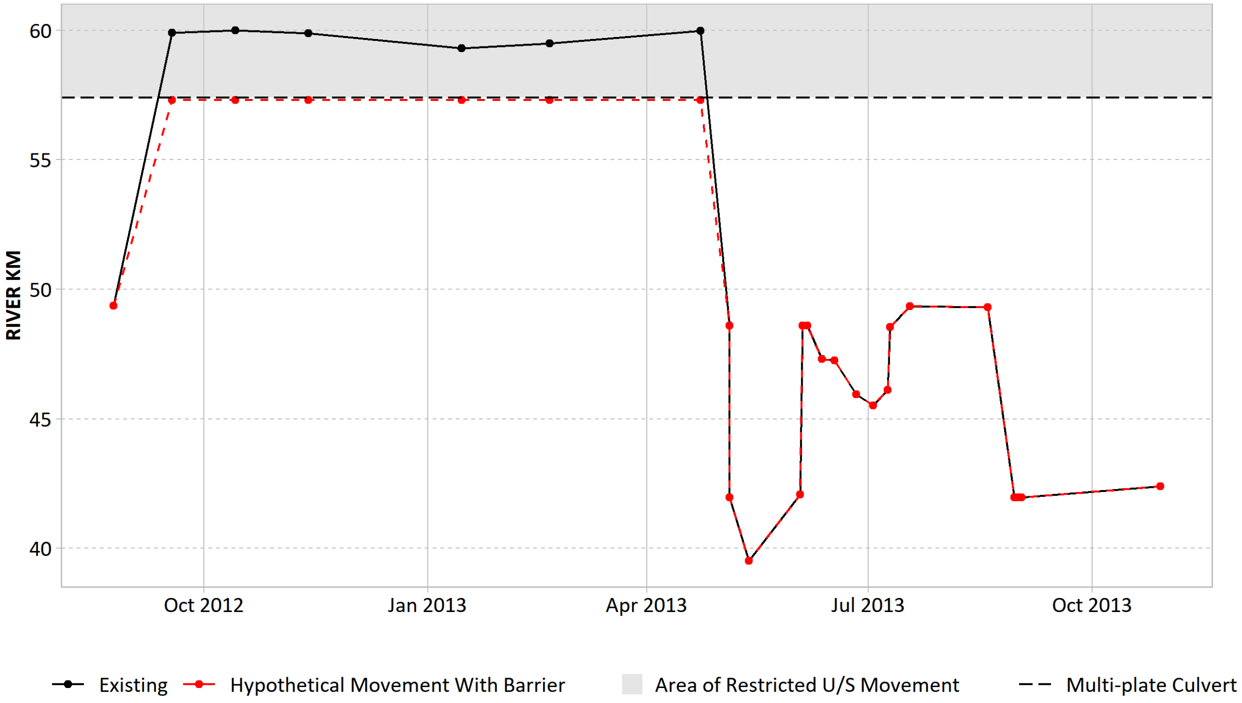
2.4. Movement Analysis

Multiple analyses were conducted on the telemetry data to isolate key patterns in fish movement in terms of timing, distance, and location. To assess the amount of the upper Fording River used, the home range of each fish was assessed. The home range was defined as the zones corresponding to the upstream-most and downstream-most detections for each fish. Movement with respect to the overwintering zone was analyzed by examining the upstream-most and downstream-most detections within each activity period. The zones corresponding to these upstream-most and downstream-most detections were then categorized as being upstream, downstream, or the same as the overwintering zone. A quantitative analysis of movement with respect to overwintering zone was also completed, where the distance between the upstream-most and downstream-most detections within each activity period was compared to the average rkm of the overwintering detections. From the frequency distribution of movement distances, an empirical cumulative distribution function was created for each overwintering zone and activity period.

2.5. Barrier Scenarios

As noted earlier, fish movements and timing may influence exposure of fish to some stressors. We explored whether distribution of fish would be notably influenced by the (hypothetical) appearance of a full barrier. (We did not undertake additional analysis to assess the implications for each of the stressors, since we expect this to be done, if relevant, by the appropriate SMEs.) The patterns identified in the movement analyses (Sections 2.4 and 3.2) were further explored by testing fish distributions under hypothetical scenarios of fish passage impedance. Two scenarios were analyzed in which a barrier was assumed to arise and remain, one at the multi-plate culvert (rkm 57.4, in S8) and another at the southern drying reach (assumed to be at rkm 50, in S7). These scenarios were meant to approximate a situation in which some fish may have been precluded from their preferred overwintering habitat. In each of the scenarios, it was assumed that the hypothetical barrier was impassable and persistent for the entire telemetry study. It was assumed that, based on the first detection of each fish, detections beyond the hypothetical barrier location signified that movement in this direction would be restricted. For example, if a fish were first detected at rkm 49.4, and the multi-plate culvert barrier was located at rkm 57.4, any detections during the study that occurred at rkm >57.4 were assumed to be restricted by the presence of the hypothetical barrier; in this case movement upstream would be prevented by the barrier (Figure 3) in this hypothetical scenario.

Figure 3. Example of telemetry data from Fish #11 illustrating simulated hypothetical restriction on U/S movement due to the presence of the multi-plate culvert by red line.



2.6. Exposure to Conditions at FR_FRCP1

Water quality analyses indicated especially poor water quality in the Fording River mainstem downstream of Cataract Creek (represented by station FR_FRCP1 at rkm 51.7) as characterized by potential higher-level effects of multiple constituents. Some number of fish may have been exposed to these adverse water quality conditions during the fall and winter of 2018/2019 (overwintering migration and overwintering periods). To assess the proportion of fish potentially exposed to the poor water quality, the method for the barrier analyses (Section 2.5) was used to assess the relative proportion of fish in the vicinity of FR_FRCP1. Fish were assigned to their corresponding overwintering zones, and based on the record of telemetry detections for each fish, the number of fish belonging to the following categories was determined: fish assumed to have not crossed the location of FR_FRCP1, fish assumed to have moved across the location of FR_FRCP1 in the downstream direction, and fish assumed to have crossed the location of FR_FRCP1 in the upstream direction. This analysis assumes that a fish crossed the location of FR_FRCP1 if it was detected on both sides of FR_FRCP1 at some point in the record of telemetry data. Fish observed to overwinter in S6-8, the zone containing FR_FRCP1, may also have been exposed to conditions at FR_FRCP1, depending on their movements within this zone during the period of interest.

2.7. Habitat Use

The aim of this analysis was to estimate the number of fish present in each zone during a given year and activity period. Each fish in the telemetry data was detected at various locations on various dates throughout the study period. To more accurately assess fish use during an activity period, the discrete telemetry data were converted to a continuous daily time series of fish locations. For each of the individual detections, it was assumed that a fish would continue to be in the same location over time, until the next detection. To avoid detections from persisting indefinitely (e.g., following death of a fish), a limit of 30 days was used for each detection (i.e., a fish was assumed to stay in the same location as the most recent detection up to a maximum of 30 days).

Since each cohort of fish spanned multiple years, the fish use assessment was split by year with respect to periodicity (each year starting with spawning migration and ending with overwintering). On each day during the study period, the proportion of fish within each zone was calculated. Next, the average proportion within each zone was calculated across all days for each activity period and year. This approach allowed the average use to be weighted by the proportion of time each fish spent in a given zone.

2.8. Fall Migration and Overwintering Timing

Results of the fish use analysis were used to evaluate patterns of movement, specifically during the fall migration period, with the goal of validating the assumed definition of this period. Historical discharge and water temperature data from two gauges in the study area — FR_FRNTP, located in segment S8 upstream of Kilmarnock Creek, and FR_HC1, located in Henretta Creek downstream of Henretta Lake — were used to assess if observed movement patterns were related to temperature and flow. The discharge and water temperature data were converted from 15-minute resolution to daily average in order to be combined with the daily time series of habitat use data calculated by zone (Section 2.7).

