BOTTLENECKS TO SURVIVAL
MOVEMENT AND HABITAT USE OF COASTAL CUTTHROAT TROUT IN SHELLY CREEK

Prepared by Ally Badger and Jamieson Atkinson

2024

PACIFIC SALMON FOUNDATION

BRITISH COLUMBIA CONSERVATION FOUNDATION

EXECUTIVE SUMMARY

This technical report examined the migratory movements of a coastal cutthroat trout population in the upper reaches of Shelly Creek during the summer of 2021. Fish sampling and tagging were used to provide information on the population and their movements in relation to stream hydrology. This study was conducted to assess if there are habitat bottlenecks within an upper reach of Shelly Creek.

The Mid Vancouver Island Habitat Enhancement Society (MVIHES) saw an opportunity with the BCSRIF Funded Bottlenecks to Marine Survival Project to use the project's Passive Integrated Transponder (PIT) technology to gain helpful information on movements of a cutthroat trout population of concern.

Results suggested that cutthroat movements within the upper reaches were limited during low flows, and that stream flow was a significant predictor of cutthroat movements. A generalized additive model was used to assess stream discharge and movement distance. The model showed that discharge had a statistically significant influence on movement (P = >0.01) and indicated that only 8.83% of the variability in migration distance could be explained by discharge. However, other unknown factors (spawning, age, etc.) likely contributed to the distance fish migrated unrelated to stream flow. Additionally, no cutthroat were detected on the Englishman River mainstem PIT array, suggesting this stock is likely a resident life history type.

This study concluded that restrictions to migrations and movements in the upper reaches, caused by anthropogenic impacts and the installation of culverts, have likely resulted in two life history types being extirpated. The report recommends that traditional culverts be discouraged in Shelly Creek in favour of clear-span bridges to allow for fish movement in all flow conditions.

This information will be used to support restoration efforts within the Shelly Creek watershed, and the study reach to reduce the impacts low flows and anthropogenic structures have on cutthroat trout movements.

Original citation:

Badger, A. and Atkinson, J.B. 2022. Movement and Habitat Use of Coastal Cutthroat Trout in Shelly Creek. Prepared for the Mid-Vancouver Island Habitat Enhancement Society. P 28.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) are an integral freshwater species in British Columbia. Often the only native trout throughout much of their range, coastal cutthroat trout (hereinafter referred to as cutthroat), play an important role in the aquatic ecosystems they inhabit by serving as apex aquatic predators (Budy et al. 2020), and by providing nutrients to both terrestrial and aquatic ecosystems (Slaney and Roberts 2005). Historically, cutthroat were widely distributed across coastal British Columbia; however, recently, they have displayed drastic declines in both their numbers and distribution (Costello 2008). In response to these declines, the Province of British Columbia assigned cutthroat as a Blue listed species in 2004 (BC Conservation Data Center 2023).

Cutthroat trout are a unique salmonid species due to their numerous life history, strategies and characteristics. They can display one of four life history types: resident, fluvial, adfluvial, and anadromous; all types can be present within a single watershed (Zydlewski et al. 2009). Over the last few decades, it has become clear that cutthroat are being displaced from their preferred small stream habitats, as logging, urban sprawl, and other anthropogenic impacts are degrading these habitats (Rosenfeld et al. 2002). As a result of their wide range and highly variable and adaptive life history strategies, understanding unique cutthroat populations is critically important and integral to proper management and habitat protection.

Shelly Creek is a small tributary of the Englishman River and home to what is believed to be a resident cutthroat population. Shelly Creek is a small, low-elevation coastal watershed which confluences with the larger Englishman River one kilometre above tidal water. While it is assumed this population is resident, due to an anadromous anthropogenic barrier (culvert), the geographic location of this population suggests it could also have fluvial and anadromous life history types in the past (Anderson 2008).

The natural hydrology of Shelly Creek has been significantly altered by land development and other anthropogenic activities in the watershed, including the introduction of impervious surfaces, such as roads and driveways, redirection of flow paths, and reductions in the forest canopy and riparian cover (Dumont 2017). The impacts of these activities have resulted in increased flows during the winter due to increased surface runoff and precipitation drainage, and depressed flows during the summer and fall because of reductions in interflow (shallow groundwater) reaching the stream (Dumont 2017). These effects have contributed to a loss of available aquatic habitat in Shelly Creek (Law et al. 2016).

The resident life history type typically inhabits larger portions of a watershed than Pacific salmon and for extended periods (Costello 2008). As such, resident cutthroat are particularly vulnerable to shifts in water quality, hydrology, and changes in spawning and rearing habitats. As a result of their sensitivity to their surroundings, cutthroat trout were identified as sentinel species, meaning that the health of cutthroat trout populations can be a key indicator of watershed quality and health (Slaney and Roberts 2005).

Approximately 1.5km of the upper reach of Shelly Creek supports a population of resident cutthroat trout that are considered at high risk of extirpation because of their small population size and the reduction and degradation of stream habitat. The lower (0.7 km) reach of Shelly Creek is known to provide important overwintering habitats for juvenile coho salmon, rainbow trout, and cutthroat rearing that migrate from the Englishman River. Restoration of degraded salmon rearing habitat has been a focus of MVIHES volunteers and property owners for the past four years with funding provided by Pacific Salmon Foundation.

In an effort to better understand the habitat preferences of resident cutthroat and how local stream hydrology can act as a bottleneck in limiting fish movement to preferred habitats, MVIHES decided to undertake this study.

The objective of this project was to use PIT technology to assess the movement behaviour and preference of instream habitat types by resident cutthroat concerning stream flow conditions in an upper reach of Shelly Creek. More specifically, it aimed to determine when and how resident cutthroat move within upper Shelly Creek under different stream flows and at different times of the year. It also investigated whether there are instream habitat conditions that resident trout avoid or prefer during certain times of the year and whether existing stream degradation areas act as barriers to fish migration under certain flow conditions.

While the primary objective of this project was to assess the movements of the resident population, this project is in collaboration with the Bottlenecks to Marine Survival Project, funded by the BC Salmon Restoration and Innovations fund and managed by the B.C. Conservation Foundation and the Pacific Salmon Foundation. As such, the project's mainstem PIT array located at river kilometre 0, was utilized to determine if any Shelly Creek – Hamilton Road cutthroat trout were detected leaving the Englishman River.

METHODS

Study Area

Shelly Creek flows into the Englishman River approximately 1 km upstream of tidewater near Parksville, B.C., and is located along the East Coast of Vancouver Island. The creek originates at the base of Little Mountain, and it flows for 6.5 km north-northeast through maturing second-growth forests, suburban neighbourhoods, and farmland before converging with the Englishman River.

This project was conducted in an upper reach of Shelly Creek, located between Hamilton Avenue to the north and the E & N Railway crossing to the south, approximately 1.7 km upstream of the Englishman River confluence (Figure 1). The study reach was approximately 338 m in length, has a channel width ranging from 2 to 4 m, and an average gradient of 4% (Hilson and Hill 2014). The channel morphology of the study section is characterized by step pools created by large woody debris jams, boulders, and exposed tree roots. The adjacent riparian lands are owned by the City of Parksville and are managed as a municipal park (Shelly Creek Park North and Shelly Creek Park South).

Figure 1. Location of study site in upper Shelly Creek, Parksville, BC. The red star indicates the location of the stationary array. (Inset source: iMapBC)

Culverts delimit the study area at the lower and upper site boundaries, which are considered impassable for fish except during high flows. A groundwater spring provides all the base flow for Shelly Creek. During the annual low flow period (July to October) approximately 80 m of the creek dries downstream of the E & N Railway culvert. Shelly Creek above the study area (upstream of the E&N culvert) is not fish-bearing, as there is no surface water during the summer to sustain fish life processes (Law et al. 2016).

Shelly Creek Flow Data Collection

Stream depth (± 0.001 m) was recorded hourly using a Levelogger (Solinist, Model 3001). The levelogger was installed in a small eddy located approximately 2.2 km upstream from the confluence with the mainstem Englishman River near Hamilton Avenue in Shelly Creek North Park (49.307218, -124.303905) (Figure 2). The levelogger was housed in a protective standpipe mounted to a T post. A 1 m reference staff gauge was also installed in this eddy, mounted to a T post. The station control is a small, natural riffle located on right bank beneath the walking path bridge on the Shelly Creek Park trails; this control is highly mobile and was likely subject to several changes during the study period. Barometric pressure data was collected from the Environment Canada airport station located 8 km from the gauge in Qualicum Beach.

