Autumn and winter movement and habitat use of resident bull trout and westslope cutthroat trout in Montana
by Michael Joel Jakober

A thesis submitted in partial fulfillment of the requirements for the degree Of Master of Science in Fish and Wildlife Management
Montana State University

Abstract:
Autumn and winter movements and habitat use of resident bull trout and westslope cutthroat trout were investigated using radiotelemetry and snorkeling. Movement occurred in two distinct stages and was closely tuned to unique stream icing conditions. As autumn water temperatures declined, bull trout moved downstream into beaver ponds and pools containing complex large woody debris (LWD). Bull trout remained in these habitats throughout winter in streams lacking anchor ice. With extensive anchor ice formation, however, bull trout abandoned autumn pool habitats and moved further downstream in search of favorable overwintering habitats. Westslope cutthroat trout moved little (< 100 m) , preferring to overwinter in LWD-dominated pools near summer habitats. Beaver ponds and deep pools offering combinations of LWD and large substrate were critical overwintering habitats for both species. Trout exhibited different diel behavioral strategies during winter. During the day, small trout concealed in LWD and substrate interstices. Trout too large to find suitable hiding cover aggregated in deep pools. At night, fish of all sizes moved into the water column away from cover. Both species selected nighttime focal points closer to the substrate, further from cover, in shallower water, and in slower velocities than daytime positions. Although cutthroat trout preferred winter focal positions higher in the water column than bull trout, microhabitat use was similar for both species. As water temperature declined below 7 C, daytime trout densities declined in all habitats except beaver ponds. Pond densities dramatically increased as large aggregations (> 100 cutthroat and bull trout) formed prior to winter ice cover. Winter night densities were 5-6 times greater than winter day densities. Preferred winter habitats possessed extensive cover, low velocity flow (< 10 cm/s), and depth (> 50 cm) . Complex LWD accumulations were an important winter hiding cover for both species regardless of stream size.

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by

Michael Joel Jakober

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Michael Joel Jakober

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date May 19, 1995

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ABSTRACT

Autumn and winter movements and habitat use of resident bull trout and westslope cutthroat trout were investigated using radiotelemetry and snorkeling. Movement occurred in two distinct stages and was closely tuned to unique stream icing conditions. As autumn water temperatures declined, bull trout moved downstream into beaver ponds and pools containing complex large woody debris (LWD). Bull trout remained in these habitats throughout winter in streams lacking anchor ice. With extensive anchor ice formation, however, bull trout abandoned autumn pool habitats and moved further downstream in search of favorable overwintering habitats. Westslope cutthroat trout moved little (< 100 m), preferring to overwinter in LWD-dominated pools near summer habitats. Beaver ponds and deep pools offering combinations of LWD and large substrate were critical overwintering habitats for both species. Trout exhibited different diel behavioral strategies during winter. During the day, small trout concealed in LWD and substrate interstices. Trout too large to find suitable hiding cover aggregated in deep pools. At night, fish of all sizes moved into the water column away from cover. Both species selected nighttime focal points closer to the substrate, further from cover, in shallower water, and in slower velocities than daytime positions. Although cutthroat trout preferred winter focal positions higher in the water column than bull trout, microhabitat use was similar for both species. As water temperature declined below 7 C, daytime trout densities declined in all habitats except beaver ponds. Pond densities dramatically increased as large aggregations (> 100 cutthroat and bull trout) formed prior to winter ice cover. Winter night densities were 5-6 times greater than winter day densities. Preferred winter habitats possessed extensive cover, low velocity flow (< 10 cm/s), and depth (> 50 cm). Complex LWD accumulations were an important winter hiding cover for both species regardless of stream size.

CHAPTER 1

GENERAL INTRODUCTION

Bull trout (*Salvelinus confluentus*) and westslope cutthroat trout (*Oncorhynchus clarki lewisi*), two native salmonids of the interior Pacific northwest, have declined substantially throughout their native ranges due to a variety of factors, including the degradation and loss of spawning and rearing habitat, competition and hybridization with introduced salmonids, habitat fragmentation, and overexploitation (Liknes and Graham 1988; Fraley et al. 1989). In order to effectively manage both species and prevent further declines, more specific habitat information is needed over different stages of life history and different seasons, especially information pertaining to movements, behavior, and habitat requirements during winter.