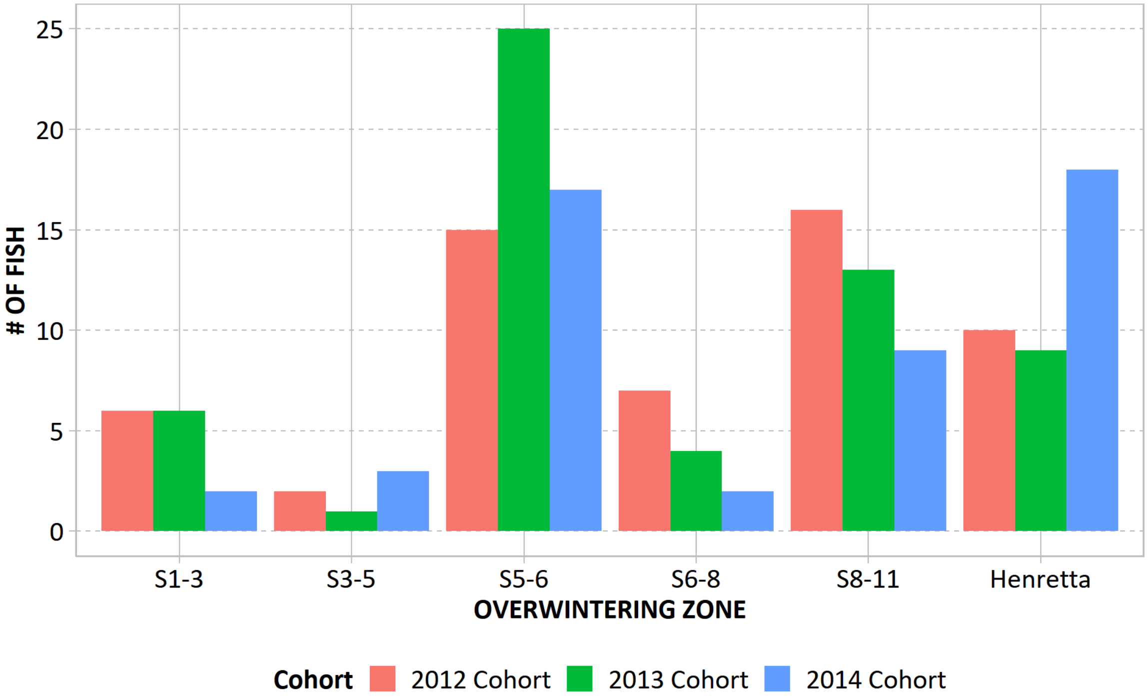
Qualitative methods were also used to compare movements to the assumed periodicity. Mobile and fixed receiver detections were plotted for individual fish (see Figure 3) and compared visually to the periods when fish are expected to be moving.

3. RESULTS

3.1. Overwintering Zone

Based on the detections during overwintering, the majority of adult and sub-adult fish overwinter in the S5-6 (n = 57), upper S8-11 (n = 38) and Henretta (n = 37) zones (Figure 4). The trends were fairly consistent between cohorts, suggesting that there was variation but no major differences in overwintering patterns across years. Additionally, the fish in the Fording River headwaters (i.e., S8-11 and Henretta zones) appear to be evenly split between those that use Henretta Creek (likely Henretta Lake) and those that do not.

Figure 4. Frequency histogram of fish by overwintering zone and cohort.



3.2. Movement Analysis

The home range analysis indicates that the majority of sub-adult and adult fish do not move large distances within the study area (Figure 5). In the upper section, the majority of fish were only detected upstream of S8, meaning they did not move into river segments downstream of S8. Patterns varied across the other zones. Of the fish detected in the middle of the study area, home ranges and movement from S5-6 to S8-11 and S3-5 to S6-8 were the most common. In the lower part of the study area, a home range of S1-3 was the most common. The patterns shown in Figure 5 are also reflected in Figure 6 because the majority of fish were detected in 3 or fewer zones, indicating the low occurrence of fish travelling long distances. Nevertheless, some individuals did make use of large stretches (i.e., more than 3 zones) of the river.

Table 3 is a summary of the distribution of the upstream extent of detections for each individual fish. These data summaries can be used to illustrate the proportion of fish that reside in each zone or in a combination of zones. For example, roughly half the fish reside below S8 without venturing further upstream; likewise, roughly 75% of fish were detected at least once upstream of S6. If detections are compared to the location of the drying reach barrier at S7 (rkm 48.06), 59.7% of fish were detected upstream of this barrier at all times. Fish distribution within activity periods will likely differ from these generalized summaries, since individual fish move different distances to complete key activities like spawning and rearing and then back to overwintering areas.

Figure 5. **Frequency histogram of fish by home range and cohort. Each group of bars provides information for fish that remain within a zone (e.g., within S1-3 zone), or move from one zone to another zone (e.g., zone S1-3 to zone S3-5). The results show all combinations of zones and are arranged from downstream-most to upstream-most.**

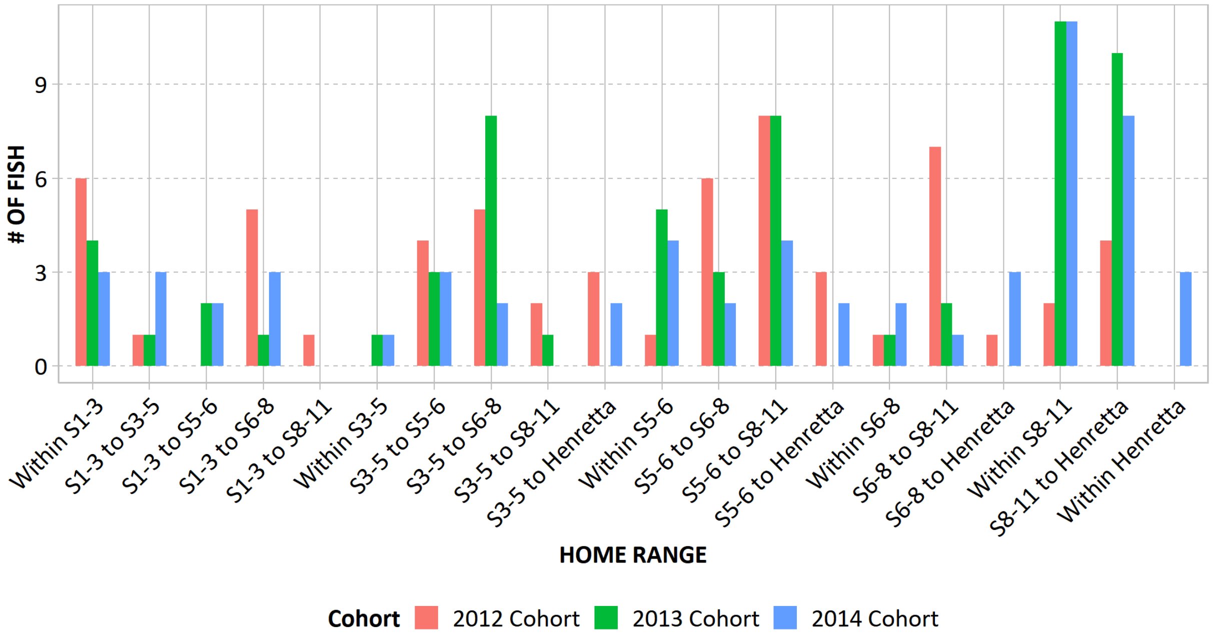


Table 3. **Summary of zone corresponding to upstream extent of fish detections.**

U/S Extent	% of Total Fish
S1-3	7.2
S3-5	3.9
S5-6	13.3
S6-8	21.5
S8-11	32.6
Henretta	21.5

Figure 6. **Frequency histogram of fish by home range and cohort; home range is defined as the number of zones used by a fish.**

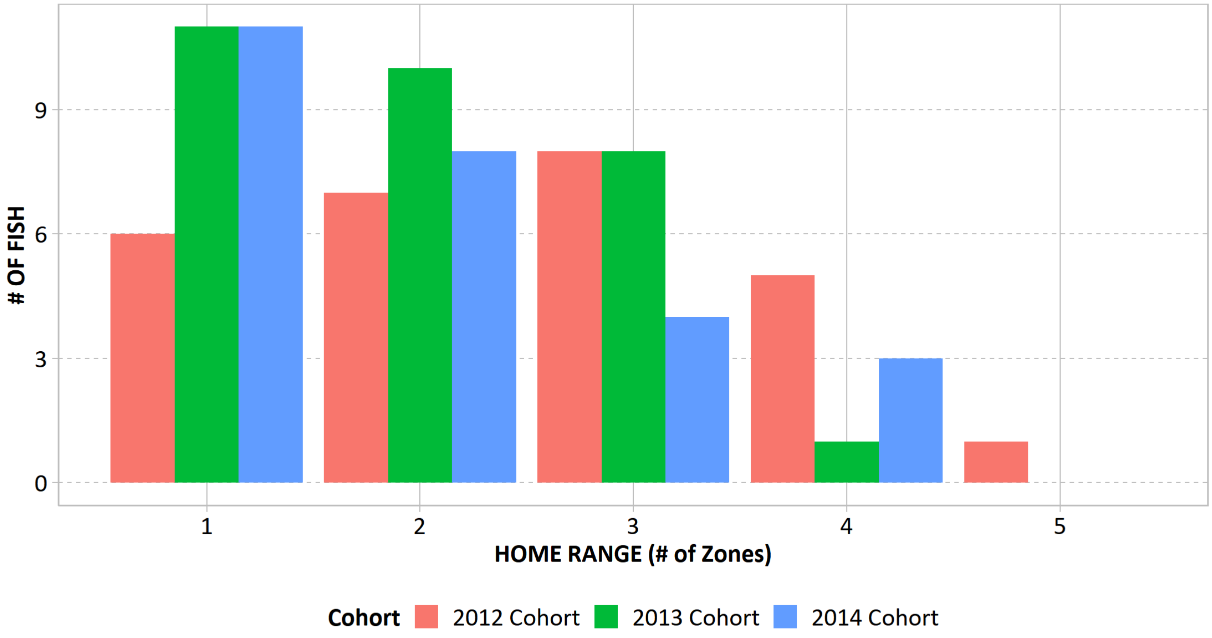


Figure 7 provides a breakdown of movement patterns by activity period, indicating the frequency of fish that moved upstream or downstream from their overwintering zone. Similar to the results of the home range analysis, fish that overwinter upstream of S8, and fish that overwinter downstream of S3 tend not to move beyond their zone at any time; although, there was slightly more movement observed during spawning and rearing. The large number of S5-6 fish that were observed to move out of this zone across all periods likely suggests use of a larger area than just S5-6. Based on the frequency distributions in Figure 8, it appears that these movements are only to adjacent zones, and the high number of fish that moved outside the S5-6 zone is likely in part an artefact of the way zones were assigned. Across other overwintering zones, movement varied, but fish with no movement were the most common. Consistent with Figure 4, the overwintering zones with the largest number of fish detected were S5-6, S8-11, and Henretta, and detections were most common during overwintering and rearing (Table 3).