Figure 2. Photo depicts level logger and staff gauge location in Shelly Creek. 2022.

MVIHES volunteers collected cross-sectional discharge measurements on 30 occasions throughout the duration of the study using the Mid-Section method with a FlowTracker1 acoustic doppler velocimeter (SonTek, San Diego, CA, USA) in the vicinity of the logger location.

Fish Capture and Tagging

Cutthroat were captured during four tagging events between June and October 2021 using baited minnow traps (bait was cured salmon roe, 16-hour soak time) and pole seining (6.4 mm hole size, knotless nylon mesh).

Cutthroat were transferred to one or more aerated holding buckets. Individual fish were anesthetized in a solution of stream water mixed with tricaine methane sulfonate (TMS or MS222®, Syndel, Ferndale, WA, USA; 50 mg/L) and buffered with sodium bicarbonate (100 mg/L). Vidalife (Syndel, Ferndale, WA, USA; 0.1 ml/L) was added to all fish baths to preserve fish mucus during handling.

Once anesthetized, each fish was measured for their fork length (F.L.; to the nearest mm), and a 12 mm PIT tag (FDX; Biomark, Boise, ID, USA) was inserted into the abdominal body cavity of individuals ≥ 65 mm F.L (Figure 3). PIT tags were inserted using a Biomark MK25 (Biomark, Boise, ID, USA) tagging gun and single-use 12-gauge hypodermic needle (Biomark, Boise, ID, USA). Each tagged fish was scanned using an HPR Lite scanner (Biomark, Boise, ID, USA) immediately after tag insertion, and the tag identification number was recorded. Tagged fish were placed into an aerated recovery bucket and monitored until they had fully recovered from anesthesia (i.e., swimming normally). Fish were released back into the creek, following a full recovery, within less than 10 minutes after capture.

Figure 3. The left image PIT-tagging kit shows the HPR scanner, MK25 tagging gun, pre-loaded FDX-B tagging tray and static baths with MS222 and aerators. The right image shows the 12 mm FDX-B PIT tag.

Mobile Scanning: Fish Movement and Habitat Use

A total of 20 mobile PIT scans were conducted approximately every two weeks between June 2021 and July 2022, but did not occur over a three-month period from December 2021 to February 2022. Mobile scans were completed using an HPR Plus portable handheld PIT reader equipped with a scanning wand (Biomark, Boise, ID, USA) (Figure 4). The read range of this unit was approximately 30 to 40 cm; however, the read range of mobile PIT antennas varies depending on tag orientation, detection plane, and electrical interference. Data collected by the HPR Plus reader included each detection's unique tag identification number, time, and GPS location. The instream habitat type (pool, riffle, glide) and type of cover (undercut bank, woody debris) occupied by tagged fish was also recorded for each detection.

Figure 4. The right image shows the Biomark HPR Plus mobile scanner utilized for mobile scanning and the left image shows the head unit of the Biomark HPR Plus scanner.

Each scanning session was conducted by starting at the farthest downstream boundary of the study site (Hamilton Ave culvert) and walking in an upstream direction sweeping the scanning wand over the width of the creek, including underneath woody debris and undercut banks. On two occasions, the riparian vegetation adjacent to the stream was also scanned using a BCCF custom-built mobile PIT scanner. These riparian scans did not encompass the entire riparian zone within the study site; however, they broadly covered the area adjacent to the stream bank (approximately 20 m) along both sides of the length of the creek.

Stationary PIT Arrays

A stationary instream PIT array was used to monitor downstream fish movement out of the study site. The array was installed approximately 15 m downstream of the Hamilton Avenue culvert and comprised of two PIT antennas arranged in sequence (~10 m apart), which allowed for the directional movement of PIT-tagged fish to be determined (Figure 5). The antennas were custom designed to cover the entire width of the creek and oriented flat along the stream bed in a "pass-over" design. The antenna frames were fabricated from solid core 3.81 cm ABS, while the internal wiring comprised five conduits, 12 AWG 600-volt copper wire. One antenna was installed on October 21, 2021, and the other on November 1, 2021. Aside from one antenna not working from November 19 to 24, 2021, the result of a connection issue, the system operated continuously throughout the study. The read range of these antennas was determined to be approximately 35 cm. The reader boards (IS1001; Biomark, Boise, ID, USA) and power supply (four 12-volt 100 Ah AGM batteries) were stored in a weather-proof metal job box on land adjacent to the array.

Figure 5. The Top image shows the downstream stationary PIT antenna. The lower image shows the upstream stationary pit antenna.

Data collected by this system included the tag identification number, date, and time of each detection. The reader boards were downloaded onto a laptop bi-weekly, usually on the same day that mobile scans were conducted. A Biomark HDPE instream PIT array was installed in the lower mainstem Englishman River in August of 2021 (Biomark, Boise, ID, USA) as part of the larger BCSRIF project. This array was utilized to detect tagged cutthroat that may have moved downstream from upper Shelly Creek into the river. This mainstem array was comprised of two transects, each with 4 – 6.5 m and 1 – 5 m HDPE antennas with subnodes containing IS1001 reader boards (Biomark, Boise, ID, USA). The array is managed by a Biomark master controller located on the right bank (Biomark, Boise, ID, USA). The read range of these antennas was determined to be approximately 35 cm. The array is powered by eight 12-volt 100 Ah AGM batteries, connected in series and parallel for a 24-volt system and are stored in a weather-proof metal job box on land adjacent to the array.

Englishman River Install. Danny Swainson.

DATA ANALYSIS

Shelly Creek Flows

Jon Jeffery (BC Provincial Hydrometric Specialist) performed data processing and analysis in Microsoft Excel. Continuous stage data was roughly corrected (but unverified) based on average sensor resets found using an estimated sensor reset correction (SRC) of -0.020 to correct for some systematic error. Reference stage readings and several discharge measurements have suspected significant error associated, but were used as provided. The corrected stage data was compensated using interpolated MET data from the Qualicum Airport MSC station. A stage-discharge rating curve (R1.00) was produced using an estimated point of zero flow (PZF) of 0.18 m with the equation Q=7.17(HG-0.18)^2.21, and deemed applicable for the range between 0.000 - 1.32 m^3/s (approximately double the highest measured discharge of 0.665 m^3/s). This equation was used to estimate rated discharge based on the compensated stage data provided. Potential breakpoints were not identified or considered in this rating; a single-segment relationship was assumed for ease of analysis (Jon Jeffery 2022).

Coastal Cutthroat Trout

All fish data were analyzed using R (R Core Team 2020). Data wrangling (dplyr), statistical analyses (dplyr), and graphing (ggplot2) were done using the Tidyverse package (Wickham et al. 2019). Dispersal distances were determined from GPS coordinates using the geosphere package (Hijmans 2021).

Cutthroat parr.

RESULTS

Shelly Creek Flows

Further discharge data review is required to finalize the Shelly Creek dataset to meet the Provincial standard. Field stage and discharge measurements collected by MVIHES contained errors and uncertainties, which limits the accuracy of data grading for this dataset. All derived data quality is "U – Unknown" according to RISC grading criteria. However, while flow data does not meet Provincial standards, its utilization for fish movements does not require highly accurate flow data and analysis in this report used the existing rating curve and rate discharge.

Shelly Creek had a mean daily discharge rate of 0.063 m^3/s during the study period (June 2021 – June 2022) (Figure 6). The maximum value measured (3.933 m^3/s; however, this value is an estimation past the upper values in the rating curve, 1.32 m^3/s) was during the 2021 atmospheric river events, which caused major flooding across British Columbia.