Although once abundantly distributed throughout all major watersheds west of the Continental Divide, bull trout in Montana have suffered severe reductions in abundance and distribution in the last century and are currently only found in limited numbers and habitat (Thomas 1992). The bull trout is presently listed as a Category I species by the United States Fish and Wildlife Service (USFWS), meaning that listing under the federal Endangered Species Act is warranted.

Westslope cutthroat trout were once abundantly distributed throughout western Montana (east and west of the Continental Divide), central and northern Idaho, a small section of Wyoming, and southern portions of three Canadian provinces (Liknes and Graham 1988). Within the last century, the westslope cutthroat has declined throughout its historic range due to competition from introduced salmonids, habitat degradation, introgression, and overexploitation, and is presently only found in 27% of its historic range in Montana (Liknes 1984; Liknes and Graham 1988). The westslope cutthroat trout is listed as a Class B Species of Special Concern by the Montana Department of Fish, Wildlife, and Parks (MDFWP), and special harvest restrictions have been widely implemented to preserve and perpetuate the remaining wild stocks.

Both species exhibit three similar life history patterns: (1) fish reside in large rivers or streams and migrate up smaller tributaries to spawn (fluvial); (2) fish reside in lakes or reservoirs and migrate up smaller tributaries to spawn (adfluvial); and (3) fish do not migrate and spend their entire lives in small headwater streams (resident) (Liknes and Graham 1988; Goetz 1989). Small tributaries act as rearing areas for juveniles of migratory fish, and juveniles live in these tributaries for

1 to 4 years before migrating downstream to rivers, lakes, or reservoirs (Liknes and Graham 1988; Fraley and Shepard 1989). Resident fish of both species are greatly reduced in size compared to their migratory counterparts, and have low fecundity (Goetz 1989). Most of the literature available on bull trout is based on studies of migratory populations (Fraley and Shepard 1989; Goetz 1989), whereas almost no information is available on small, resident populations.

Although movement is a fundamental characteristic that differentiates bull trout life history forms, it is not known whether resident populations have always been distinct from migratory forms, or if resident fish are the remnants of formerly fluvial populations. Knowledge of the spawning movements of all three life history forms can help answer this question. Adfluvial bull trout typically commence spawning migrations in late spring, arriving at the mouths of spawning tributaries by mid-summer (Shepard et al. 1984). Both adfluvial and fluvial bull trout ascend spawning tributaries in late summer (late July - September), staging in deep pools offering extensive cover (complex woody debris jams, undercut banks, etc.) near spawning beds of unembedded, loosely compacted gravel and cobble substrate (McPhail and Murray 1979; Shepard et al. 1984). Sites offering groundwater infiltration appear to be highly important bull trout spawning areas (Shepard et al. 1984). Although the timing and magnitude of adfluvial and fluvial bull trout spawning movements have been well documented (Shepard et al. 1984; Fraley and Shepard 1989), the extent of spawning migrations conducted by resident bull trout inhabiting small headwater streams is unknown.

Resident (fluvial) westslope cutthroat, conversely, are thought to be relatively sedentary throughout their lives (Leathe and Enk 1985). Recent evidence, however, suggests that westslope cutthroat trout in headwater streams may move often, sometimes over relatively long distances, to find suitable overwintering habitat (Bernard and Israelsen 1982; Brown, in press).

The quantity and quality of available overwintering habitat in small streams strongly affects movement patterns and may be the limiting factor for stream salmonid populations (Hunt 1974; Mason 1976). As water temperatures decrease rapidly in late autumn, fish metabolic rates decline, and suitable cover areas become more critical. Although salmonids continue to feed throughout the winter, activity and aggression are greatly reduced and survival depends more on finding suitable shelter and minimizing energetic costs than on capturing food (Mason 1976; Cunjak and Power 1987a).