The cumulative probability distributions (Figure 8) provide a more detailed summary of the movement patterns. The patterns in Figure 8 indicate the distances of upstream and downstream movement corresponding to different percentiles; for example, the distance corresponding to cumulative probability 0.8 indicates that 80% of fish move less than this distance. These distributions suggest that fish that cover the largest distances are individuals from S8-11 and Henretta zones and do so during spawning and rearing periods. In general, the largest movements occurred during spawning and rearing periods, whereas the smallest movements occurred during overwintering migration and overwintering periods.

In summary, the fish movement patterns present in the telemetry data can be described both spatially (where do fish that overwinter in a certain zone go, and how far do they move?) and temporally (when do fish move with respect to periodicity?). Overall, the majority of fish exhibit considerable movement among zones through the year, though most fish do not use the entire river. Spatially, the majority (~82%) of fish do not use the downstream-most zone (S1-3) and were not detected there at any time during the study. Of this 82% of fish, there are 3 common groups: fish that are detected in zone S3-5 (~25%), fish that are detected in the middle zones (S5-8) that do not use zone S3-5 (~42%), and fish that are only detected in the upper most zone (~33%). The fish that are detected in S1-3 tend to not go further upstream than S8, while the majority of fish detected in the middle zones also use the upper most zone. There are also a relatively high proportion of fish that were only detected in either S1-3 or S8-11. These patterns suggest that fish using the lower part of the river tend to stay there or use some portion of the middle zones; the fish using the middle zones tend to also use the upper zone and Henretta Creek; and the fish using the upper zone and Henretta Creek tend to stay there as well. These general patterns hold true when fish are considered by where they overwinter, as well. Overwintering zone also appears to be spatially heterogenous, with the majority of fish overwintering in three zones: S5-6, S8-11, and Henretta Creek.

With respect to periodicity, similar numbers of fish were detected across all periods within each zone (Table 4), and a review of the individual fish detected suggested that fish do not exclusively move to other areas during a given period. However, movement patterns across zones still do vary across periods. Surprisingly, the least amount of inter-zone movement was observed during not only overwintering, but overwintering migration and spawning migration, and this holds true for most fish regardless of overwintering zone. This suggests that the overwintering period could possibly be longer than assumed in the analysis. Other interesting trends include a large proportion of fish that overwinter in S5-6 were observed to move into an upstream zone during overwintering, and a clear increase in movement of fish that overwinter in S8-11/Henretta during spawning and rearing, compared to other periods (Figure 7).

Table 4. Count of fish detected by overwintering zone and activity period across all years of the study.

Overwintering Zone	# of Fish				
	Overwintering Migration	Overwintering	Spawning Migration	Spawning	Rearing
S1-3	11	14	12	13	14
S3-5	3	6	3	3	6
S5-6	46	57	51	49	57
S6-8	10	13	9	9	13
S8-11	28	38	28	34	38
Henretta	25	37	32	35	37

Figure 7. Frequency histogram of movement with respect to overwintering zone by periodicity.

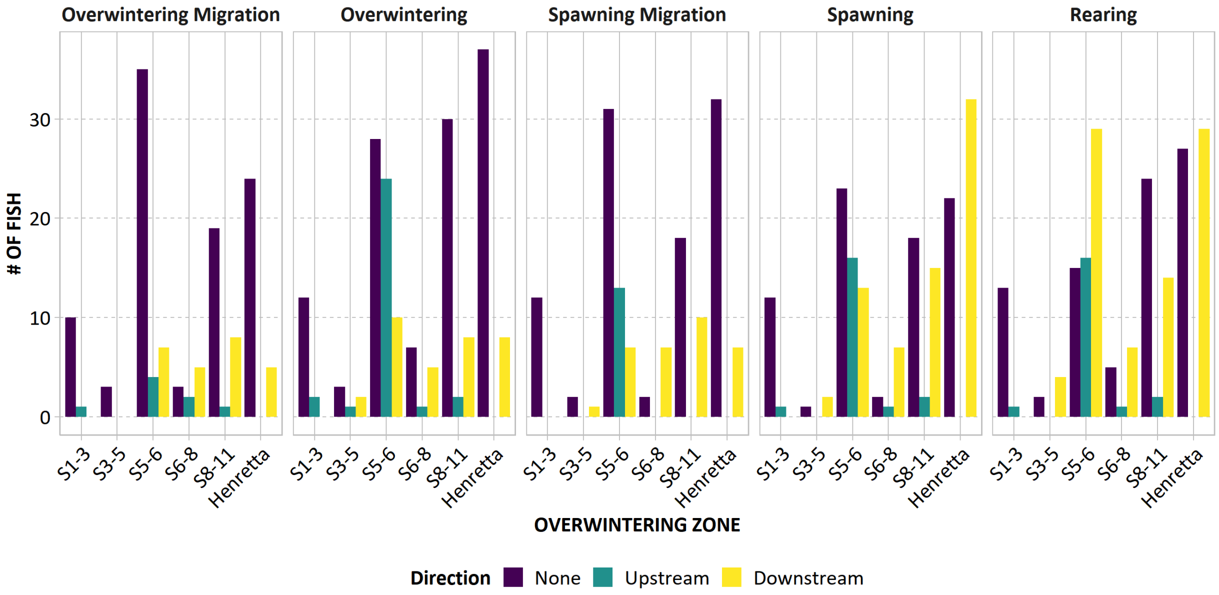
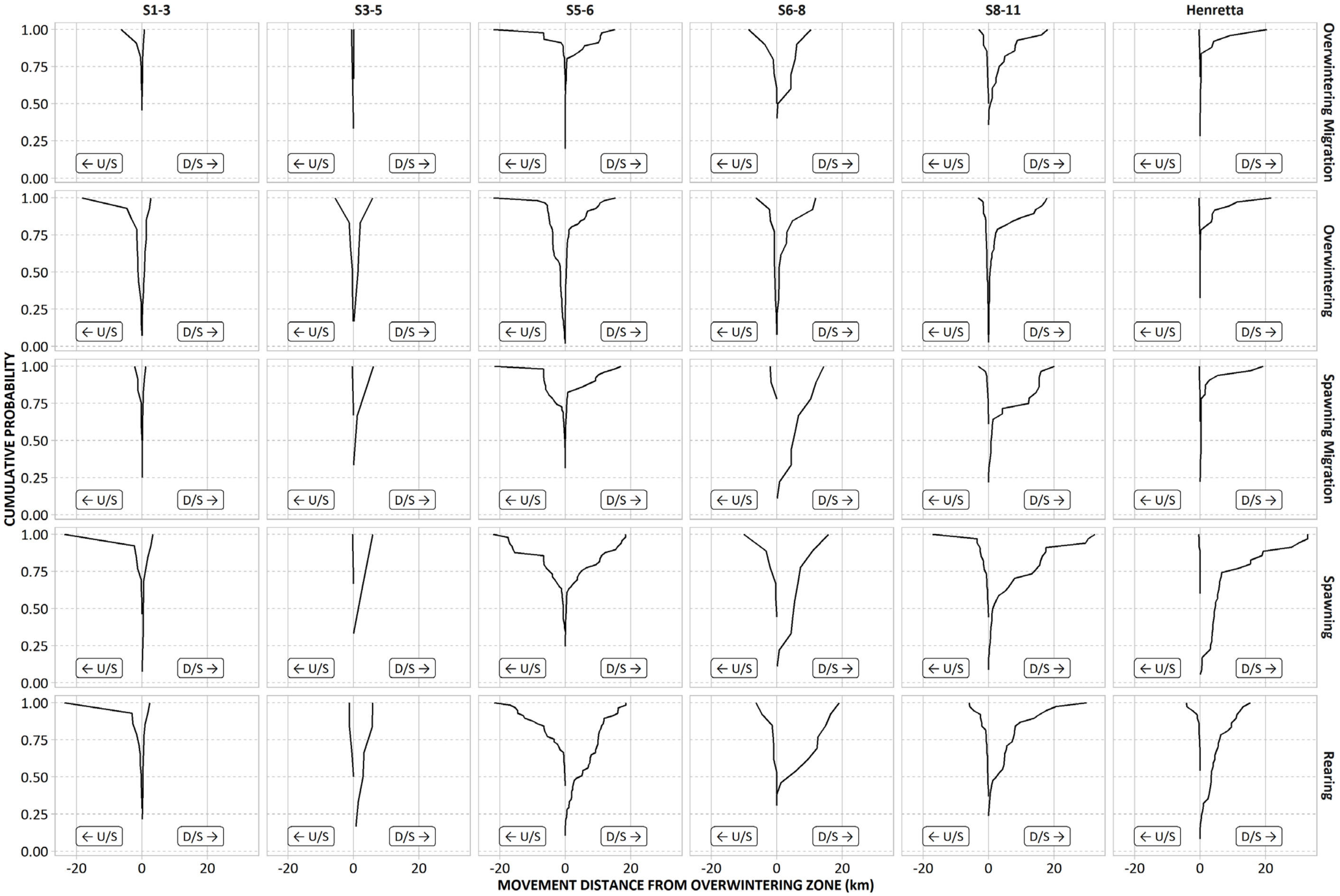


Figure 8. Cumulative probability distributions of movement with respect to overwintering zone by activity period. For each overwintering period, movement distance is expressed in terms of kilometres from the centre of the zone (0 km). The cumulative probability indicates the proportion of fish belonging to each overwintering zone that travel up to a given distance from the centre of the zone.



