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The Survival and Growth of Adult Bonneville Cutthroat Trout (Oncorhynchus clarkii utah) in Response to Different Movement Patterns in a Tributary of the Logan River, Utah

Jared W. Randall
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SURVIVAL AND GROWTH OF BONNEVILLE CUTTHROAT TROUT (*ONCORHYNCHUS CLARKII UTAH*) USING DIFFERENT MOVEMENT PATTERNS IN TRIBUTARIES OF THE LOGAN RIVER, UTAH

by

Jared W. Randall

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Fisheries Biology

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UTAH STATE UNIVERSITY
Logan, Utah

2012
ABSTRACT

The Survival and Growth of Adult Bonneville Cutthroat Trout (*Oncorhynchus clarkii utah*) in Response to Different Movement Patterns in a Tributary of the Logan River, Utah

by

Jared W. Randall, Master of Science
Utah State University, 2012

Major Professor: Dr. Chris Luecke
Department: Watershed Sciences

I evaluated movement patterns, survival and growth of adult Bonneville cutthroat trout *Oncorhynchus clarkii utah* in two tributaries of the Logan River in Northern Utah. My objectives were to detect movement patterns and compare survival and growth rates among trout exhibiting different movement patterns. In this study area both resident and fluvial (migrating between tributaries and main-stem river) life history strategies were observed. Significant differences were found in seasonal movement as movement was highest during spring and fall. No significant difference in growth was present between resident and fluvial groups of fish or between fish exhibiting other movement patterns. Survival rates were lowest during the summer for fluvial individuals. My results support the findings that adult cutthroat trout can be mobile or sedentary and that fluvial strategies exist in a population. Management
efforts should focus on protecting and enhancing connectivity between tributaries and mains-stem habitats.
The Survival and Growth of Adult Bonneville Cutthroat Trout (*Oncorhynchus clarkii utah*) in Response to Different Movement Patterns in a Tributary of the Logan River, Utah

By

Jared W. Randall

In the past many inland trout species were believed to be sedentary, only occupying small stream segments (20 meters) during their life span. Recently it has been found that cutthroat trout do move and many populations do contain both mobile and non-mobile strategies. Most organisms move to attain greater growth rates, but movement also leads to higher detection by predators. Both mobile and non-mobile strategies have been observed in Spawn creek, a tributary of the Logan River in Northern Utah. My research evaluated the movement patterns, survival, and growth of adult Bonneville cutthroat trout *Oncorhynchus clarkii Utah*. My objectives were to compare survival and growth rates among trout exhibiting different movement strategies (mobile and non-mobile).

To accomplish my objectives I marked trout with Passive Integrative Transponder (PIT) tags that can be electronically detected with waterproof antennas. I followed the movements of 491 cutthroat trout from June 2009 to September 2010 to determine movement strategies.

I detected seasonal movement patterns and found that movement was highest during spring and fall. No difference was detected between growth rates of mobile and
non-mobile groups of trout. While mobile strategies were not found to increase growth rates they did lead to higher mortality during summer months.
I would like to acknowledge Brett Roper and Chris Luecke for their dedication to this project, their desire to see it succeed, and for seeing potential in me as an undergraduate student. Brett and Chris also provided me with many hours of their time, much needed encouragement, and great insight and instruction.

A big thank you goes to Frank Howe who provided me with many useful ideas in all aspects in completing this work especially by providing insightful edits. I would like to also thank Phaedra Budy, Robert Al-Chockhachy, Peter MacKinnon, Gary Theide and Tracey Bowerman for their help, ideas and being a big part in the success of this project.

Funding for the project came through both the U.S. Forest Service and the Utah State University College of Natural Resources Watershed Department. I am extremely grateful for help with the field work of this project by talented and dedicated technicians Colin Cook and Erika Tollitson Hopkins. Lastly, I would like to dedicate this work to my supportive wife and two children. They provided me with love, motivation, encouragement and helping me to stay positive through many of the difficulties in finishing this work.

Jared W. Randall
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CHAPTER 1

INTRODUCTION

The rates of both growth and survival are parameters that contribute greatly to the overall reproductive success and fitness of an organism (Williams 2002; Biro et al. 2006). Growth is closely tied to fitness and is often used as a substitute for fitness given the challenges of measuring reproductive success. (Lima 1998; Lind and Cresswell 2005).

Certain movement behaviors can be highly related to the rates of growth and survival and the tradeoffs between the two, as indicated by Werner and Anholt (1993):

Searching for and harvesting resources requires movement for most animals. Movement however, usually increases encounter rates with or detection by predators. These relationships lead to a fundamental trade-off between growth rate and risk of predation as functions of activity level.

One good example of movement and the potential tradeoffs between growth and survival can be found in the life history characteristics of salmon and other anadromous fish species. Juvenile anadromous salmonids leave inland waters and undertake a long migration to the ocean only to return again as adults to reproduce. Long migrations lead to a lower survival rates, but individuals use vast ocean resources in an effort to maximize their rate of growth.

Unlike most anadromous salmonids, inland species exhibit a variety of complex movement and life history strategies including: stream residents (spend entire life within relatively small stream reaches); fluvial (migrate from large main-stem rivers to smaller streams to spawn); adfluvial (migrate from lakes to inlet or outlet streams to spawn); and lacustrine (spend entire life within lake environment) (73 FR 52235, 2008).
In some instances multiple life history strategies have been found within a single population.

The variation in life history and movement strategies observed in inland salmonids leaves many unanswered questions. Are there any differences in survival and growth between different movement and life history strategies found within a single population? Why would some individuals choose to be residents of a stream while other individuals migrate to larger habitat in main-stem rivers? My thesis addresses these questions by first attempting to indentify movement strategies and second by comparing measures of growth and survival among different movement strategies.

In Chapter 2 I describe the movement patterns expressed by cutthroat trout in two tributaries of the Logan River in northern Utah. Movement strategies are identified along with seasonal patterns of movement.

In Chapter 3 I examine the growth rates of cutthroat trout and compare the growth of different movement strategies. I also describe how both movement and body size are linked to growth rate of individuals. I also describe how survival of individuals varies with movement strategies and season for this population of cutthroat trout.

Finally I describe how my study contributes to our knowledge of inland salmonid movement and how these findings are useful for the management of salmonid populations. The high degree of movement demonstrated by cutthroat trout in the tributaries of the Logan River indicate that management of these populations must occur at the watershed scale and that barriers to movement will impact the population
structure of these fish. These findings are relevant to the many populations of inland trout species throughout the intermountain region of North America.

REFERENCES

12-Month Finding on a Petition To List the Bonneville Cutthroat Trout as Threatened or Endangered, 73 Fed. Reg. 52235 (Sept. 9, 2008) (to be codified at 50 C.F.R. pt. 17).


CHAPTER 2

MOVEMENT STRATEGIES AND FACTORS INFLUENCING MOVEMENT OF CUTTHROAT TROUT IN TRIBUTARIES OF THE LOGAN RIVER

INTRODUCTION

The movements of organisms occur at different spatial scales and for different reasons. Variation of individual movement in a population can be influenced by factors such as: density, size and condition, food, habitat, cover and migration (Behnke 1992; Gresswell et al. 1997; Young et al. 1997; Hughes 1998; Boss and Richardson 2002).

