Habitat use and movement of coastal cutthroat trout *Oncorhynchus clarkii clarkii* in relation to seasonal flow dynamics in a small stream on Vancouver Island, British Columbia

An undergraduate research project

by Ally Badger

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ABSTRACT

In British Columbia (BC), fish populations of species such as coastal cutthroat trout rely on small creeks in urban settings as key habitat for important life cycle stages, such as spawning and juvenile rearing. However, the natural hydrological dynamics of urban watersheds are often heavily altered as a result of anthropogenic interference, which can create barriers to fish movement and migration. This study used Passive Integrated Transponder (PIT) technology to assess the movement and preference of instream habitat types of coastal cutthroat trout in relation to stream flow conditions in an upper reach of Shelly Creek, in Parksville, BC. A total of 52 cutthroat trout were PIT tagged and monitored using a mobile PIT antenna and a stationary instream PIT array during summer and fall of 2021. Fish dispersal distances ranged from 11 to 224 m, and 65.9% of fish moved (> 10 m) at least once during the study period. The frequency and magnitude of fish movements increased during mid-fall, which coincided with a substantial increase in stream discharge. The instream habitat locations occupied by PIT-tagged trout showed slight variation during the study, however, habitat availability was largely limited to perennial pools during the summer. These results emphasize that flow dynamics are influential in fish movement, and that cutthroat trout can inhabit and rely on relatively small stream reaches quite extensively, particularly during sensitive periods of the year, suggesting that urban stream-resident cutthroat trout populations may benefit from local, site-based restoration projects.

INTRODUCTION

The ecological value of small, urban streams and their capacity to support populations of vulnerable and at-risk fishes is becoming increasingly recognized (Silver *et al.*, 2018). In British Columbia (BC), species of high economic and ecological importance such as Pacific salmonids regularly rely on small creeks in urban settings as key habitat for various stages during their life cycles. Salmonids often regulate the trophic structure within these freshwater environments by serving as apex aquatic predators (Budy *et al*., 2020), and by providing nutrients to both terrestrial and aquatic ecosystems (Slaney and Roberts, 2005). Thus, the streams these fishes occupy can play a fundamental role in the ecosystem function of the encompassing watershed (Costello, 2008; Favaro *et al*., 2014). Not surprisingly however, the natural hydrological dynamics of urban watersheds are often heavily impacted by human land-development activities (e.g., high proportions of impervious surface area, over-channelization of storm-water runoff, and insertion of instream culverts) (Paul and Meyer, 2001; LaPointe *et al.*, 2013). These anthropogenic features often result in increased stream discharge during the winter, and unnaturally low flows during the summer, which ultimately degrade or diminish available aquatic habitat (Heggenes *et al.*, 1991; Sheldon and Richardson, 2022), and can also directly obstruct fish movement and migration (Favaro *et al*., 2014). There is an increasing need to better understand how stream-dwelling salmonids move through, and use, available habitat because this information is critical to many aspects of their conservation (Hilderbrand, 2003; Gresswell and Hendricks, 2007; Goetz *et al.*, 2013; Budy *et al.*, 2020). This is especially true for fish inhabiting urban waterways, because these streams are often the most imperiled (Paul and Meyer, 2001; Silver *et al*., 2018).

In BC, coastal cutthroat trout, *Oncorhyncus clarkii clarkii*, is an important native salmonid that has experienced substantial population declines that have been influenced significantly by habitat loss resulting from human encroachment (Hilderbrand, 2003; Costello, 2008). Coastal cutthroat trout (hereafter referred to as "cutthroat trout") have a wide distribution across western North America (Slaney and Roberts, 2005), and due to their small physical size at maturation, are able to inhabit smaller streams that are suboptimal for larger salmonids (Slaney and Roberts, 2005; Costello, 2008). As such, cutthroat trout are often found in headwaters of urban watersheds, many of which are highly impacted by development and land management practices that routinely neglect small, peripheral streams (Rosenfeld *et al*., 2002). Their population sizes are often quite small, i.e., fewer than 100 individuals, and can typically vary significantly from year to year (Costello, 2008). These factors make cutthroat trout particularly sensitive to habitat alteration and degradation, such as greatly reduced summer stream flows and increased water temperature conditions that are common during periods of low precipitation (Sheldon and Richardson, 2022). These impacts can be compounded by direct anthropogenic interference, as well as climate change (Williams *et al*., 2009; Ward *et al*., 2020). Cutthroat trout are now classified as a blue-listed species of special concern in BC (Slaney and Roberts, 2005).

Cutthroat trout are known to exhibit a number of different life history strategies, including anadromous, fluvial, and resident forms, with multiple forms potentially occurring within the same stream (Costello, 2008, Goetz *et al.*, 2013). Resident trout are considered non-migratory and may spend their entire life within a single reach or tributary of a stream (Budy *et al*., 2020). Fluvial fish migrate short-distances to the main stem of rivers, and anadromous forms travel from tributaries all the way to marine environments (Budy *et al.*, 2020). Such variation in migration strategies is believed to be related to environmental conditions, and factors associated with fitness trade-offs, such as growth and reproduction (Zydlewski *et al*., 2009). However, the mechanisms underlying many of these processes are still not clearly understood (Costello, 2008). Urban stream populations that are isolated above an obstruction (e.g., a culvert) or an area of habitat degradation, are often at increased risk of extirpation (Hilderbrand, 2003; Gresswell and Hendricks, 2007). Reduced immigration and emigration opportunities, and the resultant reductions in gene flow can ultimately reduce the resiliency of populations, and leave fish more vulnerable to environmental fluctuation, stochastic events, and anthropogenic impacts (Carim *et al*., 2017; Campbell *et al*., 2018; Silver *et al.*, 2018). Even limited immigration has been shown to markedly reduce the risk of extirpation in small trout populations (Hilderbrand, 2003; LaPointe *et al*., 2013).

Although it is recognized that salmonids can exhibit complex movement and migration patterns such as described above (Goetz *et al*., 2013; Budy *et al.*, 2020), physical stream characteristics are recognized as an important variable in the movement and connectivity of cutthroat trout populations (Gresswell and Hendricks, 2007; Budy *et al.*, 2020; Sheldon and Richardson, 2022). For example, in a 14-month, mark-recapture study, Gresswell and Hendricks (2007) found that stream discharge and temperature were influential in the movement patterns of cutthroat trout living above an anadromous barrier. Overall, these trout travelled a remarkably short distance throughout the entire study (an average of 22 m), however, trout occupying shallow reaches were found to move far more than those within deeper pool habitats (Gresswell and Hendricks, 2007). This preference of stream-resident cutthroat trout for slow-moving, deep pools (> 22 cm water depth) compared with high velocity riffles (>20 cm/s) has also been described by other studies that found stream discharge to be a key factor involved in trout habitat selection (Heggenes *et al*., 1991; Campbell *et al.*, 2018).