3.3. Barrier Scenarios

Results from testing hypothetical scenarios of barriers are shown for the multi-plate culvert (Figure 9) and drying reach (Figure 10). Results are similar to the other movement analyses. Since the majority of fish were not observed to move large distances, and fish that overwinter in the upper-most section of the study area tended to stay within this area, the presence of a barrier would not affect the majority of fish. For example, the multi-plate barrier is located in S8, so few fish from zones downstream would be affected by this barrier. Since spawning and rearing were the activity periods associated with the most movement, it is during these periods that fish that overwinter in S5-6 would be impacted the most. 10 fish (18%) that overwinter in S5-6 would be restricted in the upstream direction, and 1 (1.8%) fish would be restricted in the downstream direction across all periods if the multi-plate was assumed to be a hypothetical barrier. S8-11 and Henretta fish would be restricted by the hypothetical multi-plate barrier mainly during spawning and overwintering, with 18 fish (24%) being restricted in the upstream direction, and 16 fish (21%) being restricted in the downstream direction across all periods. Across all fish and all periods, the movement of 28% of fish would be restricted in some way if the multi-plate culvert were assumed to be fully impassable in this hypothetical scenario. It is important to note that movements that are considered to be restricted do not necessarily correspond to movement into or out of a given zone, as they may correspond only to movement within a given zone.

The effect of a barrier at the drying reach shows somewhat similar patterns to a barrier at the multi-plate culvert. Fish that overwinter in S5-6 would be most affected, with 9 fish (16%) being restricted in the upstream direction, and 5 (8.8%) fish being restricted in the downstream direction across all periods by a hypothetical drying reach barrier. Movement of fish that overwinter in the S8-11 and Henretta zones to the S5-6 zone would also be restricted, mainly during spawning, with 5 fish (6.7%) being restricted in the upstream direction, and 19 fish (25%) being restricted in the downstream direction across all periods by a hypothetical drying reach barrier. Across all fish and all periods, the movement of 26% of fish would be restricted in some way should the drying reach become and remain fully impassable.

Table 5. **Summary of potential movement restrictions caused by hypothetical barriers.**

Hypothetical Barrier	Overwintering Zone	Unrestricted Fish		Fish Restricted in U/S Direction		Fish Restricted in D/S Direction	
		#	%	#	%	#	%
Multi-plate Culvert at rkm 57.4	S1-3	14	8.5	0	0.0	0	0.0
	S3-5	6	3.6	0	0.0	0	0.0
	S5-6	46	27.9	10	6.1	1	0.6
	S6-8	11	6.7	1	0.6	1	0.6
	S8-11	16	9.7	12	7.3	10	6.1
	Henretta	25	15.2	6	3.6	6	3.6
	Total	118	71.5	29	17.6	18	10.9
Drying Reach at rkm 50	S1-3	14	8.5	0	0.0	0	0.0
	S3-5	6	3.6	0	0.0	0	0.0
	S5-6	43	26.1	9	5.5	5	3.0
	S6-8	8	4.8	4	2.4	1	0.6
	S8-11	25	15.2	4	2.4	9	5.5
	Henretta	26	15.8	1	0.6	10	6.1
	Total	122	73.9	18	10.9	25	15.2

Figure 9. **Frequency histogram of potential movement restrictions based on an assumed full barrier at the multi-plate culvert.**

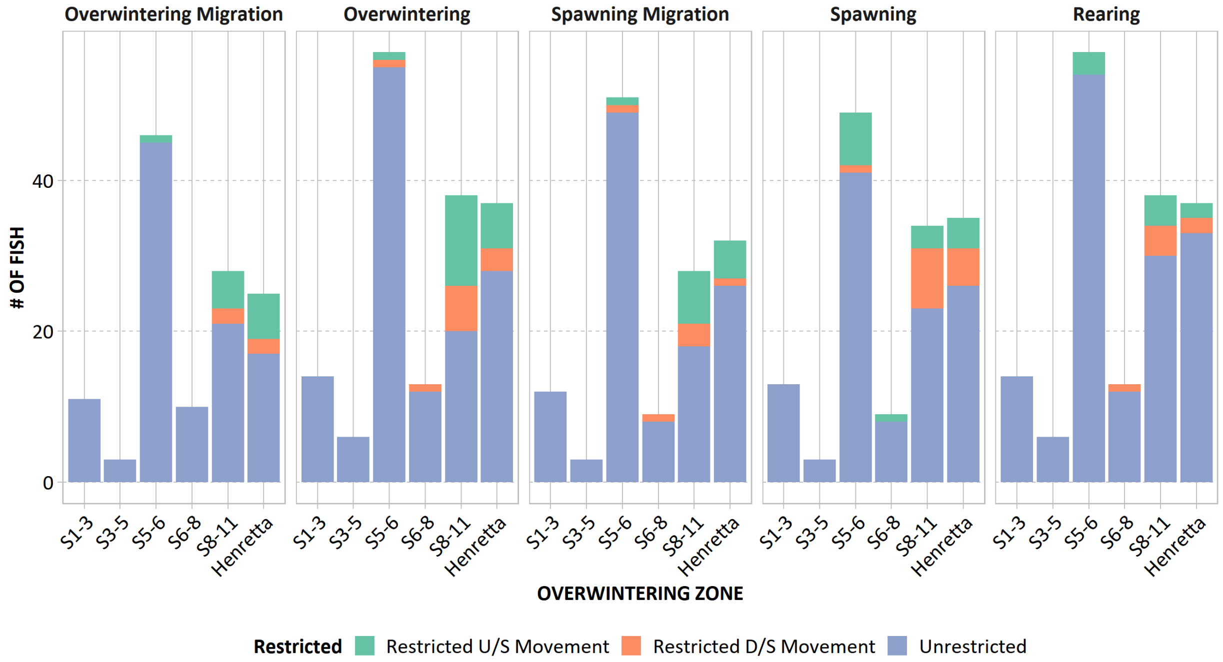
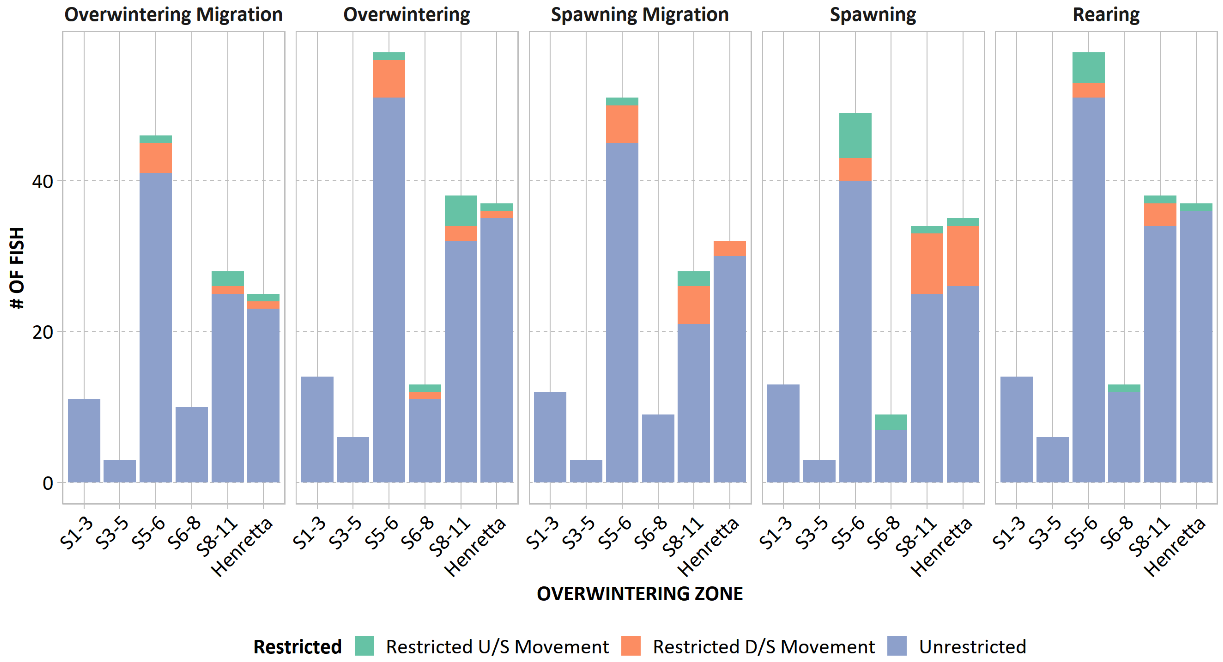


Figure 10. Frequency histogram of potential movement restrictions based on an assumed barrier at the southern drying reach.