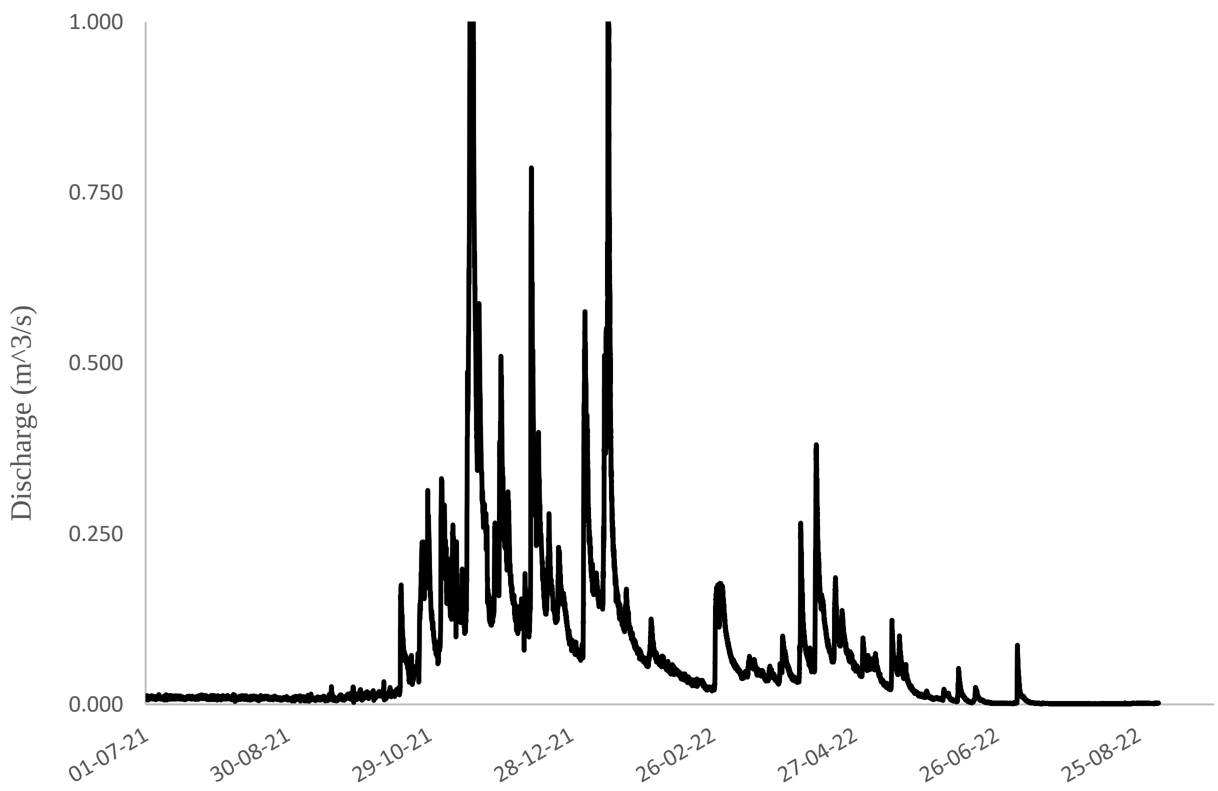


Figure 6. Shelly Creek estimated mean daily discharge (m3/s) from January 7, 2021, to August 25, 2022 (data courtesy of Jon Jeffery).

Fish Capture and Tagging

In total, 86 cutthroat were captured across the four sampling days (Table 1). Of these, 52 individuals were large enough to be PIT-tagged (Table 2); the remaining 34 were released untagged (< 65 mm F.L.).

Table 1. The number of captured and PIT-tagged cutthroat among four sampling dates in upper Shelly Creek during the summer and fall of 2021. Fish measuring < 65 mm fork length were released untagged.

Sampling Date (2021)	Fish Captured		PIT-tags Administered	Total Fish Tagged To Date
	Total	Recaptured		
June 9	8	N/A	6	6
June 17	15	0	15	21
September 1	34	13	14	35
October 30	29	2	17	52

Table 2. Summary of mean fork length (mm) for cutthroat trout captured in Shelly Creek, 2022.

Fork Length (mm)			
N	Mean	SD	SE
52	137.19	37.70	5.23

Fish Movements

Mobile Scanning

During the study period, 50 out of the 52 PIT tags administered (96%) were detected at least once by either a mobile antenna or stationary array (Table 3). The average detection rate of mobile scans (ratio of the number of tags detected to the total number of tags administered) was 37% ± 14.7% (S.D.). The highest detection rates occurred during scans in the early to mid-Fall of 2021, while scans in June and July of 2022 yielded the lowest detection rates (Figure 7).

Table 3. Summary of PIT-tag detections by the mobile scanner and stationary array in Shelly Creek.

Tag Detections	System	
	Mobile Scanner	Stationary Array
Unique	50	7
Total	793	67,163

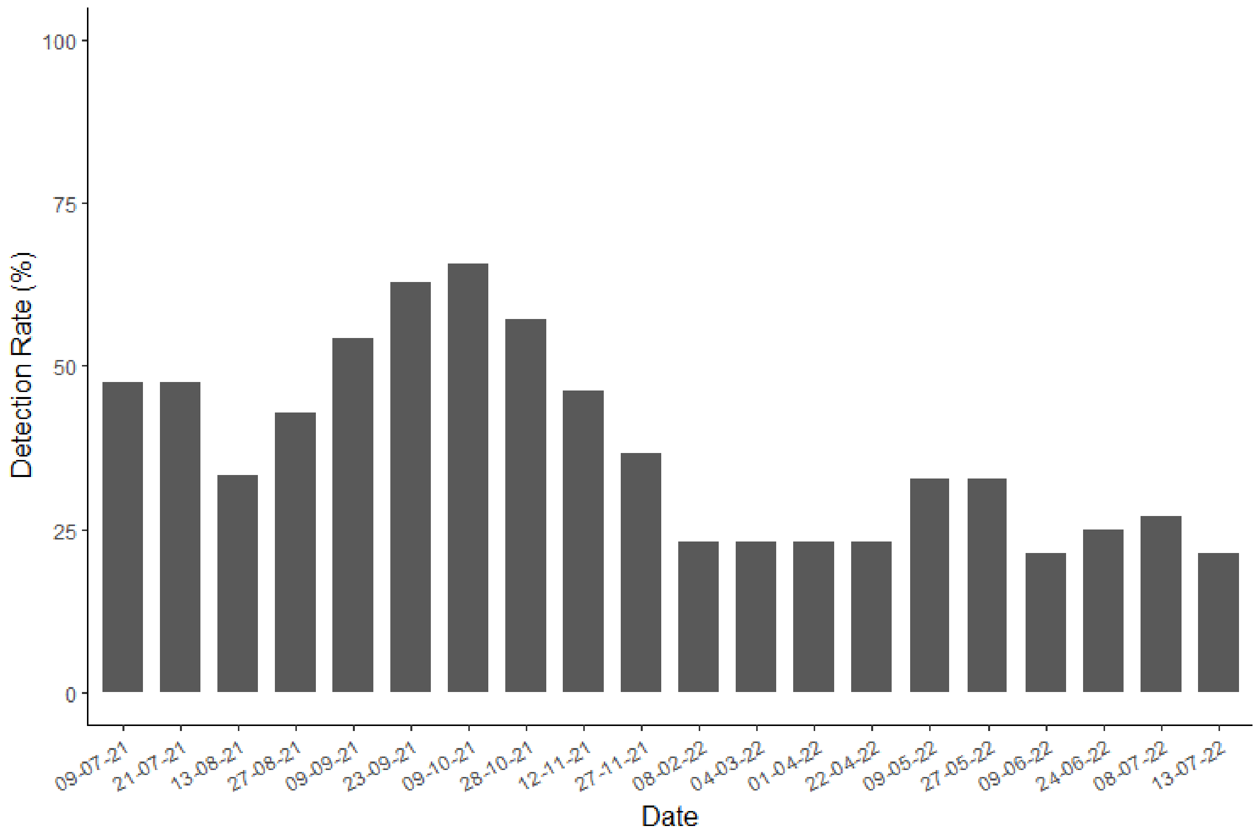


Figure 7. Summary of detection rates of mobile scans conducted in Shelly Creek.

Unless broken, PIT tags have an unlimited lifespan because they do not require a power source. As such, detecting a PIT tag using a mobile antenna can represent a live fish, rejected tag (i.e., a tag shed by fish after insertion), or mortality. Across the study period, 12 tags (23%) were identified as either rejected or mortalities; this was determined as the tags were detected in exactly the same location across multiple mobile scans. Additionally, these tags were detected in habitats unsuitable for fish (i.e., dry gravel). Three of these tags were located outside of the stream during the riparian zone scans. Only tag detections determined to be in live fish were used to analyze movement and habitat use.