Shelly Creek is a small tributary to the Englishman River in Parksville, BC, that supports a population of resident cutthroat trout. It is the last fish-bearing stream within Parksville city limits, and its natural hydrology has been significantly altered by land development and other human activities in the watershed. This includes the introduction of impervious surfaces, such as roads and driveways, redirection of flow paths, and reductions in forest canopy and riparian cover (Dumont, 2017). These activities and changes have resulted in larger stream discharge volumes during the winter months due to increased surface runoff and precipitation drainage, and greatly reduced 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 habitat for the small population of cutthroat trout that resides in the upper reaches of Shelly Creek (Law *et al*., 2016).

The main objective of this study was to use Passive Integrated Transponder (PIT) technology to assess the movement behaviour and preference of instream habitat types by cutthroat trout in relation to stream flow conditions in an upper reach of Shelly Creek. This project was conducted in partnership with the Mid-Vancouver Island Habitat Enhancement Society (MVIHES), which has been investigating the connections between fish, aquatic habitat conditions, water quality, and hydrology in the Englishman River watershed for over 15 years and has identified the preservation of trout in Shelly Creek as a high priority. This cutthroat trout population is considered particularly vulnerable to local extirpation because of its small population size, and residency within an urbanized waterway (Law *et al*., 2016).

The specific objectives of this project were to determine when and how resident trout move within Shelly Creek under specific stream flows, and whether there are instream habitat conditions that resident trout avoided or preferred during certain times of the year. Additionally, it determined whether existing areas of stream degradation were acting as barriers to fish migration under certain flow conditions. Understanding how movement of the trout is affected by changing stream hydrology will inform and refine future aquatic habitat preservation efforts in Shelly Creek. This information will also add to existing knowledge, because research on the movement of resident salmonids within small stream networks is currently limited (Gresswell and Hendricks, 2007), and cutthroat trout are particularly understudied in this region (Zydlewski *et al.*, 2009; Campbell *et al.*, 2018).

MATERIALS AND METHODS

This project took advantage of a concurrent and ongoing study by the BC Conservation Foundation (BCCF) and Pacific Salmon Foundation entitled "*Determination of Bottlenecks Limiting Wild and Enhanced Juvenile Salmon and Steelhead Production in BC using PIT tags and Spatially Comprehensive Arrays*." This large-scale, ongoing study is using PIT tags to gain information on survival bottlenecks for salmonids in both freshwater and marine environments in BC, including the Englishman River. The BCCF provided the PIT tags, as well as tagging and scanning equipment for use in Shelly Creek. All research for this project was approved by the Vancouver Island University Animal Care Committee under Animal Use Protocol 101177. Fish capture and sampling were permitted by the British Columbia Ministry of Forests, Lands and Natural Resource Operations under the Fish Collection Permit NA21- 623324.

Study Site

Shelly Creek originates at the base of Little Mountain in Parksville, BC, and flows for 6.5 km north-northeast through maturing second growth forest, suburban neighborhoods, and farmland before converging with the Englishman River (Hilson and Hill, 2014). The specific location of this project was an upper reach of Shelly Creek, located between Hamilton Avenue to the north and the E & N Railway crossing to the south, that is approximately 1.7 km upstream of the Englishman River confluence (Figure 1). This section of the stream is approximately 400 m in length and is delimited by a concrete double-cell box culvert at the lower site boundary and a single corrugated metal pipe culvert at the upper site boundary. Both culverts are considered to be passable for fish during high flows. Approximately 80 m downstream of the E & N Railway culvert, a groundwater spring provides all of the flow for this section of Shelly Creek during the summer and early fall months. Immediately upstream of this spring, the stream often runs dry during the summer months and is impassable by fish (Law *et al.*, 2016). The study site has a channel width ranging from 2 to 4 m, an average gradient of 4%, and is within a protected public park that is surrounded by single-family residential properties (Hilson and Hill, 2014). The morphology of this section of the stream is characterized by step-pools created by large woody debris jams, boulders, and exposed tree roots. In many of these areas, sediment carried downstream during high-flow events has accumulated in these obstructions and begun to fill in available pool habitat (Law *et al.*, 2016).

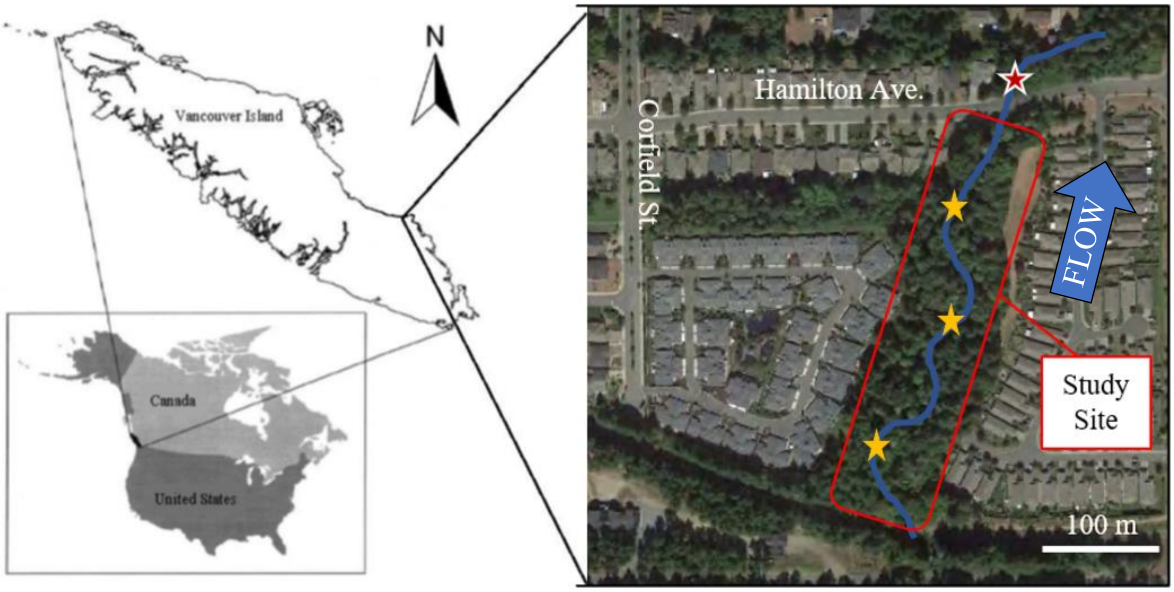

Figure 1. Location of Shelly Creek and the study site (adapted from Dumont, 2017). The red star indicates the approximate location of the stationary PIT array. The yellow stars indicate the approximate locations of photos taken in Figure 6.