Winter cover requirements differ from, and are more restrictive than those of summer. Structurally complex accumulations of large woody debris (LWD) are an important component of winter habitat (Bustard and Narver 1975;

Tschaplinski and Hartman 1983). Large woody debris increases pool frequency, depth, and volume, retains sediment, protects fish from the scouring effects of ice, and creates low velocity pockets of shelter offering shade and complex 3-dimensional hiding structure (Bustard and Narver 1975; Bilby and Likens 1980; Lisle 1986; McMahon and Hartman 1989).

In larger streams where LWD is less common, the amount of unembedded substrate or undercut banks probably controls the availability of quality overwintering habitat (Hillman et al. 1987; Smith and Griffith 1994). Clean substrate interstices provide critical overwintering habitat for many species of juvenile salmonids (Rimmer et al. 1984; Heifetz et al. 1986; Heggenes et al. 1993; Bonneau 1994), and the deposition of fine sediments can fill interstitial spaces and substantially decrease winter survival rate (Smith and Griffith 1994).

Resource partitioning is an important mechanism controlling seasonal interactions between juvenile bull trout and westslope cutthroat trout (Nakano et al. 1992). The summer habitat preferences of both species reflect differences in foraging tactics and microhabitats. Cutthroat trout prefer deep-water pool habitats offering mid-water column feeding stations beneath overhead cover, whereas bull trout prefer more diverse habitats containing complex substrate cover (Nakano et al. 1992). In winter, the need to minimize energetic costs and obtain shelter from predators dominates the behavior of both species; therefore, winter habitat requirements are much more similar (Bonneau 1994).

This study examines the autumn and winter movement patterns of resident bull trout and westslope cutthroat (Chapter 2), and compares differences in autumn and winter habitat use at the microhabitat and channel unit scales (Chapter 3) in two headwater tributaries of the Bitterroot River in western Montana.

Historic bull trout populations in the Bitterroot River drainage were probably dominated by fluvial fish in the mainstem Bitterroot River (Chris Clancy, MDFWP, personal communication). However, the historic presence of resident bull trout in headwater tributaries has not been established. Today, fluvial bull trout in the mainstem are rare, and most of the remaining bull trout populations consist of small, resident fish sympatric with westslope cutthroat in small headwater streams. Current management goals seek to preserve remaining bull trout populations, while attempting to describe critical habitat needs and define core areas containing the strongest populations with the highest potential for future recolonization.

Suitable winter habitat in Bitterroot River tributaries may depend on channel morphology and stream size. Streams within the drainage can be roughly classified into two morphological types: (1) small (mean wetted width < 7 m) LWD-dominated streams lacking boulders; and (2) larger (mean wetted width > 7 m) boulder-dominated streams lacking LWD. The quantity of instream LWD is probably the most important feature limiting the availability of quality overwintering habitat in smaller streams, while the amount of unembedded substrate probably controls the availability of quality overwintering habitat in larger streams.

Specific objectives of this study were to (1) compare the autumn and winter microhabitat preferences of both species, (2) document autumn and winter movement patterns, (3) compare differences in winter habitat use, and (4) define critical overwintering habitats which may be limiting the abundance and distribution of resident bull trout and westslope cutthroat trout populations in the Bitterroot drainage.

CHAPTER 2

ROLE OF STREAM ICING CONDITIONS ON WINTER MOVEMENTS AND HABITAT USE BY BULL TROUT AND WESTSLOPE CUTTHROAT TROUT

Introduction

The movement patterns and habitat preferences of headwater populations of resident bull trout (*Salvelinus confluentus*) and westslope cutthroat trout (*Oncorhynchus clarki lewisi*) are not well understood. Until recently, most researchers have concluded that movement is not a critical component in the life histories of resident salmonids (Miller 1957; Leathe and Enk 1985). Adult resident trout are assumed to establish feeding territories or dominance hierarchies and remain within a restricted home range for most or all of their lives (Riley et al. 1992). However, because seasonal habitat, spawning areas, and food resources are patchily distributed in streams, movement is possibly more common in stream salmonids than previously thought. This is particularly true during autumn, as fish seek out suitable overwintering habitats in response to declining water temperatures and photoperiod (Rimmer and Paim 1990; Meyers et al. 1992; Fraser et al. 1993).