The GPS receiver on the mobile antenna was determined to be accurate in resolving distances with an average error of ± 10 m; this value was calculated from detections of individual known rejected tags which remained stationary over multiple months of scanning. Therefore, movement distances (the individual distance fish moved between scanning events) were resolved to movements > 10 m, with distances between 0 to 10 m considered "0 m" for analysis. The farthest movement distance observed was 237 m (fish #8795). However, most fish moved less than 50 m between detections (Figure 8). The representative tracks of three fish that had a high frequency of detection and one fish that was detected during several mobile scans and on stationary array are shown in Figure 9.

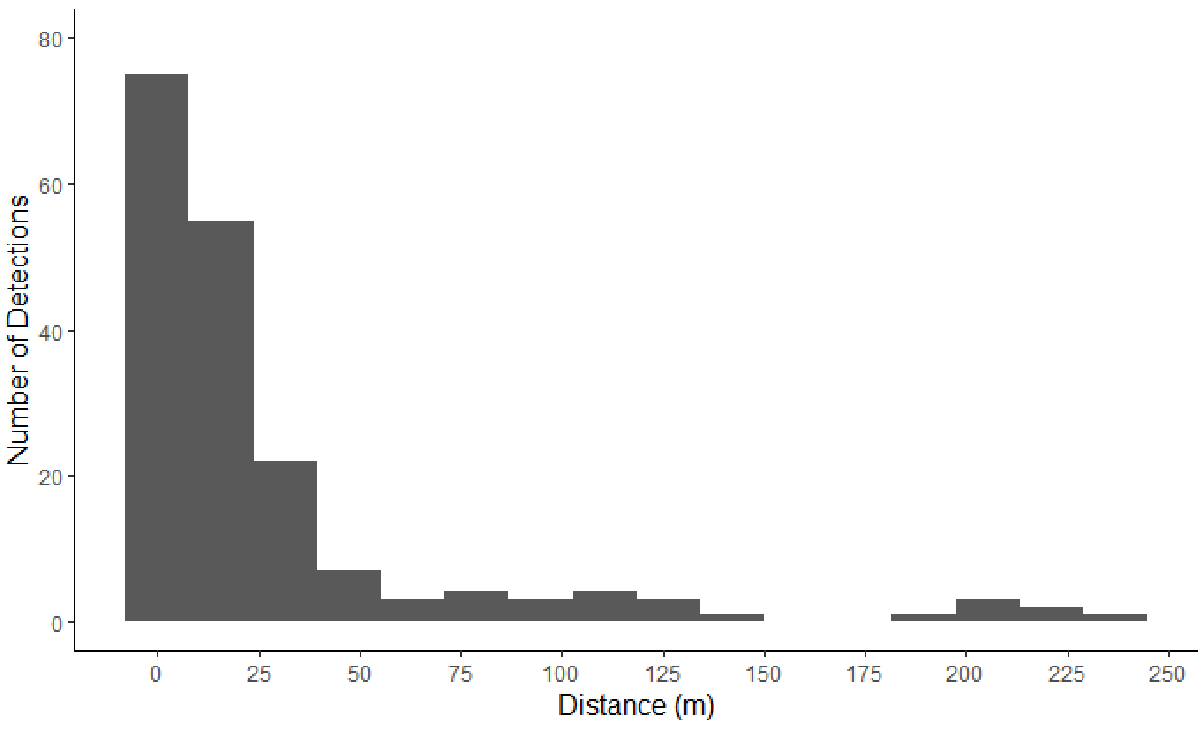


Figure 8. Summary of the distances PIT-tagged cutthroat moved between mobile scan detections in an upper reach of Shelly Creek from July 2021 to July 2022. Movements between 0 and 10 m are labelled as "0 m".

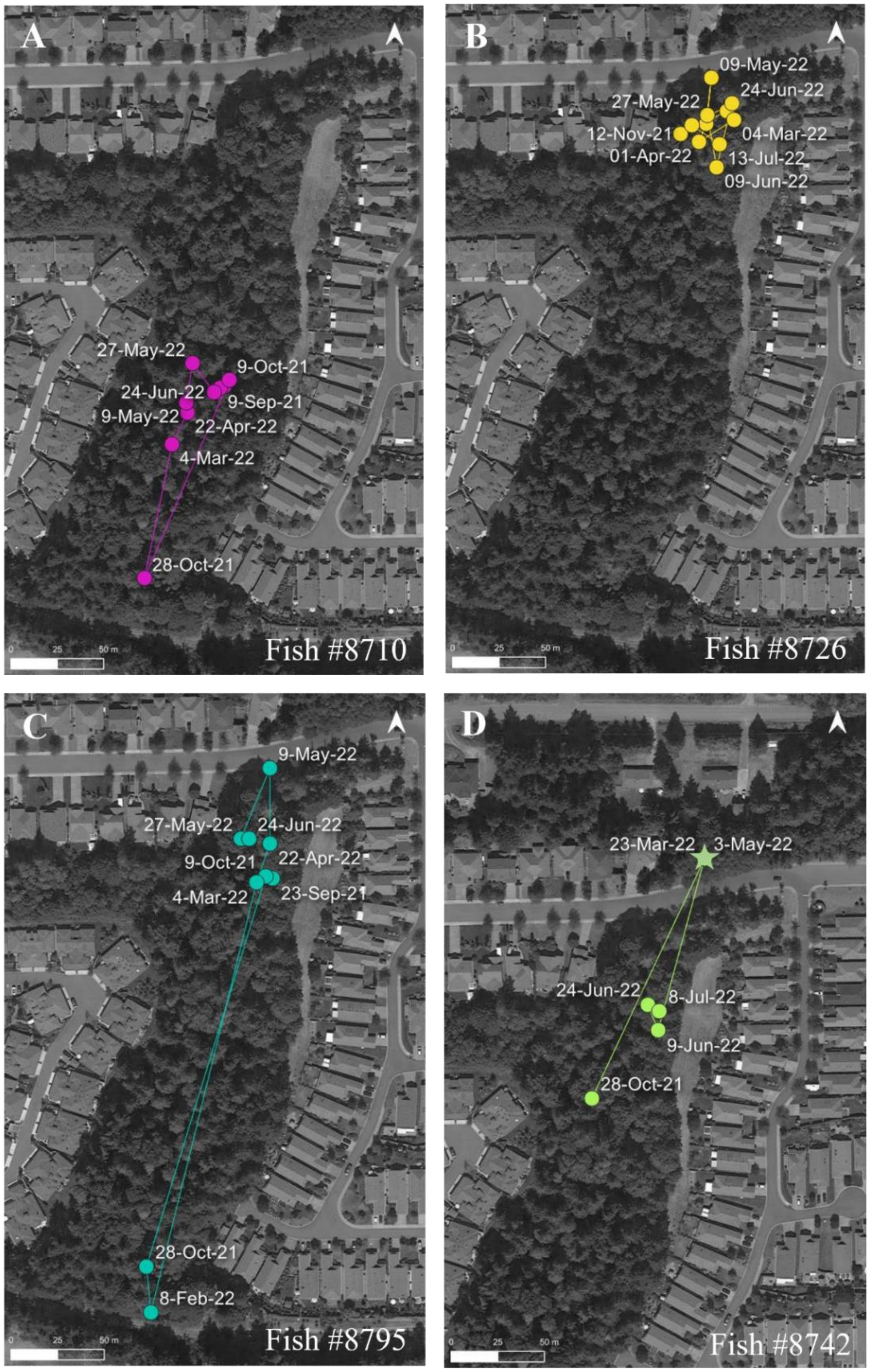


Figure 9. Detections of four individual PIT-tagged cutthroat at the Hamilton Road reach of Shelly Creek during mobile scans conducted between July 2021 and July 2022. Lines connecting points are representative of linear movement between locations. The star in D represents two detections by the stationary array that were approximately 1.5 months apart.

A generalized additive model was used to assess the influence of river discharge with cutthroat trout movements (Figure 10). The results of the model indicate that there is a significant positive relationship between river discharge and migration distance ($F(8.671, 167.8)$, $p < .001$). The adjusted R-squared value was 0.0878, indicating that 8.83% of the variability in migration distance can be explained by discharge.