Fish Collection and Tagging

Between June and October, 2021, cutthroat trout were captured during four separate sampling events using a combination of baited minnow traps (bait was cured salmon roe, 16-hour soak time) and pole seining (6.4 mm hole size, knotless nylon mesh). Captured trout were transferred to one or more aerated holding buckets, and individual fish were anaesthetized 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 appropriately anaesthetized (stage II, deep narcosis; Ackerman *et al.* 2005), each fish was measured for fork length (FL; to the nearest mm), and a 12 mm PIT tag (FDX; Biomark, Boise, ID, USA) was inserted into the abdominal body cavity of individuals ≥ 70 mm FL (Vollset *et al*., 2020). PIT tags were inserted using a tagging gun equipped with a single-use, hollow 12-gauge 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 PIT tag identification number was recorded. Tagged fish were placed into an aerated recovery bucket and monitored until they had fully recovered from anaesthesia (i.e., swimming normally). Following full recovery, fish were released back into the creek within less than 10 m of their capture location.

Habitat and Movement Monitoring

Scans of the study site were conducted approximately every 2 weeks between June and December 2021, and began approximately 2 hours after sunrise to coincide with increased activity of the fish (Goetz *et al.*, 2013) and for consistency across sampling dates. Scans were completed using an HPR Plus portable handheld PIT reader equipped with a scanning wand

(Biomark, Boise, ID, USA). The "read-range" of mobile PIT antennas varies depending on tag orientation and detection plane (Hodge *et al.*, 2015), but in this study, read range was determined to be approximately 30 to 40 cm. Data collected by the HPR Plus reader included the unique tag identification number, time, and global positioning system (GPS) location of each detection. The instream habitat type was also recorded for each tag detection using three categories: deep pool, riffle, or glide. Deep pools were defined as having a residual depth of ≥ 40 cm throughout the low-flow summer period. 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 [in accordance with methods in Campbell *et al*. (2018)].

A stationary, instream PIT array was used to monitor downstream fish movement out of the study site and was installed approximately 15 m downstream from the Hamilton Avenue culvert (Figure 1). This array was composed of two independent PIT antennas arranged in sequence (~5 m apart), which allowed for the directional movement of PIT-tagged fish to be determined (Zydlewski *et al*., 2006). The antennas were constructed to fit the entire width of the creek, and oriented flat along the stream bed such that tagged fish would be detected as they swam overtop (read range ≈ 34 cm). The required reader boards (IS1001; Biomark, Boise, ID, USA) and power supply (Four 12-volt batteries) were stored in a weather-proof box on land adjacent to the array. One antenna was installed on October 21, 2021, and the second one on November 1, 2021. Aside from one short break due to a connection issue that took place from November 19 to 24, 2021, this stationary detection system operated continuously following installation throughout the duration of the study. Data collected by this system included the tag identification number, and time (date and time) of each detection.

Stream Parameters and Data Analysis

Flow measurements were collected by MVIHES volunteers throughout the entire duration of the study using a FlowTracker1 (SonTek, San Diego, CA, USA). Stream depth (± 0.001 m) was recorded at hourly intervals using a Levelogger (Solinist, Georgetown, ON, Canada). A rating curve model was produced by plotting the Flowtracker measurements against stream depth levels recorded by the Levelogger (Appendix A). The depth-discharge relationship determined by this model was used to estimate stream discharge during the period of study. Water temperature (± 0.2 °C) was also recorded at hourly intervals using a HOBO temperature logger (Onset, Bourne, MA, USA). Fish movements were analyzed using R (R Core Team, 2022), and dispersal distances were determined from GPS coordinates using the geosphere package (Hijmans, 2021).

RESULTS

Fish Sampling and Detection Efficiency

From June to October, 2021, 86 cutthroat trout were captured across four sampling days within the study reach in upper Shelly Creek (Table 1). Of the total, 52 individuals were PIT-tagged. Fork lengths of PIT-tagged fish ranged from 70 to 239 mm with a mean length of 137 ± 38 mm (SD). During subsequent tagging sessions, 15 PIT-tagged cutthroat trout (28.8%) were recaptured and the locations of tag insertions on all recaptured fish were found to be healing well with minimal inflammation or scarring. Mobile scans of the study site were completed from July 9 to November 27, 2021. During the entire study period, 90.4% of PIT tags administered were detected at least once by either mobile antenna or stationary array. The detection rate of individual mobile scans (ratio of the number of tags detected to the total number of tags administered) was relatively consistent across all scanning dates with a mean rate of 50% ± 10.3% (SD).

Table 1. Number of captured and PIT-tagged cutthroat trout among four sampling dates within an upper reach of Shelly Creek during summer and fall of 2021. A total of 52 PIT tags were administered to fish measuring ≥ 70 mm fork length (FL) across all sampling dates. Fish measuring < 70 mm FL were released untagged.

Sampling Date (2021)	Fish Captured		PIT tags Administered	Total Fish Tagged to Date
	Total	Recaptured		
Jun 9	8	N/A	6	6
Jun 17	15	0	15	21
Sep 1	34	13	14	35
Oct 30	29	2	17	52

Tag Retention

Because PIT tags do not require a power source and have a long operating life, the detection of a PIT tag using a mobile antenna can represent a live fish, rejected tag (i.e., a tag shed by fish after insertion), or a retained tag inside a dead fish (Hill *et al.*, 2006; Bateman *et al.*, 2009). In this study, tag status was recorded as an assumed live fish if the tag location changed over multiple detections during a single scanning event, or if the tag was detected in several locations over multiple scans. Three tags (5.8% of total) were identified as rejects during mobile scanning because they were detected in the exact same location over multiple (≥ 5) scanning events, and were located in very shallow water with no fish visible (Bateman *et al*., 2009; Saboret *et al.*, 2021). Therefore, these tags were excluded from any analysis of movement and habitat use. Additionally, five PIT tags were never detected by either the mobile or stationary antennas. In total, 44 tags (of the 52 total PIT tags administered) were assumed to be live fish and useable for analysis.