3.4. Exposure to Conditions at FR_FRCP1

Table 6 provides a summary of the expected numbers of fish observed to cross the location of FR_FRCP1. As expected from results described in Sections 3.1 to 3.3, fish that overwinter in the lowermost sections were not observed at any time to be in the vicinity of FR_FRCP1. In total, the proportion of fish observed to cross the location of FR_FRCP1 varies from 7.9% during rearing, to 20.3% during spawning. During overwintering, it was observed that 9.7% of fish crossed the location of FR_FRCP1, with an additional 7.3% of fish that overwinter in the same zone as FR_FRCP1 (S6-8), suggesting possible exposure of these fish as well. During overwintering migration, 8.1% of fish crossed the location of FR_FRCP1. It is important to note these figures include fish overwintering in zones upstream of FR_FRCP1 that still exhibited movement that crossed the location of FR_FRCP1 (i.e., movement across zones occurs in winter even though fish predominantly occupy one zone). In summary, of all fish in the study area, 8.1% crossed the location of FR_FRCP1 during overwintering migration, and 9.7% crossed during overwintering, with an additional 7.2% being resident in the same zone as FR_FRCP1.

Table 6. **Summary of expected numbers of fish being exposed to conditions at FR_FRCP1.**

Overwintering Zone	Period	# of Fish		
		No Interaction with CP1	Interaction with CP1 Moving D/S	Interaction with CP1 Moving U/S
S1-3	Spawning Migration	12	0	0
	Spawning	13	0	0
	Rearing	14	0	0
	Overwintering Migration	11	0	0
	Overwintering	14	0	0
S3-5	Spawning Migration	3	0	0
	Spawning	3	0	0
	Rearing	6	0	0
	Overwintering Migration	3	0	0
	Overwintering	6	0	0
S5-6	Spawning Migration	47	3	1
	Spawning	41	2	6
	Rearing	52	0	5
	Overwintering Migration	43	2	1
	Overwintering	53	3	1
S6-8	Spawning Migration	8	1	0
	Spawning	8	0	1
	Rearing	12	0	1
	Overwintering Migration	9	0	1
	Overwintering	12	1	0
S8-11	Spawning Migration	21	4	3
	Spawning	23	9	2
	Rearing	32	4	2
	Overwintering Migration	25	1	2
	Overwintering	30	2	6
Henretta	Spawning Migration	29	2	1
	Spawning	26	7	2
	Rearing	36	0	1
	Overwintering Migration	22	1	2
	Overwintering	34	1	2

3.5. Habitat Use

Average fish use within each zone varied between years (Table 7), in some cases quite notably. The general spatial trends of fish use over time are in agreement (e.g., the majority of fish use habitat upstream of S5), but there are key exceptions: use of the lower zone declines during rearing and overwintering migration in 2015-2016, Henretta spawning use was higher during 2015-2016, and overwintering use of the middle zones seems to shift from concentration in S5-8 to concentration in S5-6 starting in 2013-2014.

When comparing the overwintering fish use estimates to those reported in Cope *et al.* (2016), we note some differences, particularly in the estimates for Henretta Lake. While Cope *et al.* (2016) notes ~20% of fish use Henretta Lake for overwintering, our estimate is lower, ranging from 10.9-16.7% across years. It is likely that this discrepancy is driven by two factors: 1) our definition of overwintering runs from October 15-March 31, whereas Cope *et al.* (2016) excludes the "shoulder season" portions and covers November 1-February 28; and 2) our fish use estimates assume that each detection only persists up to a maximum of 30 days. During overwintering, it is likely that movement of fish away from Henretta Lake is minimal, preventing these fish from being detected at the fixed receiver station downstream of Henretta Lake frequently enough to be persistently captured in our analysis.

3.6. Fall Migration and Overwintering Timing

The same fish use data discussed in Section 3.5 were examined as a daily time series for each year the telemetry study was conducted, while being compared to the assumed periodicity (Figure 11). Looking at trends between years, 2012 is notable in that it features a relative lack of change in fish use (i.e., relative lack of movement) during the assumed fall migration and overwintering periods. (Note: the apparent movements in late August are due in part to effects of the initial detections as this was the start of the telemetry study; the small sample sizes at the beginning of the study caused large variability in fish use estimates within this period.)

In 2013, fish use is relatively constant during the fall migration period. The observed spikes in fish use during this time are likely an artefact of our analysis method whereby detections older than 30 days are dropped from the calculation of fish use until they are detected again. Thus, it is more appropriate to examine the broader trends in fish use over the period, rather than shorter durations within a period. In November 2013, however, there does appear to be a shift in use from S5-6 upstream into S8-11.

2014 features the clearest trends in fish use during these periods. In the first two weeks of October, there is an increase in use of S5-6 and Henretta corresponding with a reduction in use of S1-3 and S8-11. In November, the use of Henretta appears to decrease slightly in favour of S8-11, potentially indicating some movement between these two zones.

During the last few months of the study in 2015, the observed patterns appear to be inconclusive due to the low number of fish being detected. Mid-September to mid-October only features detections from 4-5 fish, causing several shifts in the trend lines. Nevertheless, there appears to be a reduction in use of S8-11 in favour of S6-8, suggesting some downstream movement in October/November.

The discharge and temperature data from FR_HC1 and FR_FRNTP indicate that the years of the telemetry study (except 2013, where data were not available) did not strongly deviate from mean conditions, and therefore did not indicate a clear association with movements. The following exceptions were noted: flows and temperature in 2014 appear to be relatively high through September, potentially associated with the observed movement patterns in early-October once flows have diminished; flows at FR_FRNTP in 2012 are elevated through November; and temperature at FR_HC1 in 2015 is consistently higher than average. In summary, the observed movement patterns were not strongly associated with changes or deviations in flow or temperature.

The qualitative assessment of movement trends was completed by plotting detections for each fish and comparing these visually to the periods when fish are assumed to be moving. Movement patterns were highly variable among individuals; some individuals exhibited movement throughout the year, whereas other fish moved infrequently and over short distances only. Nevertheless, this fish-by-fish analysis confirmed that movements occurred primarily in association with spawning in the spring and movements to overwintering locations in the fall.

The periods during which fish were moving was broadly similar to the assumed periodicity but did not align neatly with the temporal boundaries of the periodicity; some individuals do not move during the period, some individuals move prior to or after the period, and some individuals move during the period. The lack of neat alignment is likely due to several factors. First, there are expected to be interannual differences in the cues used by fish to instigate movements. The assumed periodicity is meant to capture the range of fish behaviours, so alignment on any one year is not required or expected. Second, inter-individual differences in behaviour lead to different periodicity for each fish. The assumed periodicity is meant to capture the range of fish behaviours, so differences among individual fish are expected. Third, the lack of clear alignment with the periodicity is also likely an artefact of the temporal resolution of the telemetry data. Movements were mostly indicated by mobile tracking detections that indicated different locations on subsequent detections. Since mobile tracking was completed approximately once a month, it is not possible to determine when fish may have undertaken movements between mobile detections. Overall, the patterns of movements indicated by this fish-by-fish analysis provided general support for the assumed periodicity and indicated no strong evidence that the movement patterns assumed for the Evaluation of Cause analysis are incorrect or require adjustment.

Table 7. Average fish use by periodicity and year.

Period	Year	Average Fish Use (%)[1]					
		S1-3	**S3-5**	**S5-6**	**S6-8**	**S8-11**	**Henretta**
Spawning Migration	2013-2014	10.4	7.4	35.7	6.9	23.8	15.8
	2014-2015	5.9	2.1	41.7	10.2	19.4	20.7
	2015-2016	10.4	4.2	26.6	19.3	14.9	24.6
Spawning	2013-2014	15.0	12.6	23.5	18.2	23.1	7.6
	2014-2015	13.0	6.1	33.2	5.0	36.8	5.9
	2015-2016	12.0	4.4	15.2	13.8	37.3	17.3
Rearing	2013-2014	12.4	10.2	25.2	18.9	21.8	11.6
	2014-2015	9.3	6.4	27.3	7.8	34.7	14.5
	2015-2016	4.9	5.8	24.6	8.2	33.1	23.3
Overwintering Migration	2012-2013	10.2	12.8	20.7	14.2	25.1	17.1
	2013-2014	10.6	8.9	39.3	7.6	22.1	11.5
	2014-2015	10.6	6.6	37.2	9.1	13.7	22.9
	2015-2016	1.6	1.9	70.7	0.5	4.6	20.6
Overwintering	2012-2013	10.6	3.6	28.8	14.8	31.3	10.9
	2013-2014	8.8	5.9	42.2	8.8	23.1	11.2
	2014-2015	6.0	6.2	51.3	6.4	13.3	16.7

[1] Average fish use across all days in the specified period. Individual detections are persistent for up to 30 days.