Spawning movements of fall-spawning salmonids may also be triggered by declining water temperatures in autumn. Bull trout spawning primarily occurs in September and October and is thought to be triggered by declines in water temperature below 9 C (McPhail and Murray 1979; Fraley and Shepard 1989). Despite considerable knowledge of the spawning behavior of adfluvial and fluvial bull trout, little is known of the spawning movements of resident bull trout. Adfluvial bull trout commence long (e.g. 50-200 km) upstream spawning migrations in late spring, arriving in staging areas by late summer (Fraley and Shepard 1989). Fluvial bull trout also display extensive spawning migrations (Goetz 1989). Resident fish, in contrast, are believed to move relatively short distances within their natal streams to spawn, although I could find no previous studies documenting the spawning behavior of resident bull trout.

Winter ice formation and flow reduction can reduce the amount of available overwintering habitat for salmonids in mountain streams and influence the distance required to obtain suitable winter habitat (Hunt 1974; Chisholm et al. 1987). Bjornn and Mallet (1964) recorded autumn downstream movements of up to 100 km for cutthroat trout in an Idaho river, while Miller (1957) and Leathe and Enk (1985) observed cutthroat overwintering within 50 m of their summer habitats in small streams. Bull trout winter movements are largely unknown, and I could find no previous studies documenting the winter movements of resident bull trout.

In winter, stream salmonids seek habitats which offer a combination of dense cover, low water velocities, and depth (Hartman 1965; Cunjak and Power 1986; Chisholm et al. 1987). Effective winter habitat can take the form of complex large woody debris (LWD) jams (Heifetz et al. 1986), substrate interstices (Smith and Griffith 1994), undercut banks (Hillman et al. 1987), surface ice (Maciolek and Needham 1951), beaver ponds (Chisholm et al. 1987), off-channel alcoves (Swales et al. 1986), and perennial springs (Craig 1978).

Stream ice conditions may affect cover availability, predation risk, and the timing and magnitude of winter movements (Chisholm et al. 1987; Heggenes and Borgstrom 1988; Brown, in press). Ice formation in streams is influenced by interactions between stream elevation, stream size, climate, and snowfall depth (Chisholm et al. 1987; Berg 1994). High elevation streams are characterized by snow-bridging, no surface ice, and little-to-no habitat exclusion, whereas low elevation streams are characterized by extensive surface ice cover, little snowfall, and moderate habitat exclusion (Chisholm et al. 1987). The harshest winter conditions are typically observed in mid elevation streams where incomplete surface ice cover is coupled with extensive anchor ice formation.

The type of ice may influence winter habitat conditions in fluvial environments (Maciolek and Needham 1951). Surface ice initially forms on low velocity pools when sub-surface waters are well above freezing. Without an insulating layer of snow (> 30 cm), surface ice can continue to thicken in a downward direction until the water column is completely frozen (Berg 1994). Surface ice in conjunction with an insulating layer of snow can be beneficial to overwintering trout by preventing excessive radiant heat loss from the streambed, maintaining water temperatures slightly above freezing, and providing overhead cover (Power et al. 1993). Sub-surface ice formation (i.e. frazil and anchor ice), in contrast, is detrimental to stream fishes (Power et al. 1993). On sub-freezing clear winter nights, radiant heat loss from the streambed is sufficient to supercool the temperature of the water slightly below 0.0 C (Benson 1955). When turbulent water is supercooled, small (0.1-5.0 mm) ice crystals nucleate in the water column, forming frazil ice (Benson 1955). Frazil ice crystals are adhesive and stick to each other, underwater objects, and the substrate to form anchor ice (Needham and Jones 1959). Anchor ice forms primarily in riffles and may dam and flood large sections of stream, dramatically altering winter habitat composition (Maciolek and Needham 1951; Needham and Jones 1959). Extensive anchor ice accumulation can exclude large areas of stream, forcing trout to aggregate in the few remaining pockets of open water (Cunjak and Power 1986).