Variation and spatial distribution plays an important role in the fitness of cutthroat trout populations through tradeoffs between growth and survival (Lind and Cresswell 2005; Neville et al. 2006; Berger and Gresswell 2009). Movement patterns of cutthroat trout help explain the ecology of the species including important aspects such as: energy transfers; connections between source and sink populations (Hall 1972; Schlosser 1995); longitudinal patterns of size (Hughes and Reynolds 1994); and patterns of age segregation in stream systems (Hughes 1998; Rodriguez 2002).

Bonneville cutthroat trout (Oncorhynchus clarkii utah) is one of fourteen subspecies of cutthroat trout (O. clarkii ssp.) recognized in North America. Currently two of these subspecies are extinct, three are protected under the Endangered Species Act (ESA), and five are being monitored by state and federal agencies as a sensitive or threatened species (Behnke 2002). Bonneville cutthroat trout are in this last category,
listed as a sensitive species (Behnke 2002). Conservation concerns for this subspecies have occurred following extensive habitat modifications due to anthropogenic activities (Behnke 2002). At present Bonneville cutthroat trout occur in only about 35% of their historical range (Gresswell 1988; Behnke 1992; Behnke 2002). Through the creation of dams and water diversions many waterways have lost connectivity among formerly linked tributaries. Grazing, timber harvest, recreation and other management activities have further fragmented and/or degraded habitats. Loss of connectivity and poor habitat quality has been found to alter natural movement strategies and patterns such as migrations within cutthroat populations (Behnke 2002; Fausch et al. 2002).

Studies of mobility and migration in many species of inland salmonids have produced varied and somewhat contradictory generalizations about trout movement patterns. Most adult, inland, stream dwelling salmonids were initially regarded as sedentary (Gerking 1959). Gerking (1959) found evidence that most inland salmonids hardly moved during the course of their lives, living in short segments of streams (20 to 50 m). This sedentary lifestyle has been referred to by Gerking (1959) as, “Restricted Movement Paradigm” (RMP). Many have disputed the RMP and recent studies suggest that inland salmonids, including cutthroat trout, are mobile and can exhibit a range of movement distances (Gowan et al. 1994; Rodriguez 2002; Schrank and Rahel 2004; Colyer et al. 2005). Similar research has found that within a single population of cutthroat trout individual movement can range from a few meters (sedentary) to kilometer scales (mobile) (Hilderbrand and Kershner 2000a; Rodriguez 2002; Schrank
and Rahel 2004; Colyer et al. 2005). Distance of movement by marked individuals has been found to change between years and be dependent on the size and condition of the trout (Hilderbrand and Kershner 2004). Rodriguez (2002) found that while potential for multiple movement strategies exists, on average movement distances fall within 50 meters or less for many salmonid populations.

When a significant portion of a predominantly sedentary population exhibits large movement distances a leptokurtic distribution can occur. Leptokurtosis is characterized by an acute peak around the mean with one or more large tails. Leptokurtic distributions are commonly found in studies of animal activity and have been attributed to heterogeneity in movement behavior within a population (Skalski and Gilliam 2000; Fraser et al. 2001; Hansson et al. 2003; Lowe 2010).

Little information has been collected on how two movement strategies (mobile and sedentary) benefit growth and survival and the possible tradeoffs between choosing one over another. Thus an effective assessment of cutthroat trout movement strategies and their impact on population structure is a vital piece in understanding the biology of cutthroat populations. (Hilderbrand and Kershner 2000b; Fausch et al. 2002; Colyer et al. 2005; Budy et al. 2007b).

The goal of this study is to assess movement strategies and patterns exhibited by a population of adult cutthroat trout in a tributary of the Logan River. The objectives developed to meet the goals of this study are: 1) estimate total movement, consecutive movement distance, and specific movement strategies of individual cutthroat trout
within a tributary of the Logan River; 2) to determine if patterns in timing of movement are present; and 3) to determine if movement patterns are related to biotic or abiotic factors.

METHODS

Study Area

The study area is within the Logan River drainage which is part of the Bear River watershed located in southeastern Idaho and northeastern Utah. Research efforts focused on Spawn Creek (a tributary of Temple Fork), Temple Fork (a tributary of the Logan River), and four sites found in the upper section of the Logan River near the confluence with Temple Fork (Figure 2-1). This study area is ideal as it contains one of the largest remaining populations of Bonneville cutthroat trout in its historic range (Budy 2007a). The area has also been found to contain a population of fluvial (migration of adults from the Logan River into tributaries to spawn) cutthroat trout (Bernard and Israelsen 1982; Budy et al. 2007b). Connectivity in the study area has remained intact allowing both migrations and short term movements to and from the main-stem of the Logan River to Temple Fork and Spawn Creek.

Temple Fork is located approximately 26 km from the mouth of Logan Canyon and Spawn Creek is located (1.63 km) upstream of the mouth of Temple Fork. Both streams hold vital habitat for cutthroat in the Logan River drainage. Each stream is perennial and primarily spring fed with contributions from runoff in the spring. Both
streams consist of two main types of habitat; lotic (riffle, run, pool) and lentic (beaver ponds). Temple Fork and Spawn Creek are approximately 10 km and 6 km in total length respectively. The average slope or gradient of Temple Fork and Spawn Creek is reported as 3.9% and 7.5% respectively (Fleener 1951; Hansen and Budy 2011). The average discharge (2007-present) recorded at the confluence of each stream was 0.59 \( m^3/sec \) in Temple Fork with a range of 0.39 to 2.85 and 0.13 \( m^3/sec \) in Spawn Creek with a range of 0.06 to 0.36. Average daily temperature and average minimum / maximum temperature in Temple Fork (2007-present) are, respectively, 5.4 \( ^\circ C \) and 3.4 / 8.5 \( ^\circ C \). Average daily temperature and average minimum / maximum temperature in Spawn Creek (2007-present) are respectively 6.1 \( ^\circ C \) and 3.9 / 9.5 \( ^\circ C \). During the winter conditions anchor or frazil ice was observed in Temple Fork but not Spawn Creek.

Vegetation in the riparian areas of both streams is dominated by grasses, sedges \((Carex sp.)\), riparian shrubs dominated by willow \((Salix sp.)\), and riparian trees mostly aspen \((Populus sp.)\). Grazing has occurred historically and presently continues in the riparian and upland areas near each stream. Beaver activity is high on both streams and ponds are extremely dynamic in space and time creating a mosaic of habitat features. Features created from beaver activity include: large ponds, meadows, and overland flow. Overland flow caused by beaver structures occurs mainly during spring run-off and contributes greatly to side channel habitat.

In 2005 a fence was built around the riparian zone of most of Spawn Creek to restore these areas from the negative effects of livestock grazing (Budy 2007a; Hansen
and Budy 2011). Temple Fork was not fenced and remains open to the effects of grazing. Both streams have and continue to experience considerable degradation related to recreational use such as Off Highway Vehicle (OHV) roads, hiking trails, horseback riding, dispersed camping and angling. In the past 30 years restoration efforts on Temple Fork aimed at creating larger buffers from the stream with respect to roads and trails. Current road crossings consist of bridges and culverts. In the late 1800’s an active saw-mill was located near the head of Temple Fork and timber harvesting was extensive in the upper portions of the stream.