Figure 11. Fish use within each zone by year during late summer/early fall. Assumed periodicity is indicated by shaded background. (Note that some of the assumed periods overlap, so start and end dates in the figure represent mid-points in the overlap. Please see Table 1 for periods.)

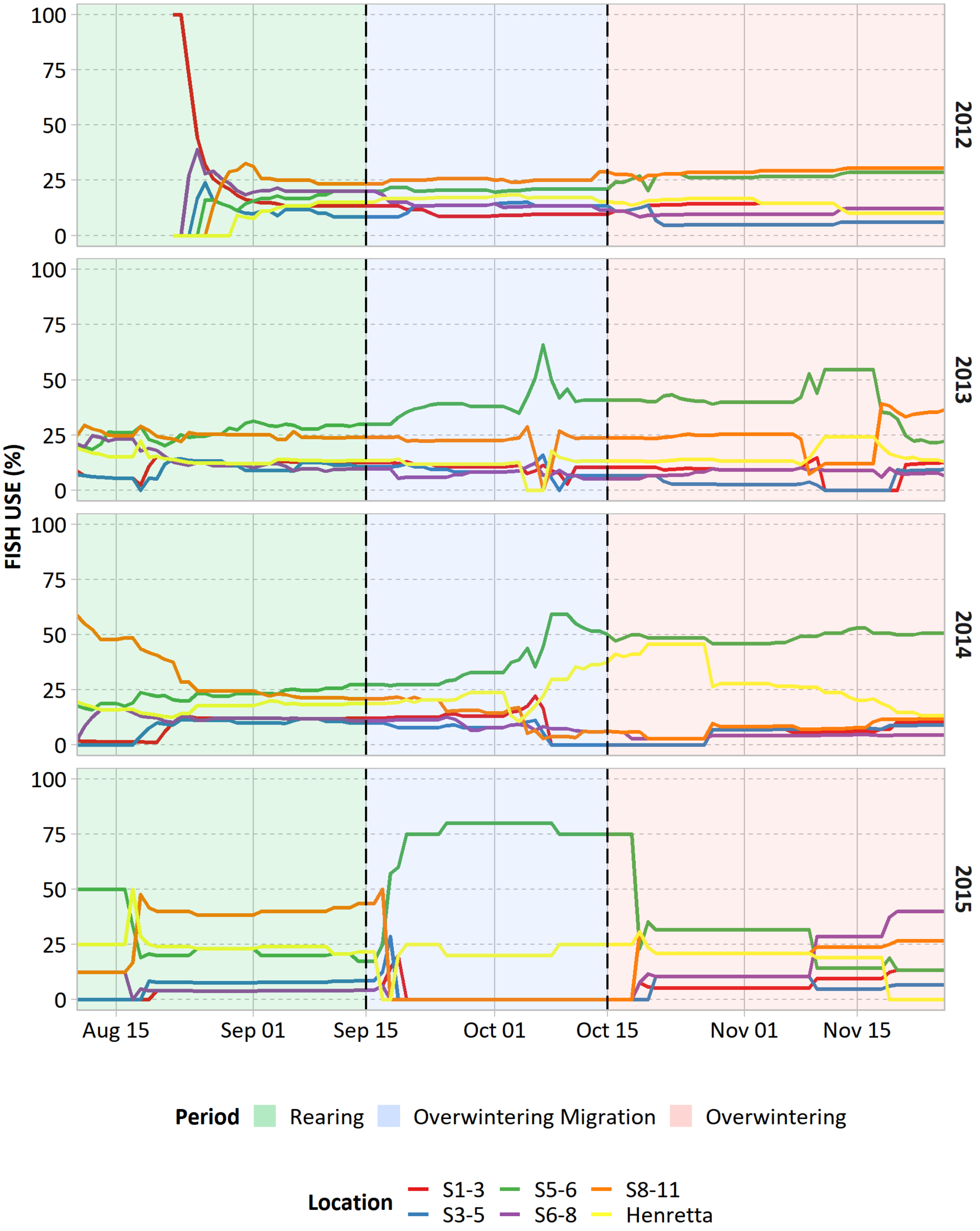
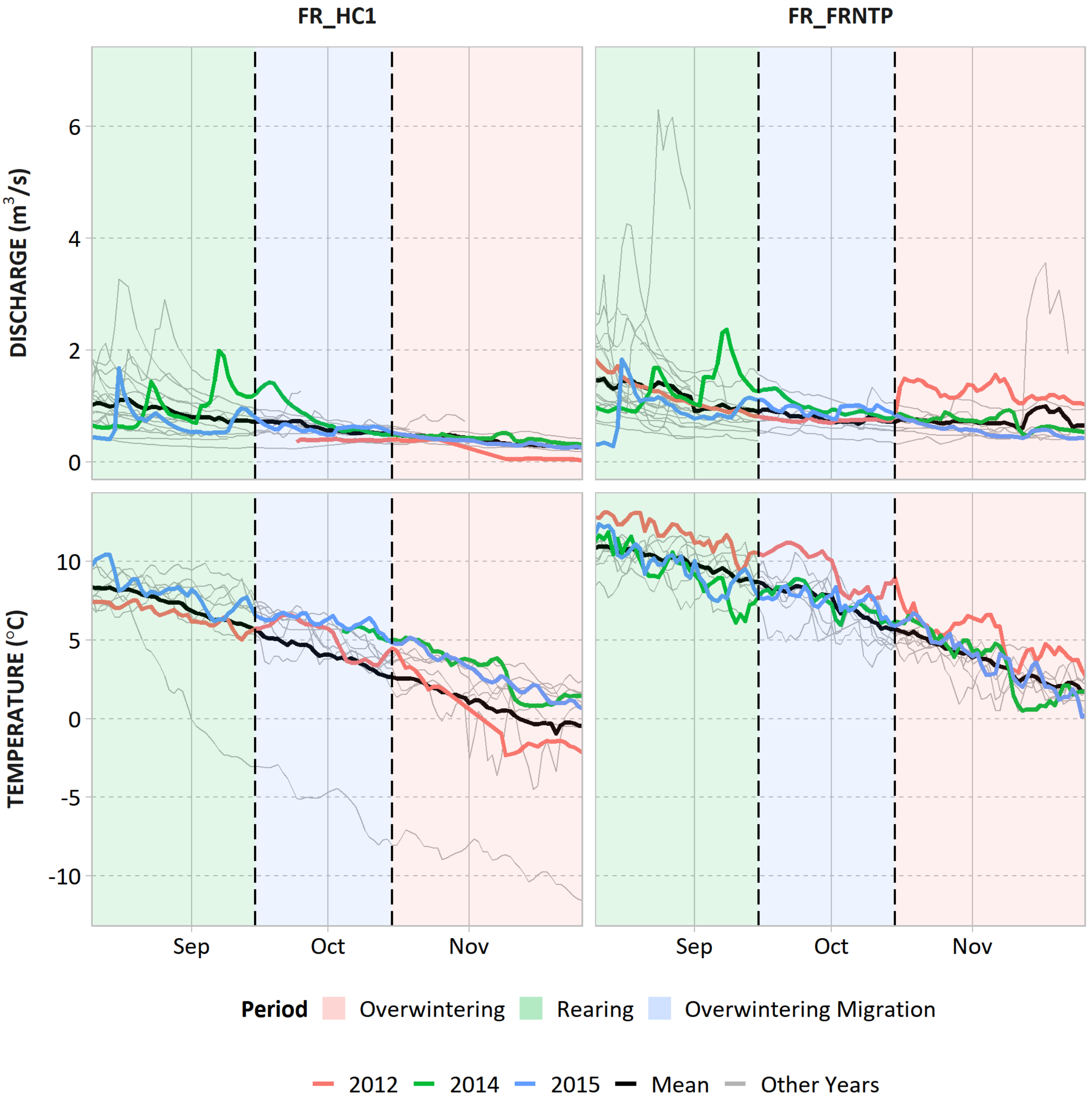


Figure 12. Historical discharge and water temperature data at FR_HC1 and FR_FRNTP for the years 1997-2019. Assumed periodicity is indicated by shaded background. (Note that some of the assumed periods overlap, so start and end dates in the figure represent mid-points in the overlap. Please see Table 1 for periods.)



4. DISCUSSION

Detailed analyses of the telemetry data highlight key trends in the movement of Westslope Cutthroat Trout in the upper Fording River. The majority of fish do not move large distances from their overwintering location. This is confirmed both in an analysis of home range of fish, and cumulative probability distributions of fish movement. Fish use appears to be heterogeneous across the study area (the majority of fish overwinter in S5-6 and upstream of S8); however, the lack of movement is consistent across zones. Fish movement is also dependent on the periodicity of Westslope Cutthroat Trout; movement is more common during spawning and rearing than other periods. Implications of movement patterns and seasonality of use of different river zones on exposure to stressors are to be assessed as relevant by each SME.