This study was designed to examine the autumn and winter movements and habitat preferences of resident bull trout and westslope cutthroat in two streams which typify those commonly occurring in the Bitterroot drainage of western Montana: a small (mean wetted width < 7 m), high elevation (1818 m), LWD-dominated stream lacking boulder substrate and sub-surface ice; and a larger (mean wetted width > 7 m), mid elevation (1424 m), boulder-dominated stream lacking LWD with large accumulations of sub-surface ice. These two streams were specifically chosen to compare the relative importance of LWD and large substrate to overwintering bull trout and westslope cutthroat trout and to examine the effects of different ice conditions on winter movements and habitat preferences. Additional sampling in nearby streams having similar morphologies was not possible because of a lack of strong bull trout populations in the drainage.

Study Area

Meadow Creek (UTM 280982 5080827) is a fourth-order, LWD-dominated tributary to the East Fork of the Bitterroot River in the Bitterroot National Forest, Ravalli County, Montana. Meadow Creek originates at an elevation of 2317 m, and flows north for 16 km (mean gradient 5.5%) before emptying into the East Fork of the Bitterroot River at an elevation of 1515 m (Figure 2.1). It drains an area of 85.5 km^2 and the geology is comprised of hard and weathered granitics. Meadow Creek ranges in wetted width from 2.0 m to 5.0 m at base flow. Gravel and cobble dominate the substrate, with very few boulders and substantial amounts of LWD. Beaver (*Castor canadensis*) dams are common in the middle section and near the mouth of Meadow Creek, but do not appear to impede fish passage. Riparian areas are primarily forested with mixed stands of lodgepole pine (*Pinus contorta*) and Englemann spruce (*Picea engelmannii*). The watershed is used for timber harvest, livestock grazing, and recreation. Angling use is light (C. Clancy, MDFWP, personal communication). Mean annual precipitation in the vicinity of the study area is about 75 cm, 80% of which falls as snow between October and May. Meadow Creek has a discharge pattern typical of those in the central Rocky Mountains - low flows from late summer until spring, after which snowmelt causes peak runoff (May and June). During