Patterns of Movement

The mobile antenna GPS receiver was determined to be accurate in resolving distances with an average error of ± 10 m, based on detections of individual rejected tags that remained stationary throughout the course of the study. Therefore, dispersal distances (the distance individual fish moved between scanning events) were resolved to movements > 10 m, with distances between 0 to 10 m considered “0 m” for analysis. Most fish (65.9%) moved (> 10 m) at least once during the study period, and dispersal distances ranged from 11 to 224 m (Figure 2). Only 11 dispersal distances greater than 100 m were detected. The representative tracks of three fish that had a high frequency of detection are shown in Figure 3. Three individuals (6.8% of PIT-tagged trout) were detected by the stationary array, and each of these fish was detected only once, travelling in the downstream direction.

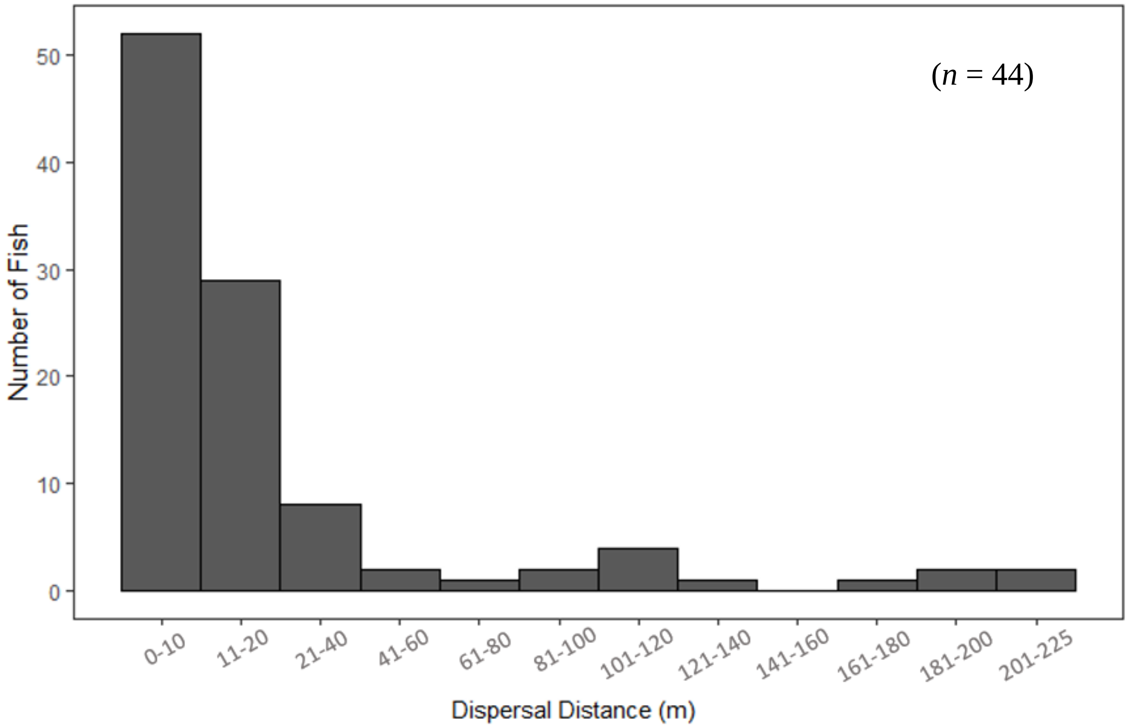

Figure 2. Movements of PIT-tagged cutthroat trout in an upper reach of Shelly Creek, Parksville, BC, during summer and fall of 2021. Dispersal distance is defined as the distance a fish moved between bimonthly mobile PIT scanning events. Movements ≤10 m were most common, and only 11 dispersal distances >100 m were detected. The distances fish moved were determined using the GPS coordinates of individual PIT tag detections.

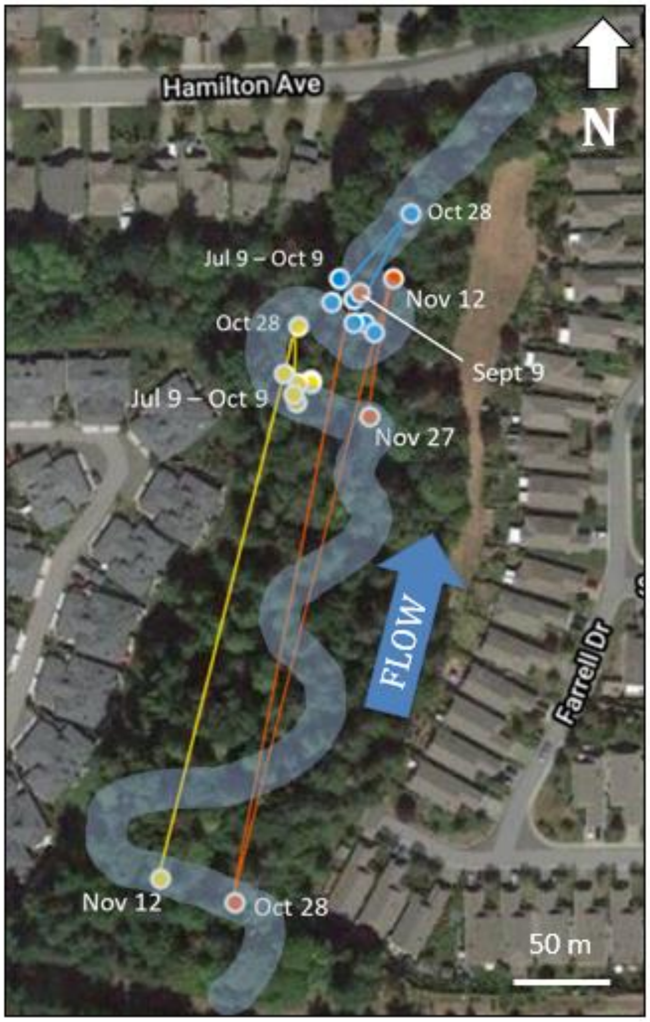

Figure 3**.** Locations of PIT tag detections of three PIT-tagged cutthroat trout in an upper reach of Shelly Creek, Parksville, BC. Colours represent individual fish, and lines connecting points are representative of linear movement between locations. GPS coordinates were collected from bi-monthly mobile PIT scans conducted from July 9 to November 27, 2021.