There was a distinct increase in the magnitude and frequency of fish movements in the fall of 2021, coinciding with a high stream discharge following heavy precipitation events. Longer distance fish movements continued to be observed throughout the late winter and early spring of 2022, while stream discharge remained high. As stream discharge steadily declined between May and July 2022, fish movement distances decreased (Figure 10).

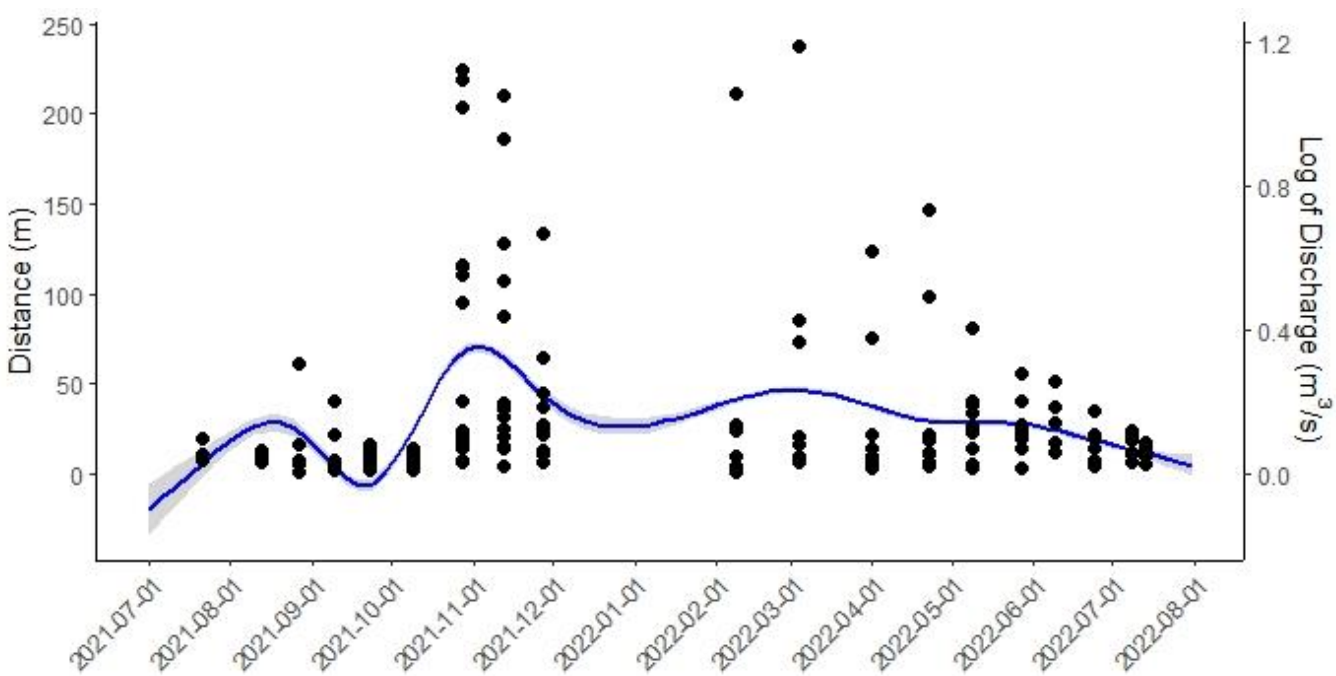


Figure 10. Distances PIT-tagged cutthroat trout moved between mobile scans with stream discharge. Distances ≤ 10 m are represented as "0 m". Discharge values are displayed on a log scale for ease of visualization. A generalized additive model was used to determine the relationship between river discharge and migration distance (blue) with standard error (grey shaded).

Habitat Use

The instream habitat conditions occupied by PIT-tagged cutthroat showed some variation over the study (Figure 11). fish were detected exclusively in deep pools during the summer low-flow period in 2021 (July 9 to August 27, 2021). Pools remained the most commonly used habitat type until early September, when after a slight increase in discharge, a higher proportion of fish began occupying riffles (~20%), and glides (~5%). As discharge substantially increased in late October 2021, fewer fish were detected in riffles, and a larger number were detected in glides. All three habitat types were occupied in approximately equal proportions by late November 2021. Throughout the mobile scans in 2022, pools remained the most utilized habitat type, with only a small proportion of fish (< 40%) occupying either riffles or glides. The use of riffles and glides observed during 2022 displayed more variation and less consistency across consecutive scans.

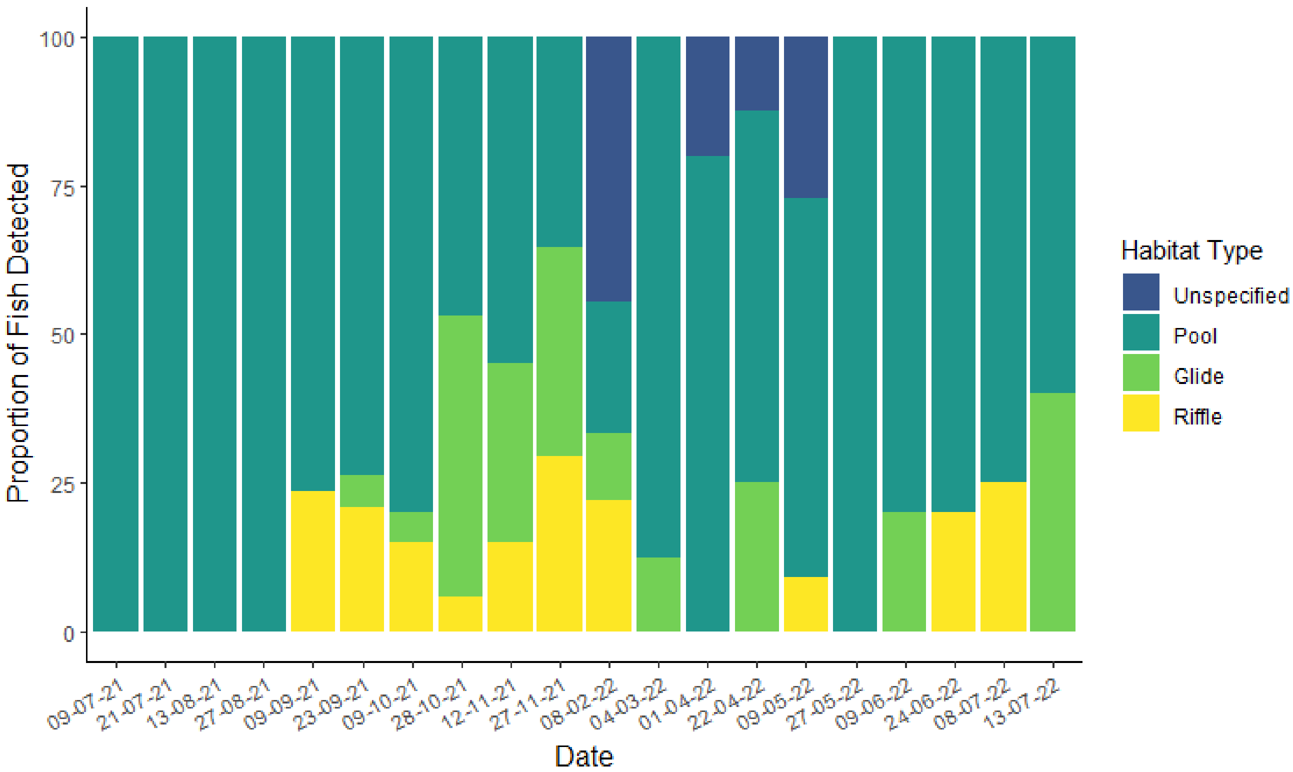


Figure 11. Instream habitat use of PIT-tagged cutthroat in Shelly Creek during mobile scans conducted from July 2021 to July 2022.

Stream cover type was also assessed during mobile tracking, and it was found that within pools, fish were predominantly detected utilizing undercut banks (Figure 12). However, due to the few data points collected within the riffle and glide categories, further comparative analysis could not be done.

A number of mobile surveys did not specify the habitat type tags were found in early 2022; similarly, cover type was also not specified for most fish detected in riffle and glide habitats. These data limitations prevented further analysis of habitat and cover use.