Three salmonid species are found within the study area: cutthroat, Brown trout (*Salmo trutta*), and Brook trout (*Salvelinus fontinalis*). Cutthroat trout are found throughout all waterways in the study area. Brown trout are present throughout the Logan River sites and Spawn Creek, but are limited to only the lower portions of Temple Fork. Brook trout are found only in upper portion of Spawn Creek and at only one of the Logan River sampling sites (Franklin Basin). Other species found at all of the Logan River sampling sites include: Mountain whitetout (*Prosopium williamsoni*) and Mottled sculpin (*Cottus bairdi*).

Capture Recapture and Tagging

Three capture/recapture sampling periods occurred each summer during 2008, 2009 and 2010 from late July to early September. Trout were sampled in approximately 2.2 km of the lower portion of Spawn Creek starting from its confluence with Temple Fork. Temple Fork was also sampled starting from its confluence with the Logan River to
approximately 4.7 kilometers upstream. Sampling also occurred at four upper Logan River sites (Twin Bridges, Forestry Camp, Red Banks, and Franklin Basin) described in Budy et al. (2007b). Electrofishing was the principle sampling method and was completed using a backpack electroshocking device (Smith-Root LR-24) within the streams and a canoe mounted device (Smith-Root Streambank Generator Powered Pulsator) was used in the main-stem of the Logan River. Angling was used as an alternate capture method during spawning periods and occurred randomly during the mid to late summer months (July, August) from 2008 to 2010.

Single pass electrofishing sampling for each tributary occurred daily until full stream reach segments were completed (2.2 to 4.7 km). Sampling the full reach segments in the streams typically lasted around a week or two weeks per stream. Effort was made to limit multiple recaptures on individual trout. I attempted to reduce impacts of electricity on spawning trout, eggs, and fry by avoiding spawning habitat and reducing the duration of sampling to exclude peak spawning times (Dwyer and Erdahl 1995). Voltage on the electro-shocking equipment ranged from 300 to 400 V DC and was adjusted when needed to reduce stress or increase stunning effects. Locations were recorded with a global positioning system (GPS; GARMIN etrex Legend HCx) with accuracies ranging from 1 to 7 meters. Locations were paired with each individually tagged trout at time of re-sighting or recapture. This was done by isolating captured trout into unique groups each associated with a single capture location consisting of GPS coordinates.
Quantifying abundance is a part of the long-term monitoring project by the Utah State University ecology lab, and as such a three pass depletion method was used at each Logan River site. Sampling at these sites took place during one single day using seine netting as a block net enclosing a 300 meter section for sampling. GPS locations for the Logan River sites consisted of a midpoint taken in the middle of each 300 meter section. Movement accuracy within these sites is limited to 300 meters as individual cutthroat location was not observed. This method has limited the precision of fine scale movement patterns to 300 meters in the Logan River sites.

Total length (TL) in millimeters and weight (grams) was recorded on all captured trout. Adult cutthroat trout above 150 mm (adults) were captured and tagged in 2009 and above 100 mm in 2010, to reduce possible mortality associated with surgically implanting Passive Integrative Transponder (PIT) tags. PIT tags (12mm) were placed in the dorsal musculature to the right of the dorsal fin following the methods of Dieterman and Hoxmeier (2009). Tag placement in the dorsal musculature reduces tag loss and improves detection by antennas (Dieterman and Hoxmeier 2009). The adipose fin was also removed from all tagged trout as a secondary marker to detect possible tag loss. Trout measured, tagged or handled in any way was anesthetized using FINQUEL MS-222 (Tricaine Methanesulfonate) when needed to reduce stress. Any trout showing signs of excess harm following electrofishing, was in most cases measured and released without implanting a tag. Following processing, captured trout were placed in shaded revival bins located in the stream to insure recovery from sampling effects before release.
Recovered trout were released in the same location as initial capture. In some cases adult trout captured at the Logan River sites received both a PIT tag and an external Floy tag.

Re-Sighting and Movement

During the course of this study three different methods were used to re-locate trout following initial capture; recapture, active re-sighting, passive re-sighting events. Re-sighting events differed from recaptured events because no trout were handled during these sampling events. Active re-sighting consisted of a mobile PIT tag reader (Biomark FS2001F-ISO) employed along with a mobile antenna (Biomark BP PorTable antenna) designed to detect PIT tagged trout in the streams. A set consisting of a reader and antenna was sufficient for Spawn Ck. whereas two were needed in Temple Fk. as it is significantly wider. The mobile reading equipment was synced to GPS equipment providing individual PIT tag information, date and time, and location. Again GPS accuracy during re-sighting events ranged from 1 to 7 m. Detection methods consisted of moving antenna in a zigzag motion changing direction upon reaching the bank or edge of water. If a trout was located without visual confirmation, attempts were made to determine if the tagged trout was actually live, dead, or if the tag had become detached. These attempts consisted of probing substrate, undercut bank or debris at location where tag was relocated. Trout with total movement (summed consecutive movements) of less than 10 meters for the entire study period were reassessed, in a separate re-sight event to verify status (live trout, dead trout, or shed tag).
Re-sighting events took place once a month at both Spawn Ck. and Temple Fk. locations. During spawning (May-July) the active antennas were used from the bank to limit disturbance and trampling of the stream bed. Mobile events occurred for the same segments described above (see Capture Recapture and Tagging) and occasionally exceeded the segments going further upstream during summer months. Re-sight events were not attempted in the main-stem of the Logan River.

The in-stream stationary readers (Biomark FS1001M multiplexing reader) and antenna arrays were used separately from the mobile units at three locations within the study area (Figure 1). These stationary readers allowed continuous collection of data and provided, time/date, location, and direction of movement. The stationary readers were powered by a combination of solar power and deep cycle 6V batteries for the entire study period (June 2009 to Sept. 2010). The first stationary antenna was installed into Spawn Creek just above the confluence of Temple Fork in mid-May 2009. A second stationary antenna was placed into Temple Fork just above the confluence of Spawn Creek in mid-July 2009 (Biomark FS2001F-ISO). The last stationary antenna was installed in Temple Fork just above the confluence with the Logan River in mid-October 2009. Test tags were used to test detection efficiency of every stationary antenna array. Relocating trout through various methods and multiple discrete events and continuous data allows for a more complete assessment of trout movement behavior.
Movement Analysis

A unique record was created for every encounter with each individual trout. When multiple encounters were observed in the space of one month by an individual and no movement occurred, then only one record was included per month. When significant movement was observed by an individual between encounters then multiple records were included, one per month for any method of encounter (active antenna, passive antennas, electroshocking, and angling).