A distinct increase in the magnitude and frequency of fish movements was observed during late October. The increase in dispersal distance during this period coincided with a substantial increase in stream discharge (Figure 4). The majority (71.2%) of all fish movements (> 10 m) occurred between October 28 and November 27, 2021, including the four farthest dispersal distances (≥ 200 m). Upstream movements were generally farther and occurred 1.3 times more frequently than movements downstream.

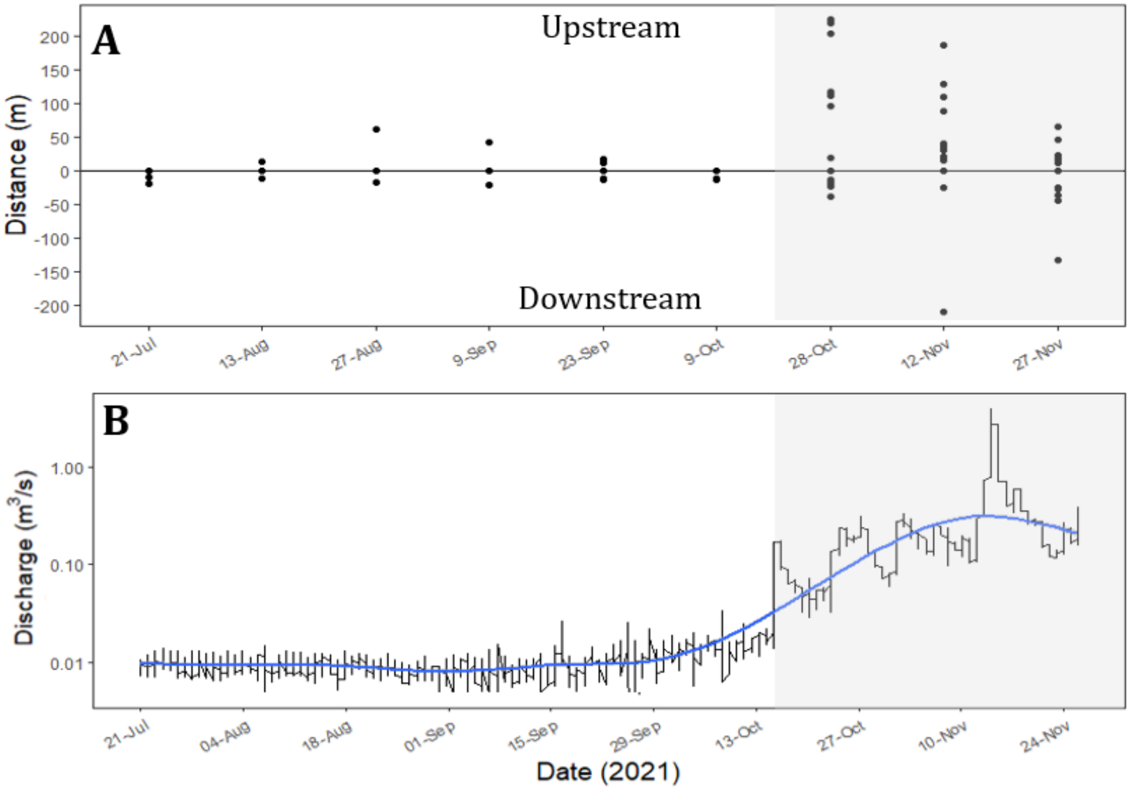

Figure 4**.** Distances cutthroat trout moved between scanning events (A) in relation to stream discharge (B) during summer and fall of 2021. Negative distances indicate movements downstream. Distances ≤ 10 m (both upstream and downstream) are represented as “0 m”. Discharge values (m^3/s) are displayed on a log scale for ease of visualization, and the blue line indicates the overall trend. A distinct increase in the distance fish moved between scans can be seen following an order of magnitude increase in stream discharge in mid-October, 2021 (highlighted by grey shading).

Habitat Use

The instream habitat conditions occupied by PIT-tagged trout showed some variation over the course of the study (Figure 5). Fish were detected exclusively in deep pools during the summer low-flow period (July 9 to August 27, 2021). Pools remained the most commonly used habitat type until late October, but a proportion of fish began to occupy riffles (~20%), and glides (~5%) starting in early September following a slight increase in stream discharge. As discharge substantially increased in late October, 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 the end of the study period in late November, 2021 (Figure 5).

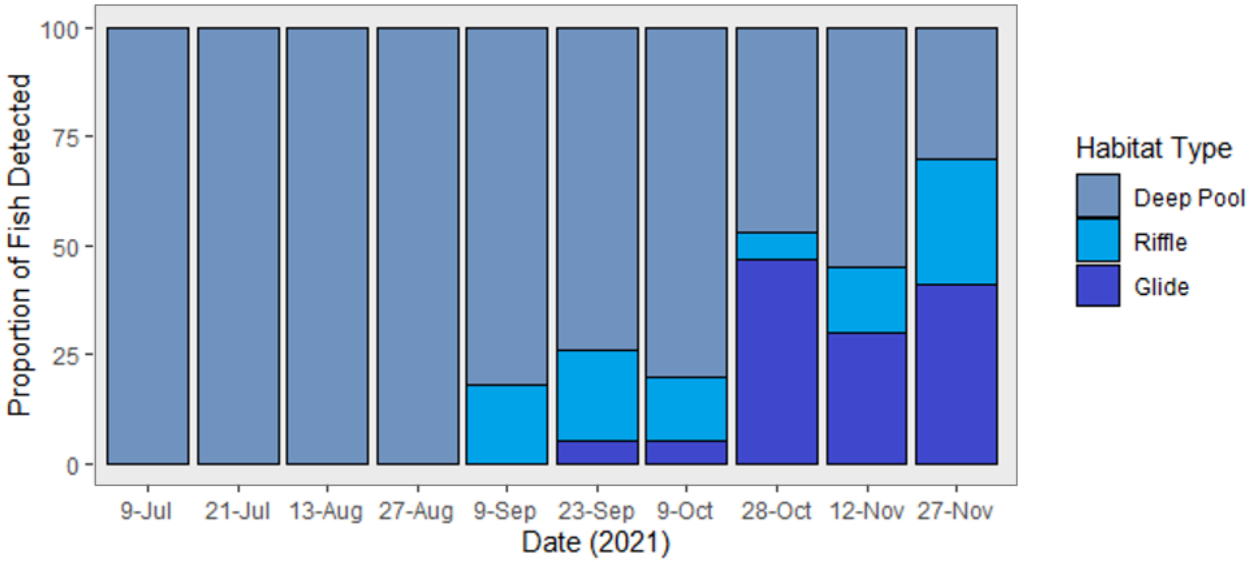

Figure 5. Habitat use of PIT-tagged cutthroat trout monitored by mobile scans conducted approximately every two weeks during summer and fall of 2021. Deep pools are defined as having a residual depth ≥ 40 cm throughout the study period. Fish were detected exclusively in deep pools during the summer low-flow period and the use of riffles and glides increased throughout late summer and early fall as stream discharge increased.