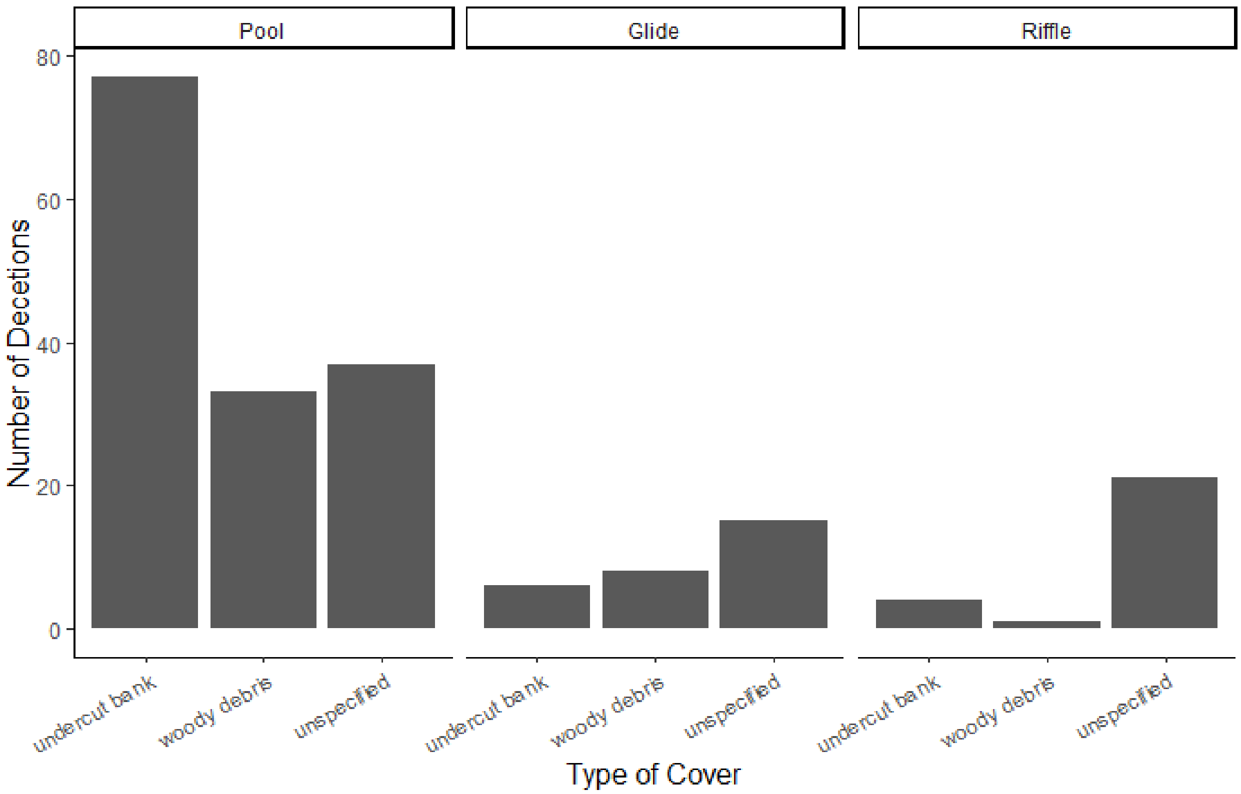


Figure 12. Cover used by PIT-tagged cutthroat within instream habitat types in Shelly Creek during mobile scans conducted from July 2021 to July 2022.

Stationary PIT Array

Of the 52 PIT tags deployed in cutthroat, the stationary array detected seven unique tags (13.5%). Four of these seven fish were detected exclusively by the array, and three were also detected by at least one mobile scan (Table 4).

Table 4. Summary of cutthroat detected by the stationary array. A high number of detections indicates that fish stayed in close proximity to the antennas over a period of time.

Tag ID	First detection	Last detection	No. of days on antenna(s)	No. of detections
8725	October 30, 2021	October 30, 2021	1	27
8786	October 30, 2021	October 30, 2021	1	1,003
8807	October 30, 2022	June 10, 2022	7	47,037
8738	February 6, 2022	February 6, 2022	1	17
8744	March 8, 2022	April 11, 2022	10	3,607
8742*	March 23, 2022	May 3, 2022	7	14,354
8787	April 3, 2022	April 3, 2022	1	1,118

*See Figure 9(D) for the representative tracks of Fish #8742.

Englishman Mainstem PIT Array Detections

The Englishman River mainstem PIT array detected 641 unique PIT tags since its installation in August 2021. None of the 52 PIT-tagged fish from upper Shelly Creek were detected on the Englishman River mainstem PIT array.

DISCUSSION

The upper reaches of Shelly Creek are home to a resident coastal cutthroat trout population that is increasingly becoming a stock of concern to local stewardship groups due to a changing climate and anthropogenic pressures. This study's objective was to assess this population's migratory movements within the upper portion of the creek. This project demonstrated that cutthroat movements within the upper reaches are likely restricted during low flows. Further, a generalized additive model suggested that stream flow was a significant predictor of cutthroat movements; however, it was only able to explain 8.38% of movements. Therefore, while a small percentage of movements of cutthroat were dependent on stream flow, other unknown factors (spawning, age, etc.) also contribute to the distance fish migrated unrelated to stream flow. Additionally, no cutthroat PIT-tagged in the upper reaches were detected on the Englishman River mainstem array, which provides additional data supporting the assumption that this stock is likely a resident life history type.

Shelly Creek Flows

There were some significant issues with data quality for streamflow monitoring. Future monitoring could aim to improve flow data collection by closely following RISC protocols for data collection. This includes: improved site selection and station equipment mounting, improved reference gauge reading confirmations (i.e., timestamped photos of gauge), improved control monitoring and evaluation (i.e. photo documentation and a written description of control condition at every visit), and adapted discharge measurement in stream widths of < 2 m (i.e., minimum 10 cm panel width rather than 20+ panels). If such changes can be made, the data quality will greatly improve for future analysis. The analysis done with the current dataset is limited and must be interpreted cautiously.

Shelly Creek appears to experience a seasonal pattern of low summer streamflow typical of many small ECVI streams. The discharge in Shelly Creek is dominated by precipitation events, with between 2-11% of discharge estimated coming from groundwater (Dumont 2017). Based on the two study years' rated discharge data, it appears that Shelly Creek reached relative baseflow conditions by approximately mid-May in 2021 and late June in 2022. By September 2022, a significant proportion of discharge is estimated to have originated from a spring located 150 m upstream from the flow monitoring station (from MVIHES field data notes).

As such, low flow conditions likely restrict cutthroat movement within the system; however, this is likely a natural condition to which cutthroat and other species in Shelly Creek have been adapted. Although the current conditions may be natural, continued anthropogenic pressures and the likely increased demand for groundwater could impact the watershed and aquifer on which Shelly Creek relies in the summer.

Cutthroat Movements and Habitat Use

The mean detection rate of individual mobile scans in this study (37%) was consistent with other PIT-tagging studies of cutthroat (Hodge et al. 2015). Several factors are known to affect the detection rate of portable scanners (i.e., the probability of tag detection), including antenna read range (Campbell et al. 2019), fish size (Saboret et al. 2021), and stream characteristics (Hill et al. 2006). Within the study site, woody debris jams, deep holes, and undercut banks may have provided areas where fish could avoid detection by moving outside the read range—ultimately resulting in stream characteristics influencing detection probabilities. During the extreme summer low-flow period in 2021, several tagged fish went undetected for several months, only to be detected or recaptured during subsequent scanning or tagging events. These situations help confirm our assumption and suggest that fish could evade detection even when movement was limited within pools. Other possibilities affecting detection efficiency include removing tagged fish from the stream by predators or migrating out of the study area (Sheldon and Richardson 2022). However, the small number of fish detected by the stationary array ($n = 7$) suggests that few members of this population migrated downstream out of the study area during its operation window. Further, it is possible that fish moved in the upstream direction when stream flows allowed the E & N culvert to be passable. The riparian zone scans indicate that removal by predation was also a contributing factor to the detection rate, as tags were detected up to 20 m away from the stream.