To aid understanding of whether connectivity may influence exposure to some stressors, a hypothetical scenario of a full and permanent barrier to fish passage at the multi-plate culvert (rkm 57.4) or the drying reach (rkm 50) was explored. For either scenario, roughly 25% of the radio-tagged fish would have been affected in either case. That is, each hypothesized barrier on its own would affect about 25% of radio-tagged fish; we did not test a combination of barriers. Since the majority of fish do not move outside of their overwintering zone, the proportion of fish that would be prevented from long-distance movement as a result of a barrier is likely lower than 25%—our summary does not differentiate between fish trying to move 0.5 km past the barrier, or 10 km past the barrier into a different zone of the river. Additionally, it is assumed that the barriers are impassable at all times, rather than varying through time. These hypothetical scenarios give a sense of the maximum proportion of fish that would be affected by a particular barrier. For example, the scenarios give a sense of the proportion of fish that would be precluded from reaching their preferred overwintering area and therefore the "additional" proportion of fish that may have been exposed to conditions downstream of the barrier during that period. The conclusion is that a barrier may have affected some individuals, but it would not be responsible for concentrating a majority of fish in a zone they would otherwise not have occupied. A similar analytic approach was used to estimate the proportion of fish that may have been exposed to poor water quality at FR_FRCP1 during overwintering migration and overwintering periods. This approach indicated an upper limit of 17% of the population may have been exposed.

Quantitative and qualitative assessment of movement trends was completed to evaluate whether the assumed periodicity for the EoC analysis was supportable. A comparison of the habitat use estimates and gauge data indicated no strong association with flow or temperature data. A qualitative fish-by-fish analysis confirmed that movements occurred primarily in association with spawning in the spring and movements to overwintering locations in the fall. The periods over which fish were moving did not align neatly with the assumed periodicity; however, the broad trends from the telemetry data indicated general support for the assumed periodicity and indicated no strong evidence that the movement patterns assumed for the Evaluation of Cause analysis are incorrect or require adjustment. Additional data would be required to refine the periodicity.

Finally, we note that movement patterns were defined based on data collected in 2012 to 2015, and some caution is warranted when extrapolating to population abundance or physical conditions outside of those during the 2012-2015 period.

Yours truly,

Ecofish Research Ltd.

Prepared by:	Reviewed by:
Signed	*Signed*
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Data Analyst	Senior Environmental Scientist

Disclaimer:

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Appendix B. PIT Tag Analysis Summary Tables

LIST OF TABLES

Table 1. PIT Tags deployed by program.

Year	Month	Sampling Program	Number of WCT	Adults	Juveniles
2016	Aug	Fish Salvage	14	1	13
2017	Jul	Effectiveness Monitoring	53	7	46
		Fish Salvage	10	0	10
		Population Study	56	19	37
	Aug	Effectiveness Monitoring	90	8	82
		Population Study	336	28	308
	Sep	Fish Salvage	167	53	114
		Population Study	14	0	14
	Oct	Population Study	50	38	12
2018	Jul	Fish Salvage	60	2	58
	Aug	Fish Salvage	10	0	10
	Sep	Population Study	68	2	66
		RAEMP	11	11	0
	Oct	Fish Salvage	11	7	4
		Population Study	1	1	0
2019	Feb	Winter RAEMP Study	1	1	0
	Jul	Baseline Data Collection	14	0	14
	Aug	Population Study	116	10	106
	Sep	Fish Salvage	44	2	42
		Population Study	45	2	43
		Baseline Data Collection	11	1	10
	Oct	Fish Salvage	7	7	0
		Total with recaptures	**1189**	**200**	**989**

Table 2. PIT Tags deployed by location.

Year	Waterbody	Total PIT Tags	Adults	Juveniles
2016	Fording River	14	1	13
2017	Chauncey Creek	51	0	51
	Dry Creek	8	0	8
	Ewin Creek	6	0	6
	Fording River	304	36	268
	Greenhills Creek	216	106	110
	Henretta Creek	105	11	94
	Lake Mountain	87	0	87
2018	Fording River	64	13	51
	Greenhills Creek	80	10	70
	Lake Mountain	17	0	17
2019	Chauncey Creek	22	2	20
	Dry Creek	10	0	10
	Ewin Creek	3	1	2
	Fording River	93	8	85
	Gardine Creek	7	0	7
	Greenhills Creek	50	9	41
	Henretta Creek	10	2	8
	Smith Creek	44	2	42
	Total	**1191**	**201**	**990**

Table 3. Comparison of the locations tags were deployed, and the number of those tags that were detected at each array, and at both arrays.

Waterbody	Tags Deployed	Detected at		
		Henretta	Multiplate	Both Arrays
Chauncey Creek	73	1	2	0
Dry Creek	18	0	0	0
Ewin Creek	9	0	0	0
Fording River	475	24	47	17
Gardine Creek	7	0	0	0
Greenhills Creek	346	2	5	1
Henretta Creek	115	49	5	3
Lake Mountain	104	24	7	5
Smith	44	1	1	0
Total	**1191**	**101**	**67**	**26**

Table 4. Summary of recaptured PIT Tags.

PIT Tag Code	Location	Date of Capture	Length at Capture [1]
982000410690426	Henretta Creek	23-Aug-17	160
	Henretta Creek	23-Aug-17	162
982000410690498	Greenhills Creek	25-Aug-17	79
	Greenhills Creek	10-Sep-18	151
982000410690609	Fording River	20-Jul-17	90
	Fording River	26-Aug-19	209
982000410690616	Fording River	21-Aug-17	132
	Fording River	19-Aug-19	174
982000410690635	Fording River	21-Aug-17	155
	Fording River	21-Aug-17	156
982000410690645	Fording River	21-Aug-17	159
	Fording River	21-Aug-17	159
982000410690677	Fording River	19-Aug-17	145
982000410690677	Fording River	19-Aug-17	187
982126054420133	Greenhills Creek	28-Aug-19	149
	Greenhills Creek	13-Sep-19	145
982126054420134	Greenhills Creek	28-Aug-19	173
	Greenhills Creek	13-Sep-19	165
982126054420167	Greenhills Creek	28-Aug-19	132
	Greenhills Creek	13-Sep-19	136
982126054420186	Greenhills Creek	28-Aug-19	112
	Greenhills Creek	13-Sep-19	113
982126054420191	Greenhills Creek	28-Aug-19	167
	Greenhills Creek	13-Sep-19	136
982126054420198	Greenhills Creek	28-Aug-19	126
	Greenhills Creek	13-Sep-19	119
989001006003908	Greenhills Creek	10-Sep-18	100
	Greenhills Creek	10-Sep-18	159
989001006003933	Greenhills Creek	10-Sep-18	110
	Greenhills Creek	13-Sep-19	171
989001006003936	Greenhills Creek	11-Sep-18	135
	Greenhills Creek	16-Sep-19	158
989001006003939	Greenhills Creek	11-Sep-18	146
	Greenhills Creek	16-Sep-19	169
989001006003974	Greenhills Creek	12-Sep-18	139
	Greenhills Creek	18-Sep-19	169
989001006084508	Greenhills Creek	13-Jul-17	121
	Greenhills Creek	25-Oct-17	144
989001006084528	Greenhills Creek	13-Jul-17	138
	Greenhills Creek	7-Sep-17	157
989001006084540	Greenhills Creek	15-Jul-17	262
	Greenhills Creek	16-Jul-17	262
989001006084543	Greenhills Creek	13-Jul-17	132
	Greenhills Creek	25-Oct-17	166
989001006084560	Greenhills Creek	13-Jul-17	164
	Greenhills Creek	21-Oct-17	245

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[1] Fish that had certain errors due to measurement, or data recording, are highlighted

Table 4. Summary of recaptured PIT Tags. Continued (2 of 2).

PIT Tag Number [1]	Location	Date of Capture	Length at Capture [1]
989001006084589	Greenhills Creek	15-Jul-17	222
	Greenhills Creek	7-Sep-17	244
989001006084595	Greenhills Creek	15-Jul-17	332
	Greenhills Creek	23-Oct-17	382
989001006084596	Greenhills Creek	15-Jul-17	162
	Greenhills Creek	22-Oct-17	209
989001006772909	Greenhills Creek	7-Sep-17	183
	Greenhills Creek	24-Sep-17	200
989001006772961	Greenhills Creek	7-Sep-17	259
	Greenhills Creek	24-Sep-17	257
989001006772975	Lake Mountain	20-Sep-17	161
	Lake Mountain	22-Sep-17	187
989001006773109	Greenhills Creek	22-Oct-17	352
	Greenhills Creek	22-Oct-17	353
989001006773140	Smith Creek	17-Sep-19	169
	Smith Creek	17-Sep-19	169
989001006773140	Greenhills Creek	7-Sep-17	217
	Smith Creek	18-Sep-19	169
989001006773174	Greenhills Creek	24-Oct-17	179
	Greenhills Creek	7-Sep-17	234
989001006773178	Greenhills Creek	7-Sep-17	246
	Smith Creek	18-Sep-19	155
989001006773181	Greenhills Creek	7-Sep-17	234
	Smith Creek	18-Sep-19	164
989001006773182	Greenhills Creek	21-Oct-17	312
	Greenhills Creek	7-Sep-17	251
	Greenhills Creek	20-Oct-17	341
989001006773183	Greenhills Creek	25-Oct-17	349
	Greenhills Creek	25-Oct-17	349
989001006773194	Greenhills Creek	21-Oct-17	150
	Greenhills Creek	24-Oct-17	150
989001006773198	Greenhills Creek	21-Oct-17	168
	Greenhills Creek	22-Oct-17	169
989001006773201	Greenhills Creek	21-Oct-17	346
	Greenhills Creek	11-Oct-18	395
989001006773729	Greenhills Creek	24-Sep-17	197
	Greenhills Creek	24-Sep-17	262
989001006773748	Greenhills Creek	24-Sep-17	250
	Lake Mountain	22-Sep-17	130
989001006773760	Greenhills Creek	24-Sep-17	283
	Lake Mountain	23-Sep-17	135
989001006773886	Greenhills Creek	16-Sep-17	187
	Greenhills Creek	18-Sep-19	204
989001006773887	Greenhills Creek	17-Sep-17	129
	Greenhills Creek	11-Sep-18	160