DISCUSSION

This study demonstrated that the movement of cutthroat trout in upper Shelly Creek was mostly confined to the study area, and that stream discharge is an important factor influencing fish movement. During the low-flow period, the availability of habitat within the study reach was largely limited to perennial pools, and fish moved relatively short distances (i.e., < 60 m) between scanning events. At the onset of higher discharge conditions in mid-October, fish movements increased in distance and complexity, and the majority of movements occurred in the upstream direction. Fish were able to move along the length of the study reach, suggesting the morphology of the stream and its natural barriers do not inhibit fish movement during high-flow conditions. The culvert at the downstream site boundary (Hamilton Ave) was also passible during high flows, however, few fish migrated downstream out of the study area.

The mean detection rate of individual mobile scans in this study (50% ± 10.3 %) was consistent with previous PIT-tagging surveys of salmonids (Hill *et al*., 2006; Hodge *et al.*, 2015; Campbell *et al.*, 2018; Saboret *et al*., 2021). A number of factors are known to affect the detection efficiency of portable scanners (i.e., the probability of tag detection) including antenna read range (Campbell *et al.*, 2018), fish size (Saboret *et al.*, 2021), and stream characteristics (Hill *et al*., 2006; O’Donnell *et al.*, 2010; Hodge *et al.*, 2015). 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 range of the scanner, and suggests stream characteristics were a contributing factor to detection efficiency. Several tagged fish went undetected for a number of months during the summer, only to be detected or recaptured during subsequent scanning or tagging events near the location where they were originally released. These situations suggest that fish could evade detection even when movement was limited within pools. It is possible that these trout may have been hiding in response to the scanner (O'Donnell *et al.,* 2010), however, the operation of the mobile antenna was not expected to have a large effect on fish behaviour (Hill *et al*., 2006). Other possibilities affecting detection efficiency include the removal of tagged fish from the stream by predators, or fish migrating out of the study area (Hodge *et al*., 2015; Campbell *et al.,* 2018; Sheldon and Richardson, 2022). Migration was unlikely to have had a major impact on detection efficiency, because during most of the study period (early June until mid-October, 2021), the most upstream section (approximately 80 m in length) of the creek was fully dewatered. Additionally, the stationary array, positioned downstream of the study site, allowed for the detection of migrations in this direction. Although the array was only able to operate during periods of higher discharge, this coincided with times when the fish were most active. Moreover, only five PIT tags (9.6% of total) were never detected by either the mobile or stationary antennas.

The tag detections identified as live fish in this study were differentiated from false-positives (i.e., rejected tag or tag retained inside dead fish) based on analyzing fish movements or recapturing fish during tagging sessions (Bateman *et al.,* 2009). In one case, a suspected reject tag was found to be inside a live fish when it was recaptured later in the season. Since this tag had been previously detected near the overhanging vertical edge of a step-pool, I suspect that the fish may have been able to burrow under the stream bank, such that it was detected through the substrate from above the pool. The small number of tags that were confirmed as 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 numerous scans. The overall tag retention rate (93.9%) is consistent with other reported values for salmonids under similar conditions (Bateman *et al*., 2009; Ostrand *et al*., 2011). However, seasonality may be a factor in the rejection rate found here, since the highest rate of tag rejections is often reported in the spring when female cutthroat trout may expel PIT tags during spawning (Bateman *et al.*, 2009; Saboret *et al.,* 2021).

In Shelly Creek, the maximum distance an individual moved between scanning events was 224 m, and many fish (34.1%) did not move more than 10 m between scanning events. These results agree with previous research that indicates populations of cutthroat trout occupying small streams may only move a relatively short distance (~200 m) over months or even years (Heggenes *et al.,* 1991; Gresswell and Hendricks, 2007; Berger and Gresswell, 2009; Verway *et al*., 2018). The error rate determined for the mobile antenna GPS (±10 m) was also fairly consistent with the accuracy of other commercially available GPS systems operated in a closed canopy environment (Wing *et al*., 2005). Although some fish may have travelled greater distances upstream and out of the study area in mid-fall, the majority of tagged fish (69.4%) continued to be detected within the study reach even after stream discharge and fish dispersal distances had increased. In addition, the small number of fish detected by the stationary array (n = 3) suggests that few members of this population migrated downstream out of the study area during its window of operation.

The relatively short dispersal distances observed during low-flow conditions suggest that fish were confined to pools within the lower section of the creek, and that connectivity between adjacent pools was very limited. This result was not surprising given that the study reach had several large obstructions (e.g., sediment plugs, woody debris jams), and some pools were separated by fully dewatered sections (Figure 6). During low-flow seasons, trout may prefer pool habitat because the energetic costs associated with swimming and foraging are minimized (Naman *et al.,* 2018; Verway *et al*., 2018), and they provide refuge from high temperatures