Distinguishing between live and non-live tag detections is one of the difficulties associated with using mobile scanners (Hodge et al. 2015). The tag detections identified as live fish in this study were differentiated from false positives (i.e., rejected tag or mortality that retained a tag) based on analyzing fish movements or recapturing fish during tagging sessions. In a few cases, suspected reject tags were determined to be live fish when they were observed moving during subsequent mobile scans or recaptured live during another tagging event. It is suspected that some of these false-negative detections may have been a result of fish burrowing under the stream bank, such that tags could be detected through the substrate from above a pool, appearing as though the detection was in an unsuitable location for live fish. The tags that were confirmed as mortalities or rejects were located in areas where live fish were unlikely to be buried in the substrate, and the locations of these tags did not change over time.

Within the study reach, the maximum distance an individual moved between mobile scanning events was 237 m, with most mobile detections representing fish movements of less than 50 m. These results agree with previous research indicating that resident cutthroat populations may only move relatively short distances (~200 m) over months or even years (Gresswell and Hendricks 2007). The error rate determined for the mobile antenna GPS (±10 m) was also consistent with the accuracy of other commercially available GPS systems operated in a closed canopy environment (Wing et al. 2005).

The relatively short dispersal distances observed during summer low-flow conditions suggest that fish were confined to pools within the lower section of the creek and that connectivity between adjacent pools was limited. This result was not surprising since the study reach had several large obstructions (i.e., sediment plugs, woody debris jams), and fully dewatered sections separated some pools. During low-flow seasons, trout may prefer pool habitats because the energetic costs associated with swimming and foraging are minimized, and they provide refuge from high temperatures (Berger and Gresswell, 2009). The availability of pool habitat in small streams is recognized as a critical factor in resident trout survival during periods of extremely low flow; however, populations of fish that are seasonally reliant on pools with limited connectivity are vulnerable to even small changes in environmental conditions (Sheldon and Richardson, 2022). Larger fish may also be at higher risk of avian and mammalian predation in small pools with limited access to cover (Penaluna et al. 2020). Predation on cutthroat trout by barred owls has been observed on several occasions within the study reach (MVIHES pers. comm.).

Habitat and cover data collection were somewhat limited, and with the understanding that cutthroat could be moving among habitat types between scanning events (Hilderbrand and Kershner, 2000), the exclusive detection of tagged fish in pools during the summer low flow period is a key finding. Moreover, it suggests that fish only began to rear in different habitat types (i.e., riffles and glides) as they became available with increased flows. Fish within pool habitat were also regularly detected near undercut banks and, to a lesser extent, woody debris, emphasizing the importance of natural refugia as cover as an important factor in cutthroat habitat selection (Penaluna et al. 2020).

As stream discharge increased in the fall of 2021, a corresponding increase in fish dispersal distance and movement complexity was observed, with movements predominantly occurring in the upstream direction. Cutthroat are likely signalled to move when a specific discharge threshold is reached (Budy et al. 2020). Due to the limitations of the flow data set, deriving a threshold discharge estimate for dispersal is not informative. However, trends in the discharge-movement relationship proved to be significant and support the assessment that stream flow significantly influences cutthroat movement in upper Shelly Creek. Cutthroat may undergo short, non-migratory movements to seek more suitable habitat conditions or to relieve competition pressures (Sheldon and Richardson 2022). In small streams such as Shelly Creek, where available habitat is considerably reduced, and invertebrate drift is likely limited during low flow times of the year, competition for the limited available resources is likely an important factor in determining fish movement relating to spatial distribution and dispersal (Naman et al. 2018). Cutthroat were the only species of salmonid captured within the study reach, suggesting that competitive interactions were almost exclusively between conspecifics. Individuals were detected moving along the entire length of the study reach, which indicates the natural barriers created by the morphology of the creek (i.e., boulders, tree roots, woody debris) are seasonally impassible and only obstruct fish movement under certain flow conditions.

Resident Cutthroat Trout

The lack of detection data on the Englishman River mainstem array for the upper Shelly Creek population suggests it is of resident life history type. However, due to its proximity to the estuary, it is surprising that no fish were detected on the mainstem array, as the ability to out-migrate is not assumed to be restricted. The culvert at the south end of Blower Rd, which is suggested to be an anadromous barrier, is likely the leading cause for the extirpation of an anadromous life history type from the upper Shelly Creek watershed.

Conclusion

The migratory behaviour of cutthroat in upper Shelly Creek was relatively minimal throughout the study. During the summer low flows, cutthroat movements were limited by seasonally impassible barriers, created in part by the natural morphology of the stream, and exacerbated by areas of stream degradation (e.g., sedimentation, erosion). Cutthroat were able to move along the length of the study reach, during higher winter flows, suggesting these barriers do not inhibit fish movement during the winter months. Additionally, long distance movements (> 200 m) were not frequently observed, which is not unusual for resident trout. The culvert at Hamilton Ave was also passable during high flows, but few fish migrated downstream out of the study reach, and no upper Shelly Creek cutthroat were detected in the Englishman River at the mainstem PIT array located at tide water. While the upper reaches of Shelly Creek are home to what is likely a resident life history type; one can imagine that historically it was home to three life history types (resident, fluvial, and anadromous), similar to those found throughout the Englishman River watershed. Restrictions to migrations and movements in the upper reaches, caused by anthropogenic impacts (urban encroachment, logging, etc.) and the installation of an anadromous barrier in the form of a culvert in the lower reach have likely resulted in two of the life history types being extirpated.

Continued anthropogenic pressures and changing climate conditions which may reduce groundwater availability would likely have severe impacts on the resident cutthroat in Shelly Creek, as they rely on groundwater to provide flow and moderate stream temperatures during the summer drought months. Moreover, the installation of traditional culverts in Shelly Creek to allow for future road access to land development must be discouraged in favour of clear span bridges, to allow for fish movement in all flow conditions, and to reduce flow restrictions and the increased velocity rates that can impact stream morphology.

ACKNOWLEDGEMENTS

Many thanks are extended to Peter Law, Ross Peterson, Doug Herchmer, Ben McManus, Dave Erickson, Susan Wilson, Barb Riordan, Shelly Goertzen, Dick Dobler, and Chris Smith of MVIHES who assisted with field work including fish capture, mobile scans, and flow measurements. Thank you to project partners and funders: Vancouver Island University Biology Department, and the Freshwater Fisheries Society of BC Native Trout Stewardship Initiative. Additional thanks to Thomas Negrin and others at BCCF who assisted with this project. This project could not have been completed without the PIT infrastructure and equipment purchased and installed by BCCF and PSF through the BCSRIF funded Bottlenecks to Marine Survival Project.

REFERENCES

Anderson, J.D. 2008. Coastal Cutthroat Trout in Washington State: Status and Management. 2005 Coast. cutthroat trout Symp. status, Manag. Biol. Conserv. (January): 11–23.

B.C. Conservation Data Centre. 2022. Species/Community Conservation Status report: species name or ecosystem name. B.C. Government. Available: http://a100.gov.bc.ca/pub/eswp/ December, 2022.

Budy, P., Thompson, P.D., McKell, M.D., Thiede, G.P., Walsworth, T.E., and Connor, M.M. 2020. A multifaceted reconstruction of the population structure and life history expressions of a remnant metapopulation of Bonneville cutthroat trout (*Oncorhynchus clarkii utah*): Implications for maintaining intermittent connectivity. Trans. Am. Fish. Soc. **149**(4): 443-461. doi:10.1002/tafs.10240

Campbell, T., Simmons, J., Sáenz, J., Jerde, C.L., Cowan, W., Chandra, S., and Hogan, Z. 2019. Population connectivity of adfluvial and stream-resident Lahontan cutthroat trout: Implications for resilience, management, and restoration. Can. J. Fish. Aquat. Sci. **76**(3): 426–437. doi:10.1139/cjfas-2017-0483.

Costello, A.B. 2008. The Status of Coastal Cutthroat Trout in British Columbia. 2005 Coast. Cutthroat Trout Symp. Status, Manag. Biol. Conserv.: 24–36.

Dumont, J. 2017. Shelly Creek Water Balance and Sediment Reduction Plan Phase 2-Computer Modelling and Assessment. Available from http://www.mvihes.bc.ca/images/pdfs/DumontJShellyCreekWBMReportPhase2-June2017.pdf.

Gresswell, R.E., and Hendricks, S.R. 2007. Population-Scale Movement of Coastal Cutthroat Trout in a Naturally Isolated Stream Network. Trans. Am. Fish. Soc. **136**(1): 238–253. doi:10.1577/t05-196.1.