The quantification of movement was accomplished with ArcMap and the Arc Toolbox using the linear referencing tools (ArcGIS 9.2 software). The two streams and Logan River were represented as lines (polyline shapefile), and routed (Linear Referencing tools; create route) starting at their mouth. Routing the streams allows the points (point shapefile) from capture, recapture, and re-sightings to be measured along the linear stream shapefiles (Linear Referencing Tools; locate feature along route) as if it was a ruler. Once points were snapped to the shapefile polyline the difference in the measurements from the first encounter to the next defines a single consecutive movement distance (Table 2-1).

Consecutive movement is each movement distance from one location to another. Consecutive movement consists of both negative (downstream) and positive (upstream) movement. The sum of each consecutive movement distance (absolute value) gives the total movement distance. Average movement was calculated by taking the averaged absolute values of consecutive movement distances (see e.g. in Table 2-1).
Frequencies of consecutive movement distances (both upstream +, and downstream -) were plotted to determine any evidence of a leptokurtic distribution. The frequency plot and Average Consecutive Movement (ACM) was used to create the three different movement classes. Movement was classified into classes of sedentary (S) (ACM < 100m), mobile (M) (100m < ACM < 500m), and very mobile (VM) (ACM > 500m). Classification was also made between trout remaining in the stream of initial capture (Resident) and trout that left the stream of initial capture (Fluvial) moving greater than 500 meters. The relationship of TL to movement classes (S, M, and VM) was tested using an analysis of variance (ANOVA) to determine if size is a factor in trout movement.

Temporal factors effecting movement such as seasonal or monthly changes in environmental conditions were also assessed. Only the largest consecutive movement distance for each individual trout occurring within a single season was used. Seasonal groups consisted of: Winter (Dec.-Mar.); Spring (Mar.-May); Summer (June-Aug.); and Fall (Sep.-Nov.). Using the four seasonal groupings makes a total of five seasonal factors (S-2009, F-2009, W-2009/2010, Sp-2010, and S-2010). An ANOVA between average movement and these five factors was used to ascertain patterns in movement in relation to seasons. Upon finding significance a post hoc analysis (Tukey) was used to determine specific differences between seasons. A Chi Squared test was used in conjunction with the ANOVA to further explain differences among movement classes and seasonal factors using a contingency Table.
Monthly movement was quantified using only the continuous data from the stationary antenna arrays and only those trout captured from ’08 and ’09. All statistical analysis will be completed using R statistical software (ver. 2.1).

RESULTS

In total, 972 cutthroat trout were tagged and 520 were either recaptured or re-sighted one or more times during the study period. Of the 520 individuals 491 were relocated at least once in Spawn Creek or Temple Fork. Only the 491 cutthroat trout captured in the streams were used to analyze movement patterns. Encounters for each individual cutthroat ranged from 2 to 15 with a mean of 4 and median of 3. Consecutive movement distances ranged from less than 5 meters to just under 14 kilometers. During the study period a total of 2326 individual records were collected each with a unique geographic location (Table 2-1). Sedentary (S) trout (ACM <100 meters) consisted of 289 individuals, mobile (M) trout (100 ≤ ACM < 500 meters) consisted of 111 individuals, and very mobile (VM) trout (500 meters ≤ ACM) consisted of 91 individuals.

The frequency distribution of consecutive movement distances of upstream (positive) and downstream (negative) movements were plotted (Figure 2-2). A Shapiro-Wilk test of normality indicated a very large deviation from normality (W = 0.444, p-value ≤ 0.00). The frequency distribution plot of consecutive movement distances provides clear evidence for a leptokurtic distribution (Figure 2-2) (Kurtosis Value =
A leptokurtic distribution would suggest heterogeneity in movement strategies (Skalski and Gilliam 2000; Fraser et al. 2001).

From the 2326 total individual encounter records only 432 maximum consecutive movement distances were estimated within a single season. Mean total movement distance was highest during Spring-2010 (491m ±102m Standard error (SE)) and lowest during Winter-2009/2010 (57m ±21m SE) (Figure 2-3A). Differences in maximum consecutive movement distance in relation to season confirmed significance (p-value ≤ 0.003) (Table 2-2). Sp-2010 along with S-2009 was found to be significantly different from W-2009/2010 while all other seasons were not significantly different (Table 3).

Differences among seasonal movement patterns were likely influenced by spawning migrations. Mean upstream total movement was highest in Spring-2010 (628m ±110 SE) (Figure 2-3B). When the year effect is removed from seasonal factors mean downstream total movement was greatest in the Fall (using data from both 2009 and 2010) (459m ±76 SE).

Examination of monthly movement patterns using stationary antennas array data also demonstrated an increase of activity during spring and fall (Figure 2-4). The peak in antennas activity comes during May, with an increase in activity in October as well. Movement of individual cutthroat trout was predominantly upstream in the spring and predominantly downstream in the fall.
Mobility was influenced by size ($p$-value < 0.001). Post hoc analysis revealed that the VM individuals were different from both mobile and sedentary. The mean of TL is larger as movement increases represented by mobility classes (Figure 2-5). When a box-plot comparison was used it was also apparent that mean TL was smaller in Spawn Creek than in Temple Fork.

Individual Movement and Patterns

Examination of records found in trout within the very mobile movement classes presented interesting patterns. One pattern utilized by multiple trout was a homing behavior where they returned to the same location (±100 meters) in successive summers (Figure 2-6). In total 41.3% or 33 of 80 very mobile trout exhibited this pattern. The mean difference of the two locations the trout were found returning to was 18.87 meters with a median of 11.27 meters, and ranged from less than 7 to 85 meters (Figure 2-6). A similar analysis was not possible for fall, winter, or spring seasons as only one year of data was collected for these seasons.

DISCUSSION

My results contribute to the growing evidence that a single Bonneville cutthroat trout (BCT) population may contain both mobile and sedentary individuals (Rodriguez 2002; Coyler et al. 2005). The results of my study found a larger proportion of mobile individuals than is commonly found in other similar studies (Rodriguez 2002). While most movement was classified as sedentary a good portion of this population (22%)
consisted of mobile and (19%) very mobile individuals. Significant portions of both mobile and sedentary groups is consistent with recent studies on stream dwelling fishes that were also found to have a leptokurtic distributions (Skalski and Gilliam 2000; Fraser et al. 2001; Lowe 2010). Finding a larger proportion of mobile individuals than expected may be a result of the method (ACM) for classifying individuals. More research is needed to clearly determine the proportion of mobile individuals within a population of BCT.

Most of the very mobile BCT were found to exhibit fluvial traits such as: emigrating both between streams (SC & TF); and in and out of the mainstem (Logan River). Upstream peak movement activity was observed during the Spring, downstream during the late Summer/Fall, and all movement was greatly reduced in winter. These temporal patterns are consistent with Bernarnd and Israelsen’s (1982) comments, where they stated, “Tributaries are used as spawning and rearing areas, and mainstem rivers for growth and maturation”. Improvements in sampling design along with technology allowed me to determine not only fluvial behaviors, but also residents within this population. More work is needed to determine what environmental conditions (hydrology, temperature, photoperiod) may trigger or influence these behaviors. The identification of multiple life history strategies and habitat usage of a population demonstrates the importance of maintaining connectivity between habitat types.