(Berger and Gresswell, 2009). Furthermore, the availability of pool habitat in small streams is recognized as a key factor in resident trout survival during periods of extremely low-flow (Verway *et al*., 2018; Sheldon and Richardson, 2022). However, populations of fish that are seasonally reliant on pools with limited connectivity are vulnerable to even small changes in environmental conditions (Hakala and Hartman, 2004; Sheldon and Richardson, 2022), including dissolved oxygen content, temperature, and nutrient availability (Zorn *et al.*, 2012). Larger fish may also be at higher risk of avian and mammalian predation in small pools with limited access to cover (Berger and Gresswell, 2009; Penaluna *et al*., 2020). In addition, stream temperatures and the severity of low-flow events are expected to increase and intensify as a consequence of climate change (LaPointe *et al.*, 2013; Ward *et al.,* 2020). As a result, fish in small streams may become increasingly dependent on deeper pools, and existing conservation issues may be exacerbated (Williams *et al.*, 2009; Verway *et al*., 2018). This situation is of particular concern in Shelly Creek, as some pool habitat has already been lost as a result of sediment deposition (Law *et al.,* 2016), and a record-shattering heatwave in June, 2021 caused air temperatures in BC to rise 3-6 ºC higher than previously recorded maximums (Overland, 2021). Upper Shelly Creek is also significantly reliant on a groundwater spring to provide flow and moderate stream temperatures during the summer months. Changing climate conditions or anthropogenic modifications to the watershed that reduce the availability of groundwater to this stream would have severe impacts on the survival of its cutthroat trout population. Understanding how water sources may respond to changes in weather patterns, and the corresponding impacts to stream-dwelling salmonids is an important direction for future studies (Ward *et al*., 2020).

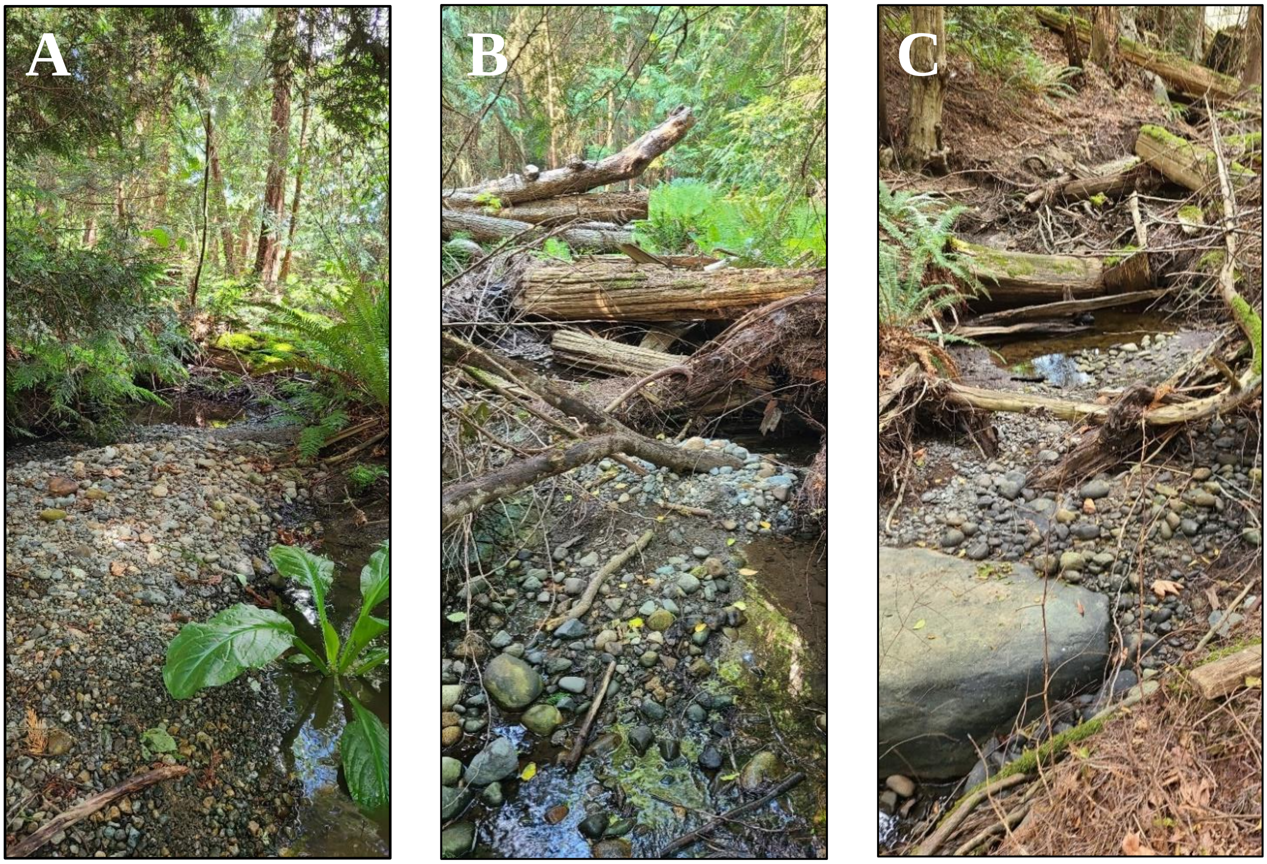

Figure 6**.** Photos of three different dewatered stream sections within the study reach in upper Shelly Creek, Parksville, BC. Photos were taken looking upstream at the lower (A), middle (B), and upper (C) sections of the study reach during June and July of 2021 (see Figure 1 for exact locations).

As stream discharge increased in mid-October, a corresponding increase in fish dispersal distance and movement complexity was observed, with the majority of movements occurring in the upstream direction. Fish may undergo short, non-migratory movements to seek out more suitable habitat conditions or to relieve pressures associated with competition (Huusko *et al.*, 2007; 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 (Hakala and Hartman, 2004), competition for limited resources may be an important determining factor in fish movement relating to spatial distribution and dispersal (Huusko *et al.*, 2007; Naman *et al*., 2018, Penaluna *et al.*, 2020). Cutthroat trout 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 suggests the natural barriers created by the morphology of the creek (i.e., boulders, tree roots, woody debris) only obstruct fish movement below some threshold stream discharge level, and fish may be signalled to move when such a threshold is reached (Budy *et al*., 2020). Stream temperature was also measured in this study, however, the lack of connectivity in wetted portions of the stream suggests that discharge had a stronger influence on fish movement during the period of study. A number of fish were found to have dispersed into the uppermost section of the study reach, which had previously been dewatered during the low-flow period. Although trout may have been moving among habitat types between scanning events or even within the same day (Hilderbrand and Kershner, 2000), the exclusive detection of tagged fish in pools until early September, suggests that fish began to utilize new habitat types (i.e., riffles and glides) as areas of the stream that were previously too shallow to inhabit became available. Consequently, habitat availability is an important factor to consider, especially in small streams, because fish may occupy a certain habitat type or location based on preference, or out of necessity (Heggenes *et al*., 1991). Although the amount of physical cover in the stream was not quantitatively measured in this study, fish were regularly detected near undercut banks, logs or other natural refugia, emphasizing the importance of available cover as another driver of cutthroat trout habitat selection (Penaluna *et al*., 2020).