Hijmans, R.J. 2021. geosphere: Spherical Trigonometry. R package version 1.5-14. https://CRAN.R-project.org/package=geosphere

Hill, M.S., Zydlewski, G.B., Zydlewski, J.D., and Gasvoda, J.M. 2006. Development and evaluation of portable PIT tag detection units: PITpacks. Fish. Res. **77**(1): 102–109. doi:https://doi.org/10.1016/j.fishres.2005.08.001.

Hilson, W., and Hill, G.H. 2014. Shelly Creek geomorphic overview of conceptual level habitat enhancement program development. Prepared for Mid Vancouver Island Habitat Enhancement Society. p.25

Hodge, B.W., Henderson, R., Rogers, K.B., and Battige, K.D. 2015. Efficacy of Portable PIT Detectors for Tracking Long-Term Movement of Colorado River Cutthroat Trout in a Small Montane Stream. North Am. J. Fish. Manag. **35**(3): 605–610. doi:10.1080/02755947.2015.1012280.

Jeffery, Jonathon (2022) Shelly Creek FLow Rating Curve Analysis and Discharge Estimates Nov. 2020 to Aug. 2022. (Pers. Comm.)

Law, P., Smith, F., and Riordan, B. 2016. Shelly Creek Stream Assessment And Fish Habitat Survey (2014 and 2015). (October). Available from http://www.mvihes.bc.ca/images/pdfs/ShellyCreekStreamAssessmentReportPLaw.pdf.

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rosenfeld, J.S., Macdonald, S., Foster, D., Amrhein, S., Bales, B., Williams, T., Race, F., and Livingstone, T. 2002. Importance of Small Streams as Rearing Habitat for Coastal Cutthroat Trout. North Am. J. Fish. Manag. **22**(1): 177–187. doi:10.1577/1548-8675(2002)022<0177:iossar>2.0.co;2.

Saboret, G., Dermond, P., and Brodersen, J. 2021. Using PIT-tags and portable antennas for quantification of fish movement and survival in streams under different environmental conditions. J. Fish Biol. **99**(2): 581–595. doi:https://doi.org/10.1111/jfb.14747.

Sheldon, K.A., and Richardson, J.S. 2022. Season-specific survival rates and densities of coastal cutthroat trout across stream sizes in southwestern British Columbia. Ecol. Freshw. Fish **31**(1): 102–117. doi:https://doi.org/10.1111/eff.12616.

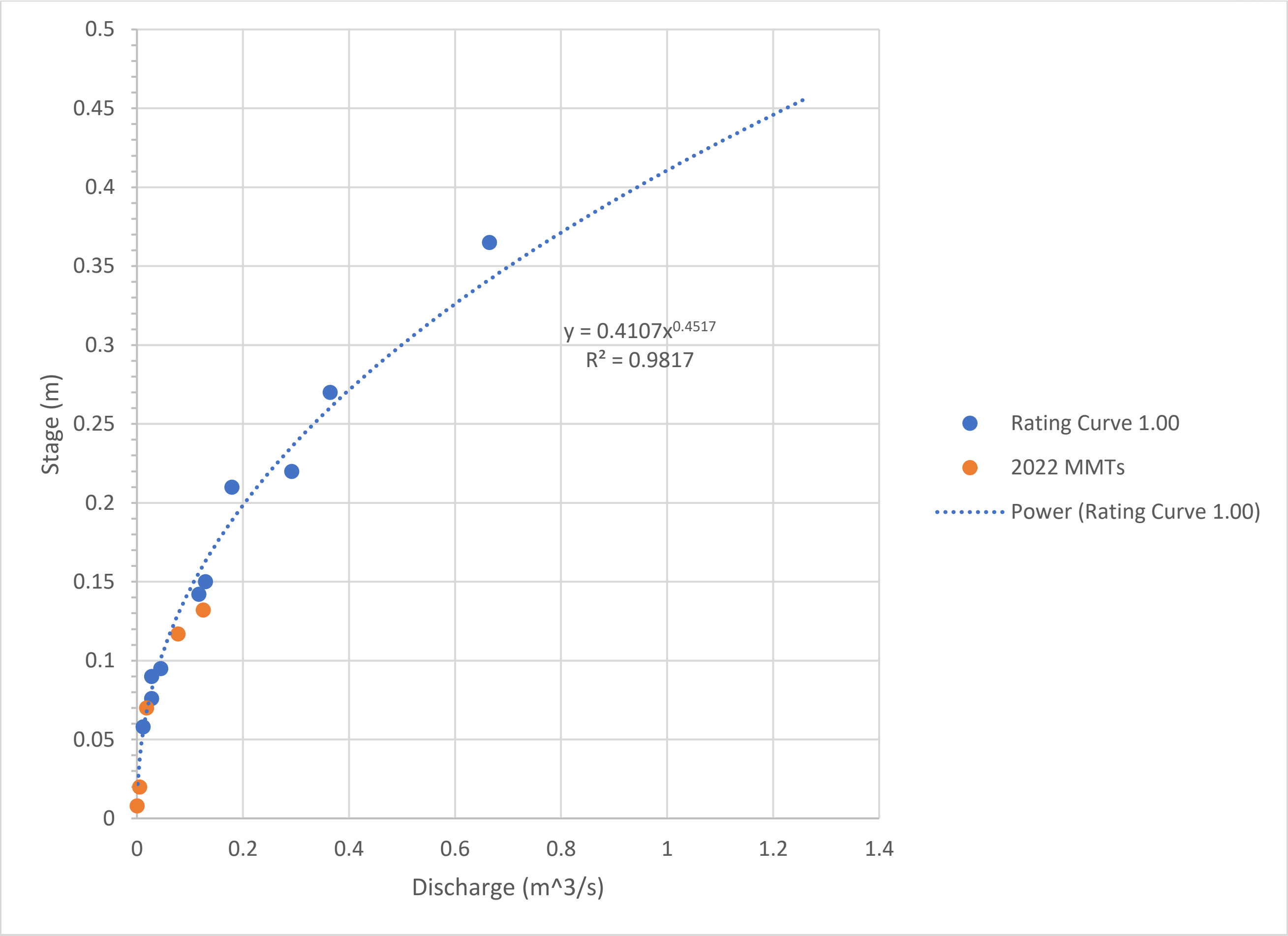
Slaney, P., and Roberts, J. 2005. Coastal cutthroat trout as sentinels of lower mainland watershed health: Strategies for coastal cutthroat trout conservation, restoration and recovery. : 83.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller, E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K., and Yutani, H. 2019. Welcome to the Tidyverse. J. Open Source Softw. **4**(43): 1686. doi:10.21105/joss.01686.

Wing, M.G., Eklund, A., and Kellogg, L.D. 2005. Consumer-grade global positioning system (GPS) accuracy and reliability. J. For. **103**(4): 169–173. doi:10.1093/jof/103.4.169.

Zydlewski, G.B., Zydlewski, J., and Johnson, J. 2009. Patterns of migration and residency in coastal cutthroat trout Oncorhynchus clarkii clarkii from two tributaries of the lower Columbia River. J. Fish Biol. **75**(1): 203–222. doi:10.1111/j.1095-8649.2009.02280.x.

APPENDIX A: FLOW RATING CURVE



Appendix A. The rating curve model was used to estimate stream discharge in Shelly Creek during the study period.

APPENDIX B: GENERALIZED ADDITIVE MODEL

Family: Gaussian
Link function: identity

Parametric coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 25.4148 0.3323 76.48 <2e-16 ***

Approximate significance of smooth terms:
edf Ref.df F p-value
s(discharge) 7.935 8.671 167.8 <2e-16 ***

R-sq.(adj) = 0.0878 Deviance explained = 8.83%
GCV = 1669.1 Scale est. = 1668.1 n = 15106

PACIFIC SALMON FOUNDATION

BRITISH COLUMBIA CONSERVATION FOUNDATION

Fisheries and Oceans Canada | Pêches et Océans Canada

BRITISH COLUMBIA

Funding for this project is provided by the BC Salmon Restoration and Innovation Fund, a contribution program funded jointly between Fisheries and Oceans Canada and the Province of BC.

Support for this specific report also came from The Freshwater Fisheries Society of BC – Native Trout Stewardship Initiative

Freshwater Fisheries Society of BC