As stated above, Rodriguez (2002) found evidence that on average movement distances of inland salmonid populations were 50 meters or less. My results were similar
to Rodriguez (2002) in that I found that on average the consecutive movement distances were 100m or less. Slightly imprecise GPS accuracy and the possibility of herding individuals led me to use 100 meters when classifying individuals as sedentary. Many GPS points did not fall on top of the (shapefile, polyline) stream layers. Points were snapped (moved) to the layer using the closest distance between the two features leading to even more loss of accuracy. I was able to observe the herding of a small portion of individuals seeking refuge in upstream pool habitat. On average movement of these few individuals was 25 meters or less.

As in other studies larger cutthroat trout were found to move further on average than smaller trout of the same species (Gowan and Fausch 1996; Hilderbrand and Kershner 2004a). Body size is important in determining the ability of trout to move against currents and to acquire resources while avoiding predation. Peak flows in the spring may also be hindering smaller individuals in their efforts to move upstream to spawning areas. Potential differences in mortality may influence our comparison of movement patterns of different sized trout.

The return of trout to previously occupied reaches during the summer suggests that trout are selecting distinct summer or post spawning recovery habitats. Evidence of high site fidelity has been found in previous studies with cutthroat trout where sampling occurred solely during summer months (Budy et al. 2007b). Some of these studies have likened high site fidelity with sedentary behaviors (Gerkin 1959). These results show that site fidelity may not always equate to sedentary behavior.
Post-reproductive homing and feeding behavior has been reported previously (Baras 1992; Parkinson et al. 1999; Lucas and Baras 2001). This homing behavior suggests that tributaries can provide spawning, rearing, and post-spawning foraging habitat for cutthroat trout. Post-spawning homing to a suitable foraging habitat implies a behavior that may be important for replenishing energy reserves prior to full migration back out to the main-stem of the Logan River. Our results suggest that tributaries provide vital habitat should be given more focus for habitat improvement projects and other similar management actions.

Another important movement observation seen in many cutthroat trout was movement around large beaver dams. In the course of this study 100 out of 492, or 20.3% of cutthroat trout passed around one or more major dam. One trout in particular moved out of Spawn Creek and up above all (6) large beaver dams on Temple Fork. A single large beaver dam on Temple Fork that posed no problems for some cutthroat trout seemed to be a barrier to Brown trout. During the course of this study brown trout were not found above this large beaver dam.
REFERENCES


Budy, P., E.S. Hansen, and G.P. Thiede. 2007a. Spawn Creek whirling disease study: evaluating the effectiveness of passive stream restoration for improving native trout health and minimizing the impacts of whirling disease. 2006 Annual Report to Utah Division of Water Quality (Non-point Source 319[h] Project, Environmental Protection Agency 310[h], Grant Number 061139) and to Utah Division of Wildlife Resources (Sport Trout Restoration. Grant number XIII. Project F-47-R). UTCFWRU 2007(3):1-46.


Table 2-1. An example of individual records for three unique trout, showing how each was classified into different movement factors (S=sedentary, M=mobile, and VM=very mobile). Consecutive movement was determined by taking the difference from the first location to the second. Under method ES=Electroshocking, and AA=Active antenna re-sighting.

<table>
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<th>Tag</th>
<th>Date</th>
<th>Method</th>
<th>Location on stream (m)</th>
<th>Consecutive Movement (m)</th>
<th>Absolute Value</th>
<th>Mean Movement (m)</th>
<th>Group</th>
</tr>
</thead>
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Table 2-2. ANOVA output of seasons VS. total movement. Significance is observed showing differences between seasons in relation to total movement.

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<th>F value</th>
<th>Pr(&gt;F)</th>
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</thead>
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Table 2-3. Tukey post hoc results from ANOVA model testing movement among seasons.

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<th>Treatments</th>
<th>Mean (m)</th>
</tr>
</thead>
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</tr>
<tr>
<td>a</td>
<td>S-2009</td>
<td>388.3964</td>
</tr>
<tr>
<td>ab</td>
<td>F-2009</td>
<td>236.7016</td>
</tr>
<tr>
<td>ab</td>
<td>S-2010</td>
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</tr>
<tr>
<td>b</td>
<td>W-2009/2010</td>
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Table 2-4. ANOVA of TL VS. Movement classes. Significance is observed showing differences between movement classes in relation to total length (TL).

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<th>F value</th>
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Table 2-5. Tukey post hoc results from ANOVA model testing TL VS. Movement Classes showing the differences between Movement classes.

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<tr>
<td>b</td>
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<td>222.614</td>
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<tr>
<td>b</td>
<td>S</td>
<td>221.526</td>
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</table>
Figure 2-1. Study area showing tributary of interest, antenna array locations, and direction of flow. (1) Just above the mouth of Spawn Creek; (2) Temple Fork just above the convergence with Spawn Creek; and (3) The mouth of Temple Fork. Only antennas arrays (1) and (2) are capable of detecting direction of movement.
Figure 2-2. Leptokurtic distribution showing every consecutive movement distance (+/-) for each trout (n=491) for the entire study period. Values at -800 include ≤ -800 and values at 800 include ≥ 800.
Figure 2-3. Comparison plot of Mean values by season. Values show the mean of each single consecutive movement made by a trout within a season (The largest value was used if more than one consecutive movement was observed by a trout). Plots include: (a.) Consecutive movement (without regarding direction); (b.) Downstream (-) consecutive movement; and (c.) Upstream (+) consecutive movement. W=winter (Dec.–Mar.), Sp=spring (Apr.–Jun.), S=summer (Jul. & Aug.), and F=fall (Sep.–Nov.). Error bars represent 95% confidence intervals.
Figure 2-4. Monthly antenna activity recorded as # of fish per month that passed only the antenna arrays 1 and 2 (see figure 1). Activity includes the direction of travel indicated by black signifying upstream and grey downstream.
Figure 2-5. Box plot comparison of TL by mobility classes separated by streams. TF=Temple Fk., SC=Spawn Ck., S=Sedentary, M=mobile, and VM=very mobile.
Figure 2-6. Highly mobile cutthroat trout showing high site fidelity for a particular location following spawning. MEAS is the location (meters) along a routed stream layer where encounter occurred and numbers show the sequence of capture.
INTRODUCTION

One important aspect of monitoring sensitive populations is assessing key population vital rates. Monitoring vital population parameters can help to determine fluctuations in population status and change over time. One obstacle in obtaining accurate population parameters is the variation in distribution and movement behavior of a population. Many studies on the movement of cutthroat trout have found that single populations may contain both sedentary and mobile individuals (Bernard and Israelsen 1982; Brown and Mackay 1995; Young 1997; Hilderbrand and Kershner 2000; Rodriguez 2002; Schrank and Rahel 2004, 2006; Colyer et al. 2005; Gresswell and Hendricks 2007; Sanderson and Hubert 2009). A lack of understanding the variations in movement within a population could bias parameter estimates (Hilderbrand and Kershner 2000; Colyer et al. 2005; Budy 2007), and provide misleading information on population trends.