In this study, the distances fish travelled between scanning events were assumed to be reflective of their overall movement. However, it is possible that fish were moving to a greater degree between scans and then returning to where they had been detected during a previous scan (Hilderbrand and Kershner, 2000; Gresswell and Hendricks, 2007). Hilderbrand and Kershner (2000) found radio-tagged stream-resident cutthroat trout moved frequently during a day, but if movements were observed on a weekly scale, they appeared considerably reduced by comparison. Increasing the frequency of mobile scans during high-flow conditions in future studies would help to reduce the uncertainty associated with movement frequency. Additionally, lengthening the period of study would provide more insight into the patterns and complexity of fish movements during higher flows, such as whether longer distance movements (> 200 m) continued to be common into late fall and winter, or if trout that had moved upstream became sedentary after a short period of dispersal (Huusko *et al*., 2007). In addition, incorporating mobile scans of the reach immediately below the study area would help to verify the efficiency of the stationary array and whether the tagged trout had migrated downstream prior to its operation.

Concluding Remarks

During the period of study, the majority of PIT-tagged cutthroat trout in upper Shelly Creek remained within the small reach that was studied. Fish movement during the low-flow period appeared to be very limited by seasonally impassible barriers, likely created in part by the natural morphology of the stream (i.e., step-pools) and further heightened by sediment and debris that has been carried downstream by high-flow events (Law *et al*., 2016). Increasing the connectivity between pools, and preserving the groundwater sources to ensure critical residual pool depths are maintained such that they provide viable refugia for fish during low-flow periods would undoubtedly contribute to sustainable cutthroat trout populations in upper Shelly Creek. The results also suggest that the trout in Shelly Creek do utilize different habitat types in the context of varying flow conditions, which emphasizes the importance of maintaining habitat heterogeneity in small urban streams to support healthy resident salmonid populations (Naman *et al.*, 2018; Budy *et al*., 2020). It is evident that cutthroat trout can inhabit and rely on relatively small stream reaches quite extensively, particularly during sensitive periods of the year, suggesting that in addition to whole stream-scale enhancements (Gresswell and Hendricks, 2007), urban stream-resident cutthroat trout populations may also benefit from local, site-based restoration projects.

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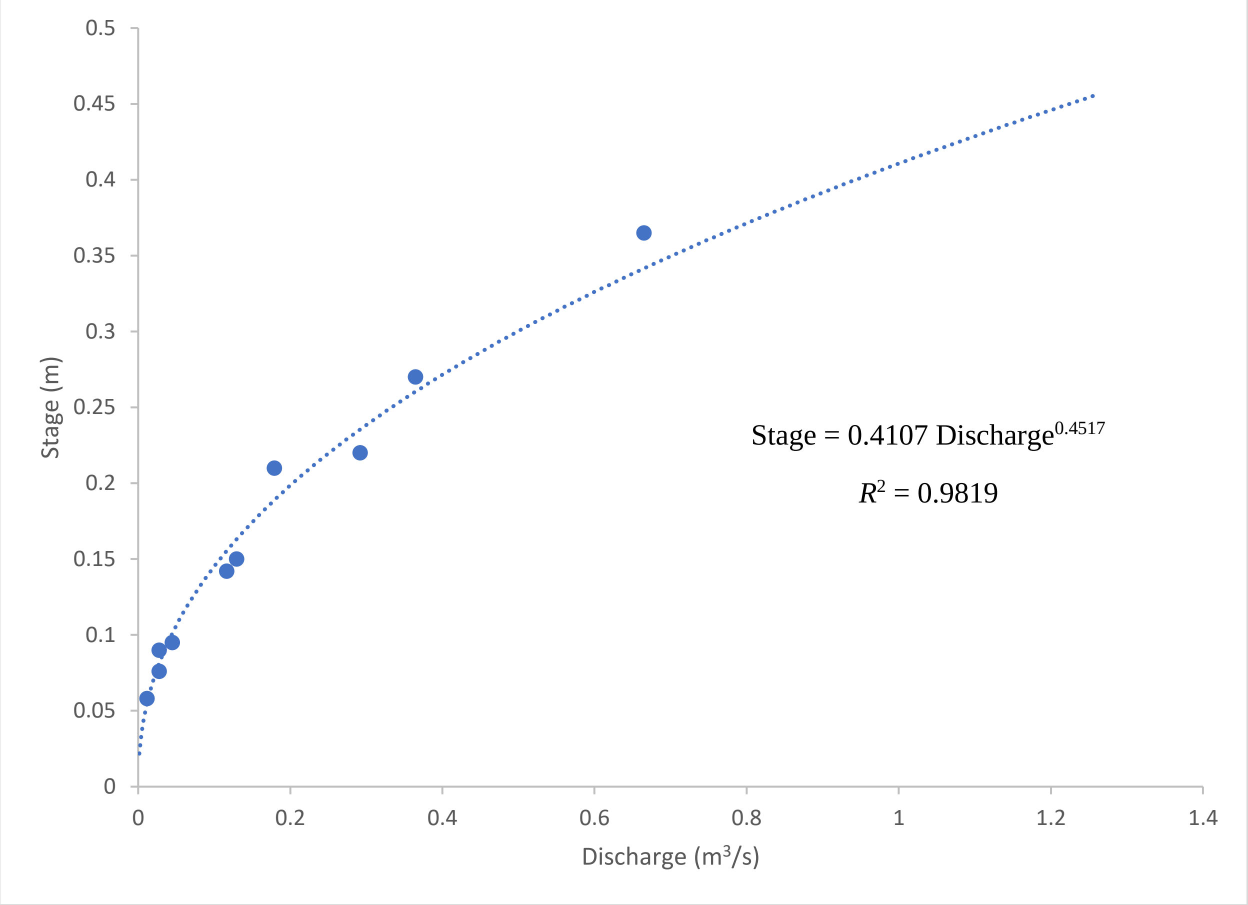
APPENDIX



Appendix A. The rating curve model used to estimate stream discharge in an upper reach of Shelly Creek, Parksville, BC. This curve was produced by plotting stream depth (stage) levels recorded by a Levelogger against discharge measurements collected using a Flowtracker1. The depth-discharge relationship determined by this model was used to estimate stream discharge throughout the period of study.