[1] Fish that had certain errors due to measurement, or data recording, are highlighted

Table 5. Array location and functionality

Array	Antenna	Location			Non-Functional Periods
		UTM Zone	Easting	Northing	
Henretta	Upstream	11U	652245	5566463	July 20, 2017 - Oct 1, 2017 [1] Oct 17, 2017 - Apr 1, 2018 Jan 2018 - June 28, 2018 [2] Mar 7, 2019 - Aug 8, 2019
	Downstream	11U	652057	5566388	Oct 17, 2017 - Apr 1, 2018 Jan 2018 - June 28, 2018
Multi-Plate	Upstream	11U	651199	5562802	Dec 22, 2017 - May 8, 2018 Dec 18, 2018 - June 20, 2019
	Downstream	11U	651213	5562793	Dec 22, 2017 - May 8, 2018 Dec 18, 2018 - June 20, 2019

[1] These dates indicate the period where the downstream antenna at Henretta was functional, but the upstream antenna had not yet been installed

[2] These dates indicate a period where the upstream antenna at Henretta was intermittent and may have missed passing tagged WCT

Table 6. Unique PIT tags detected at both arrays by month.

Year	Month	Unique Tags Detected
2017	July	21
	August	33
	September	24
	October	12
	November	1
	December	1
2018	January	0
	February	0
	March	0
	April	14
	May	27
	June	35
	July	46
	August	38
	September	25
	October	2
	November	3
	December	1
2019	January	1
	February	1
	March	2
	April	0
	May	1
	June	0
	July	3
	August	7
	September	10
	October	4
	November	1
	December	0
2020	January	0
	February	0
	March	1
	April	3
	May	0

Table 7. Summary of PIT tags that were detected at both arrays.

PIT Tag Number	Location Deployed	Date Deployed	Location Detected	Date Detected
982000410690392	Henretta Creek	23-Aug-17	Multiplate	22-Aug-18
			Multiplate	8-Sep-18
			Multiplate	9-Sep-18
			Henretta	12-Sep-18
982000410690465	Fording River	22-Aug-17	Henretta	5-Aug-18
			Henretta	6-Aug-18
			Henretta	9-Aug-18
			Henretta	10-Aug-18
			Henretta	16-Aug-18
			Henretta	17-Aug-18
			Henretta	18-Aug-18
			Henretta	19-Aug-18
			Henretta	20-Aug-18
			Multiplate	20-Aug-18
982000410690473	Fording River	22-Aug-17	Multiplate	13-May-18
			Henretta	20-Aug-18
982000410690617	Fording River	20-Jul-17	Multiplate	17-Sep-17
			Henretta	18-Sep-17
			Henretta	19-Sep-17
982000410690667	Fording River	19-Aug-17	Multiplate	7-Sep-18
			Henretta	16-Sep-18
982000410690686	Fording River	19-Aug-17	Multiplate	1-Aug-18
			Henretta	5-Aug-18
989001006003901	Greenhills Creek	10-Sep-18	Multiplate	29-Jul-19
			Multiplate	30-Jul-19
			Henretta	9-Aug-19
			Henretta	10-Aug-19
			Henretta	11-Aug-19
			Henretta	12-Aug-19
			Henretta	16-Aug-19
			Multiplate	18-Aug-19
989001006084711	Fording River	13-Jul-18	Multiplate	22-Aug-18
			Multiplate	28-Aug-18
			Henretta	12-Sep-18
989001006084766	Fording River	13-Jul-18	Henretta	17-Aug-18
			Multiplate	17-Aug-18
			Henretta	19-Aug-18
			Henretta	20-Aug-18
			Multiplate	20-Aug-18
			Multiplate	22-Aug-18
			Multiplate	7-Sep-18
989001006084769	Fording River	13-Jul-18	Henretta	17-Aug-18
			Multiplate	17-Aug-18
			Henretta	19-Aug-18
			Henretta	20-Aug-18
			Multiplate	20-Aug-18
			Multiplate	22-Aug-18

Table 7. Summary of PIT tags detected at both arrays. Continued (2 of 3).

PIT Tag Number	Location Deployed	Date Deployed	Location Detected	Date Detected
989001006772933	Lake Mountain	23-Sep-17	Multiplate	16-Jun-18
			Henretta	14-Jul-18
989001006772948	Lake Mountain	23-Sep-17	Henretta	21-Jun-18
			Henretta	23-Jun-18
			Henretta	7-Jul-18
			Multiplate	13-Jul-18
			Multiplate	16-Jul-18
989001006772974	Lake Mountain	22-Sep-17	Henretta	23-Jun-18
			Henretta	30-Jun-18
			Henretta	15-Jul-18
			Henretta	16-Jul-18
			Multiplate	18-Jul-18
			Henretta	29-Jul-18
			Henretta	4-Aug-18
989001006772999	Lake Mountain	23-Sep-17	Henretta	17-Jul-18
			Multiplate	25-Jul-18
			Multiplate	18-Aug-18
			Multiplate	22-Aug-18
989001006774032	Fording River	11-Aug-17	Henretta	12-Jul-18
			Henretta	13-Jul-18
			Henretta	14-Jul-18
			Henretta	15-Jul-18
			Henretta	17-Aug-18
			Henretta	20-Aug-18
			Multiplate	20-Aug-18
			Henretta	16-Sep-18
989001006774041	Fording River	11-Aug-17	Multiplate	17-Jun-18
			Multiplate	19-Jun-18
			Henretta	26-Jun-18
			Henretta	27-Jun-18
			Henretta	15-Jul-18
			Henretta	9-Aug-18
			Henretta	17-Aug-18
			Henretta	20-Aug-18
989001006774056	Fording River	11-Aug-17	Henretta	17-Aug-18
			Henretta	19-Aug-18
			Henretta	20-Aug-18
			Multiplate	22-Aug-18
			Multiplate	28-Aug-18
			Henretta	2-Sep-18
			Multiplate	2-Sep-18
			Henretta	4-Sep-18
			Henretta	5-Sep-18
989001006774064	Fording River	9-Aug-17	Henretta	16-Jul-18
			Multiplate	18-Jul-18
			Henretta	5-Aug-18
			Henretta	18-Aug-18

Table 7. Summary of PIT tags detected at both arrays. Continued (3 of 3)

PIT Tag Number	Location Deployed	Date Deployed	Location Detected	Date Detected
989001006774065	Fording River	11-Aug-17	Henretta	8-Jun-18
			Multiplate	11-Jun-18
989001006774081	Lake Mountain	20-Jul-17	Multiplate	22-Jun-18
			Henretta	26-Jul-18
			Henretta	27-Jul-18
			Henretta	28-Jul-18
			Henretta	4-Aug-18
			Henretta	5-Aug-18
			Henretta	6-Aug-18
			Henretta	7-Aug-18
			Henretta	8-Aug-18
989001006774114	Henretta Creek	20-Jul-17	Henretta	15-Oct-17
			Henretta	16-Oct-17
			Henretta	17-Oct-17
			Henretta	15-May-18
			Henretta	16-May-18
			Henretta	19-Jul-18
			Henretta	8-Aug-18
			Henretta	10-Aug-18
			Henretta	11-Aug-18
			Henretta	17-Aug-18
			Multiplate	17-Aug-18
			Henretta	18-Aug-18
			Henretta	19-Aug-18
			Henretta	20-Aug-18
			Multiplate	20-Aug-18
989001006774143	Fording River	9-Aug-17	Henretta	8-Jul-18
			Henretta	12-Jul-18
			Henretta	13-Jul-18
			Henretta	14-Jul-18
			Henretta	15-Jul-18
			Henretta	16-Jul-18
			Henretta	19-Aug-18
			Henretta	20-Aug-18
			Multiplate	22-Aug-18
			Henretta	28-Aug-18
989001006774184	Fording River	9-Aug-17	Multiplate	5-Sep-18
			Henretta	12-Sep-18
			Multiplate	19-Sep-18
989001006774187	Henretta Creek	20-Jul-17	Henretta	21-Jul-17
			Henretta	1-May-18
			Multiplate	22-Jun-18
			Multiplate	26-Jun-18
			Henretta	27-Jun-18
			Multiplate	28-Jun-18
989001006774201	Fording River	9-Aug-17	Multiplate	21-Jul-18
			Henretta	23-Jul-18
989001006774202	Fording River	9-Aug-17	Henretta	15-Jun-18
			Multiplate	15-Jun-18
			Henretta	17-Jun-18