Organisms have evolved behaviors that result in maximizing their individual fitness (Williams et al. 2002). Local movement behaviors can often be attributed to a balance of increasing foraging success while limiting predator encounters (Abrams 1990, 1991; Biro et al. 2003). Fitness of an individual is maximized through increasing
reproductive success while minimizing the chance of mortality. Individual growth is closely related to both reproduction and mortality (Williams et al. 2002). Measures of growth and survival are often used to evaluate the status of fish populations. Several studies have demonstrated a strong link between survival and growth and variation in migration, movement behavior and spatial distribution (Knight et al. 1999; Boss and Richardson 2002; Berger and Gresswell 2009).

Organisms have been known to forfeit growth in order to enhance survival and reproductive success. This tradeoff has been observed in anadromous salmonids which complete long migrations that allow for maximum growth increasing reproductive success, while decreasing the chance of survival (Biro and Stamps 2008). The costs associated with movement patterns of inland cutthroat trout are less well known but may help our efforts to preserve their populations.

Multiple foraging behaviors have been found in individuals of a single population of inland salmonids (Biro et al. 2003). Movement strategies related to foraging behavior are influenced by body size and the presence of predators. Both active and passive strategies for finding food have been reported (Grant and Noakes 1987; Werner and Anholt 1993; Biro et al. 2003). The results found in Chapter 2 show that individual cutthroat trout of a population of the Logan River can express both a mobile and sedentary strategy. Resident and fluvial strategies were observed where some cutthroat remained in the tributary and others migrate between the tributary and main-stem habitat.
Movement has not been studied extensively as a factor relating to the growth and survival rates of cutthroat trout populations. Understanding how growth and survival are effected by fluvial (migrate from large main-stem rivers to smaller streams) and resident (spend entire life within relatively small stream reaches) strategies are necessary to develop effective management plans for this species.

Habitat factors and their influence on growth has been studied extensively, although little is known concerning how movement strategies my influence growth (Wilzbach et al. 1986; McCullough et al. 2001; Grant and Imre 2005; Harvey et al. 2005). Less is known concerning the factors influencing rates of survival. Studies on inland salmonids have found lower survival rates associated with low flows (Carlson and Letcher 2003), reproductive stress (Petty et al. 2005), early life stages and severe winter conditions (Schindler 1999). Very little is known concerning the possible differences in survival and growth between groups of sedentary and mobile individuals in a single population.

The goal of this study is to determine how survival and growth influence movement strategies of cutthroat trout. The objectives developed to meet the goals of this study are: 1) estimate the rate of survival and growth from mark-recapture sampling; 2) to compare rates of survival and growth of cutthroat assigned to different movement strategies.
METHODS

Analysis of Growth

Sampling, capture and recapture events took place during the summers of 2009 and 2010. Sampling provided measurements of total length (TL) in cutthroat trout residing in Spawn Creek, Temple Fork, and nearby reaches of the main stem Logan River. The difference in length (recapture – capture) of each trout recaptured was used to estimate daily growth rates. Daily growth rates of individuals were calculated by dividing the differences in length by the number of days between captures. Only growth rates from cutthroat trout with approximately one-year interval between capture events were used.

During the summer of 2008 multiple angling events were conducted and 40 cutthroat trout were captured and marked. Through electro-fishing events seventeen of these were recaptured again in 2009 and two in 2010. During the summer of 2009, 489 trout were initially captured and 131 were recaptured in 2010 from electro-fishing events. Out of the 131 individuals, 12 were found to have negative growth rates in relation to TL. Negative growth was attributed to measuring error and/or low growth and negative values were modified to reflect values of growth rates of 0.00 mm/day.

Growth rates were modeled against movement patterns, a three level factor determined by average consecutive movement (ACM). Consecutive movement distance consists of the single distance moved between subsequent recapture or re-sighting events. ACM was calculated by averaging all of the Consecutive distances for each
individual cutthroat (chapter 1). The three factor levels consist of: sedentary (S) (ACM < 100 meters), mobile (M) (100 < ACM < 500 meters) and very mobile (VM) (ACM > 500 meters) (Table 3-1). Size is known to be a contributing factor to foraging behavior and therefore it was used as a covariate when comparing growth rates of differing movement strategies.

Growth rates were also modeled among individuals exhibiting different life history strategies (resident vs. fluvial), this was done separately from model of movement strategies (S, M, VM). In chapter two I found that cutthroat trout from the sedentary and mobile groups were not significantly different. These two groups were also very similar in regards to size (mean TL; 220 mm, 219 mm add standard error). These similarities lead me to merge the sedentary and mobile factor levels into one group for analysis of life history strategies. I defined the 3 new groups (life history strategies) as resident of Spawn Creek, resident of Temple Fork, and Fluvial. Residents (Spawn Creek and Temple Fork) were classified as never leaving the stream where they were initially captured and having an ACM distance of less than 500 meters. Fluvial were defined as having an ACM distance greater than 500 meters and moving between the main-stem and tributary habitat.

Growth rates were not normally distributed so they were transformed using a logarithmic (base 10) transformation. Following transformation models were formed and the top model was determined using Akaike Information Criterion (AIC). To test for significance between movement and life history strategies both an analysis of variance
ANOVA) and an analysis of covariance (ANCOVA) were used. Total length (TL) was the covariate in testing significance in the models. The alpha level was set at 0.05. Upon finding significance in the models, a post hoc analysis (Tukey) was used to determine how factor levels differed from each other. All of the statistical analysis and creation of graphical figures was completed using R (The R Project, Harnik 2011).

Analysis of Survival

Survival was estimated through three types of re-encounter events. These events consist of discrete capture/recapture, discrete re-sighting (both active sampling), and continuous re-sighting events (passive sampling). Capture/recapture events occurred as discussed above in the explanation of methods for analyzing growth. Discrete re-sighting events were completed monthly using a mobile PIT tag reader with antennas following procedures described in chapter one. Capture/recapture events were, for the purpose of modeling survival, synonymous with re-sighting events and both will be referred to from now on as discrete events. Continuous passive re-sightings were collected using three stationary antennas arrays also following procedure from chapter one.

Program MARK (White, version 6.1, 2011) was selected along with a Barker model (Barker et al. 2004) to estimate seasonal survival rates. Modeling survival using the Barker model suited the methods of this study best. The Barker model uses multiple sources of data (discrete and continuous events) to provide valid estimates of survival.
Re-sighting and recapture information was used to create an encounter history for each individual. An encounter history is a numerical code. Each encounter history consists of two digits: one digit representing a discrete event; and another digit for continuous data recorded during the interval between discrete events. Discrete re-encounter events provide information on whether an individual trout was detected and alive (recorded as 1) or not detected (recorded as 0) during each encounter event. The continuous type of re-encounter provides information on whether a trout was detected alive (recorded as 2), dead (recorded as 1) or not detected (recorded as 0) between the discrete events. Encounter histories consist of 16 encounters from June 2009 to September 2010 varying from 0.75 month, 1 month and 1.5 month intervals.

Using continuous data from stationary antennas provided information on migratory behavior and life history strategies as trout were recorded moving in and out of the study area. Information on movement allowed me to separate trout into three classes: residents of Spawn Creek; residents of Temple Fork; and fluvial cutthroat.

Resident cutthroat are classified as those that were never observed leaving the stream in which they were initially captured and having an ACM distance of less than 500 meters. Fluvial cutthroat are those that were found to leave the stream they were initially captured and having an ACM distance of greater than 500 meters. Once classified into two movement strategies (resident, Fluvial) survival across classes can be compared. Resident trout were compared across Temple Fork and Spawn Creek and against resident movement classes S, M, and VM. Comparing survival across both life
history strategies and movement behavior of resident trout provides insight in how survival may influence movement strategies between main-stem rivers and their tributaries.

Models were created to ascertain differences in seasonal survival between factors. A priori models focus on comparing factors such as season, age, and life history strategy (resident, fluvial). Recapture probability was modeled first while keeping survival constant. The best recapture model structure was then used to model survival (Lebreton et al. 1992). Akaike’s information criterion (AIC) was used to select the most accurate model. Model averaging will be used to account for uncertainty when selecting the best model.

RESULTS

Growth

Only 131 total cutthroat trout were recaptured during the second capture event (summer 2010) providing secondary measurements to determine growth rates. Of these 131, 20 were defined as being in the very mobile category, 57 were mobile, and 53 were defined as sedentary.

Growth rates of cutthroat trout in the three different movement patterns were not significantly different from one another (F-value=1.098, p=0.337); however very mobile individuals were generally larger than mobile and non-mobile groups (Table 3-1).
Differences in mean total length of each factor level were found, along with the observation that growth rates are strongly correlated with total length (Fig. 3-1).

The systematic variation in growth of different sized individuals may have overwhelmed differences in growth of trout in different movement categories. In addition to differences in growth among size classes, the location where individuals were captured also appeared to influence growth rates (Table 3-2).

Non-mobile and mobile individuals were similar in most measured characteristics. Of the Spawn Creek resident cutthroat, 19 moved less than one hundred meters during the study area and 13 moved greater than 100 meters without leaving Spawn Creek. The Temple Fork resident cutthroat consisted of 25 that moved less than 100 meters and 9 moved greater than 100 meters without leaving Temple Fork.

Growth rates of individuals from different life history strategies were significantly different when using total length as a covariate (Table 3-3). Very mobile strategies resulted in high growth rates for small trout and low growth rates for large trout. Sedentary strategies resulted in high growth for large individuals and low growth rates for smaller individuals. Resident individuals in Spawn Creek grew at a slower rate than did resident individuals in Temple Fork (Fig. 3-2).

Survival

Recapture probability and survival models were compared first across life history strategies with resident cutthroat from Spawn Creek (n=132) and Temple Fork (n=206) and Fluvial cutthroat (n=99). The top models for recapture probability included life
history strategies and time by season grouped into 3 levels: spring/summer (Apr.-Jul.); fall (Aug.-Nov.); and winter (Dec.-Mar.) (Table 3-4). The top models for survival included life history strategies (Spawn Creek; Temple Fork; and Fluvial) and time by season grouped into 4 levels: summer (Jun.-Aug); fall (Sept.-Nov.); winter (Dec.-Feb.); and spring (Mar.-May) (Table 3-5).

Using the top model, rates of survival were found to be generally higher for the very mobile life history strategy during fall through spring, but lowest during summer (Fig. 3-4). Survival rates were generally lowest for resident individuals found in Spawn creek (Fig.3-4). Survival rates were also highest during winter and lowest in the summer (Fig. 3-4).

DISCUSSION

Growth rates did not differ among individuals of different movement patterns or life history strategies. This conclusion is consistent with similar results found in growth rates of resident and mobile cutthroat in a tributary of the Logan River 15 km upstream. Hilderbrand and Kershner (2004) found that while condition was related to movement behavior, growth rates were not associated with movement. Many studies found a correlation between condition and movement strategy but not growth rate. Naslund et al. (1993) observed that resident Arctic char (Salvelinus alpines) had higher condition than those emigrating. Mobile brook trout (S. fontinalis) have also been found in poorer condition than the general population, and were generally larger than residents (Gowan
and Fausch 1996). While many studies found little impact of movement on growth rate, Kahler (2001) reported a correlation between movement and growth. His study indicated that mobile salmonids did grow faster than sedentary individuals. Potential problems with correlations between body size, movement pattern and growth rates makes these comparisons difficult to demonstrate.

In my study, size was found to be a better predictor of growth rate, than movement pattern or life history strategies. Size was also a good indicator of movement patterns as different size classes may be exhibiting different behaviors (very mobile, mobile, and sedentary). These results suggest that to maximize growth and ultimately fitness an individual should be mobile when young and switch to sedentary behavior as an adult (Fig. 3-2, Fig. 3-3). In both plots the data suggest that a switch in behavior may occur somewhere just before an individual reaches 250 mm (TL) (Fig. 3-3).

Higher survival by very mobile individuals may be attributed to an instinctive fall migration to winter habitat in the main-stem. Growth rates were found to be highest in the main-stem habitat in the Logan River. High potential for growth and more suitable habitat within the main-stem makes it an optimal choice during winter conditions. Migration to the main-stem habitat in the fall necessitates another migration back to the spawning grounds found in the tributaries in the spring.

Migration during the spring brings great risks to survival during the spring and summer months. The results from the Barker model show that fluvial cutthroat have higher mortality rates following spawning then residents. Higher mortality following
spawning from fluvial cutthroat shows that this strategy is very costly. Fluvial cutthroat trout observed during this study may incur higher mortality following spawning similar to anadromous salmonids.

A few important factors that were overlooked due to logistics include: habitat, competition/predation, trout density and handling/marketing stress.

It has been found that growth and movement are linked to habitat quality and availability (Kahler 2001). Suitable habitat conditions may be limited by many different anthropogenic activities found within the study area. Suitable habitat provides both food resources and a place of refuge from predation and if limited could severely impact growth. In areas where habitat degradation is severe, an increase in movement may be present in both mobile and sedentary strategies. Mobile individuals may experience enhanced competition for suitable habitat that has been reduced to limited patches.

Almost all of the study area contained at least one invasive species directly impacting native cutthroat through competition and predation. Invasive species also contribute greatly to overall trout density. High density can severely limit growth if densities are at or above carrying capacity in smaller streams such as Spawn Creek. Although density was not an objective of this study I found that trout densities for Spawn Creek and Temple Fork were 147/km and 136/km, respectively.

Gerking (1959) often explained low recapture probability due to handling and marking stress. While this clearly is not the largest contributing factor when considering recapture rates, I found a group of individuals did move great distances following
capture and tagging events. This was another reason why I chose to use Average Consecutive Movement (ACM) as a measure to categorize mobility.

REFERENCES


Table 3-1. Characteristics of individuals in three movement patterns. Sample size (N), mean TL (mm) and mean growth rate (mm/day) are shown. One standard error (SE) of each mean is also shown in parentheses.

<table>
<thead>
<tr>
<th>Movement Pattern (3)</th>
<th>N</th>
<th>Mean TL (+/- SE)</th>
<th>Mean Growth (+/- SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>53</td>
<td>248 (7.6)</td>
<td>0.058 (0.006)</td>
</tr>
<tr>
<td>Mobile</td>
<td>57</td>
<td>243 (5.8)</td>
<td>0.068 (0.007)</td>
</tr>
<tr>
<td>Very Mobile</td>
<td>20</td>
<td>261 (9.2)</td>
<td>0.051 (0.010)</td>
</tr>
</tbody>
</table>

Table 3-2. Factor levels of life history patterns used for modeling of growth rates.

<table>
<thead>
<tr>
<th>Life History</th>
<th>Site (3)</th>
<th>N</th>
<th>TL (SE)</th>
<th>Growth (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident</td>
<td>Spawn Creek</td>
<td>32</td>
<td>211 (6.0)</td>
<td>0.072 (0.007)</td>
</tr>
<tr>
<td></td>
<td>Temple Fork</td>
<td>34</td>
<td>262 (7.6)</td>
<td>0.065 (0.007)</td>
</tr>
<tr>
<td>Fluvial</td>
<td>2 or more sites</td>
<td>18</td>
<td>256 (9.3)</td>
<td>0.056 (0.010)</td>
</tr>
</tbody>
</table>

Table 3-3. ANCOVA output of growth rate VS. movement factors with TL as a covariate.

<table>
<thead>
<tr>
<th>Factor</th>
<th>DF</th>
<th>SS</th>
<th>Mean Sq</th>
<th>F value</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life History: TL</td>
<td>4</td>
<td>0.11204</td>
<td>0.0280094</td>
<td>20.407</td>
<td>1.622e-12</td>
</tr>
<tr>
<td>Residuals</td>
<td>107</td>
<td>0.14686</td>
<td>0.0013725</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3-4. Barker *A priori* model structure and selection of models for recapture probability using MARK and \( AIC_c \) model selection criteria.

<table>
<thead>
<tr>
<th>Model</th>
<th>AICc</th>
<th>Delta AICc</th>
<th>AICc Weights</th>
<th>Model Likelihood</th>
<th>Num. Par</th>
<th>Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site + Seasonal (4)*</td>
<td>12932.10</td>
<td>0</td>
<td>0.97669</td>
<td>1</td>
<td>24</td>
<td>12883.71</td>
</tr>
<tr>
<td>Site + Seasonal (4)+</td>
<td>12940.40</td>
<td>8.31</td>
<td>0.01533</td>
<td>0.0157</td>
<td>14</td>
<td>12912.27</td>
</tr>
<tr>
<td>Site + Seasonal (3)+</td>
<td>12941.74</td>
<td>9.65</td>
<td>0.00786</td>
<td>0.008</td>
<td>15</td>
<td>12911.59</td>
</tr>
<tr>
<td>Site + Seasonal (3)*</td>
<td>12949.98</td>
<td>17.89</td>
<td>0.00013</td>
<td>0.0001</td>
<td>21</td>
<td>12907.69</td>
</tr>
<tr>
<td>Site + Seasons (3)*</td>
<td>12972.64</td>
<td>40.55</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>12932.37</td>
</tr>
<tr>
<td>Site + Seasons (4)*</td>
<td>12973.21</td>
<td>41.11</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>12930.91</td>
</tr>
<tr>
<td>Site + Seasons (4)+</td>
<td>12974.24</td>
<td>42.14</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>12950.134</td>
</tr>
<tr>
<td>Site + Seasons (3)+</td>
<td>12979.86</td>
<td>47.77</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>12953.75</td>
</tr>
<tr>
<td>Site</td>
<td>13018.12</td>
<td>86.02</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>13000.06</td>
</tr>
<tr>
<td>Site + Size</td>
<td>13018.15</td>
<td>86.06</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>12998.08</td>
</tr>
<tr>
<td>Null (.)</td>
<td>13149.41</td>
<td>217.31</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>13137.38</td>
</tr>
</tbody>
</table>
Table 3-5. Barker *A priori* model structure and selection of models for survival using MARK and $\text{AIC}_c$ model selection criteria.

<table>
<thead>
<tr>
<th>Model</th>
<th>AICc</th>
<th>Delta AICc</th>
<th>AICc Weights</th>
<th>Model Likelihood</th>
<th>Num. Par</th>
<th>Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site + Seasonal (4)</td>
<td>12795.92</td>
<td>0.00</td>
<td>1.00</td>
<td>1.00</td>
<td>41.00</td>
<td>12712.81</td>
</tr>
<tr>
<td>Site + Seasonal (3)</td>
<td>12847.79</td>
<td>51.87</td>
<td>0.00</td>
<td>0.00</td>
<td>44.00</td>
<td>12758.52</td>
</tr>
<tr>
<td>Site</td>
<td>12934.40</td>
<td>138.48</td>
<td>0.00</td>
<td>0.00</td>
<td>27.00</td>
<td>12879.92</td>
</tr>
<tr>
<td>Site + Age</td>
<td>12937.84</td>
<td>141.93</td>
<td>0.00</td>
<td>0.00</td>
<td>29.00</td>
<td>12879.29</td>
</tr>
</tbody>
</table>
Figure 3-1. Growth rate of individual cutthroat trout as a function of the total length when they were first captured. Line represents locally weighted scatter plot smoothing LOWLESS.
Figure 3-2. Growth rate of individual cutthroat trout in 3 movement patterns as defined in Table 1. Regression lines represent the slope of growth rate for each location.
Figure 3-3. Growth rate of individual cutthroat trout in four sites as defined in Table 2. Regression lines represent the slope of growth rate for each location.
Figure 3-4. Apparent survival model (Barker) of seasons for each site.
CHAPTER 4

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

CONCLUSION

Movement of cutthroat trout will likely increase encounter rates and/or detection with predators and lead to higher mortality. Despite the risks of movement, Adult Bonneville cutthroat trout in this study were found to have a large portion (35%) of mobile individuals. While many recent studies found that cutthroat have potential to be mobile, the proportion of mobile individuals observed has been relatively small (17% or less) (Gowan et al. 1994). Detecting a larger proportion of mobile individuals can be attributed to an increased ability to collect recapture information through technological advancements. Early study designs were biased against the detection of movement due to limitations in technology. Many earlier studies dealt with low recapture rates by explaining them as high mortality (Stefanich 1952; Mense 1975) instead of considering that they may have moved out of the study area. My use of the latest PIT tag technologies allowed me to increase temporal and spatial recapture information.

My results indicate the importance for restoration efforts of cutthroat populations to include the protection and enhancement of connectivity between tributaries and main-stem rivers. The high degree of movement demonstrated by cutthroat trout in the tributaries of the Logan River indicate that management of these
populations must occur at the watershed scale and that barriers to movement will impact the population structure of these fish.

Migratory and resident strategies are present in this population of cutthroat trout. While no significant difference was found between survival and growth of individuals exhibiting these strategies it would benefit biologists greatly to know why both strategies persist.

My results showed that a variety of movement patterns can exist within a single population of cutthroat trout. Variation in movement patterns of individuals in a population may be influenced through seasonal changes, size/age, and environmental conditions. Management decisions should take into account variation in movement patterns. Restoring cutthroat trout populations should aim at enhancing/protecting variation of movement patterns.

REFERENCES