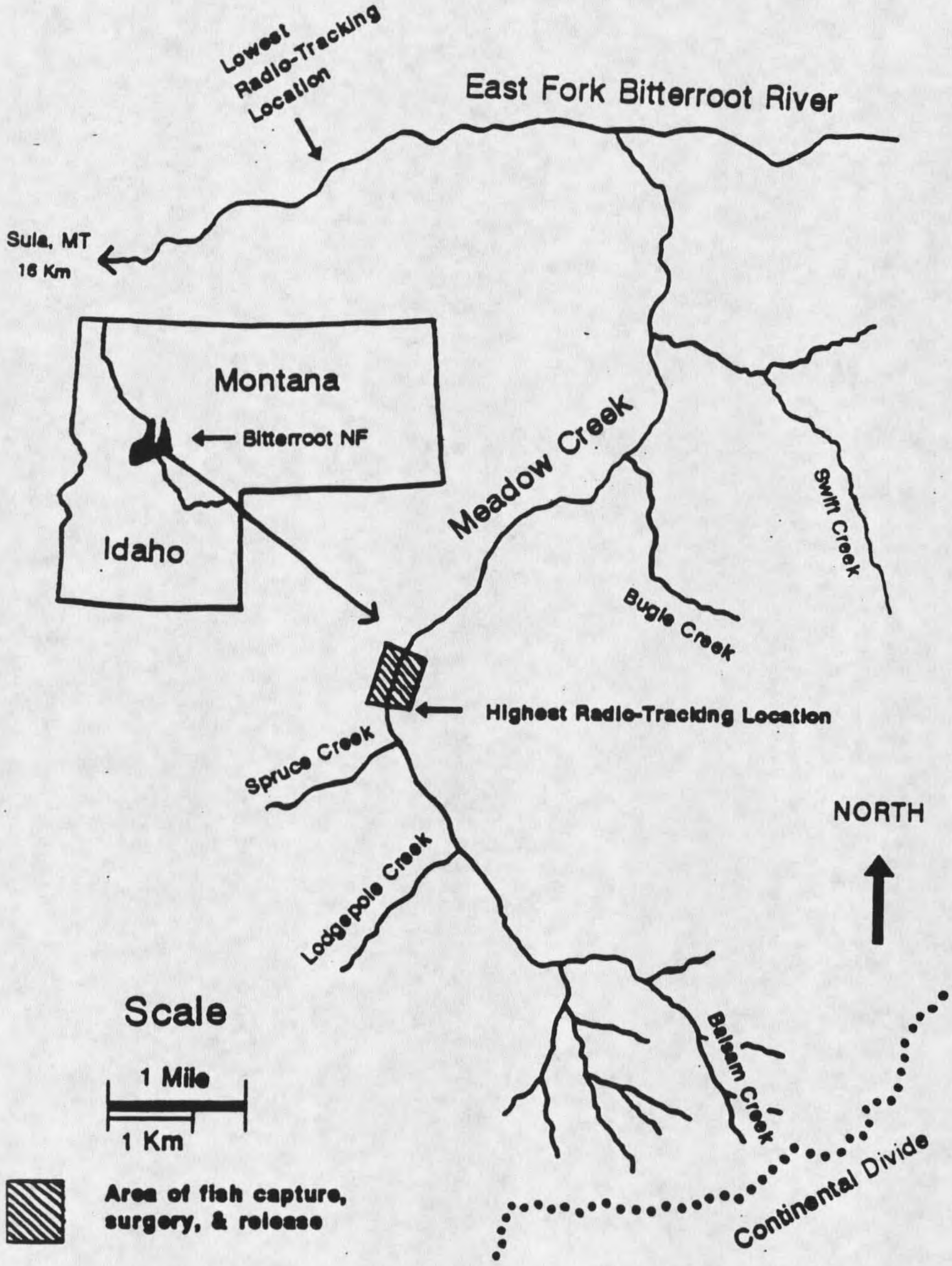

Figure 2.1. Map of the Meadow Creek drainage and radiotracking section, Bitterroot National Forest, Ravalli County, Montana.

autumn and winter study periods, flows were below 0.25 m^3/s. Peak summer water temperatures rarely exceed 13.0 C, while winter water temperatures range between 0.0-0.5 C. Meadow Creek is almost entirely covered (> 95%) with surface ice (10-30 mm thickness) from early November through late March, and this ice cover is typically insulated with > 50 cm of snow. Sub-surface ice (anchor and frazil ice) is present only in riffles in limited amounts (late October) prior to surface ice formation, and anchor ice dams are rare. The fish fauna in Meadow Creek consists entirely of endemic species: bull trout, westslope cutthroat trout, and slimy sculpin (*Cottus cognatus*). Small numbers of exotic brook trout (*Salvelinus fontinalis*) are present in lower Meadow Creek but are probably restricted to that section at present time.

Daly Creek (UTM 276191 5117775) is a fourth-order, boulder-dominated tributary to the Bitterroot River in the Bitterroot National Forest. Daly Creek originates at an elevation of 2268 m, and flows southwest for 18 km with a mean gradient of 4.85% before joining Skalkaho Creek at an elevation of 1408 m (Figure 2.2). It drains an area of 98.4 km^2 and the geology is comprised of mixed quartzite and granitic formations. Wetted width ranges from 0.7 m to 8.0 m at base flow. Boulders and large cobbles dominate the substrate and LWD is uncommon. No barriers to fish movement exist in the lower 12 km of Daly Creek where the study was

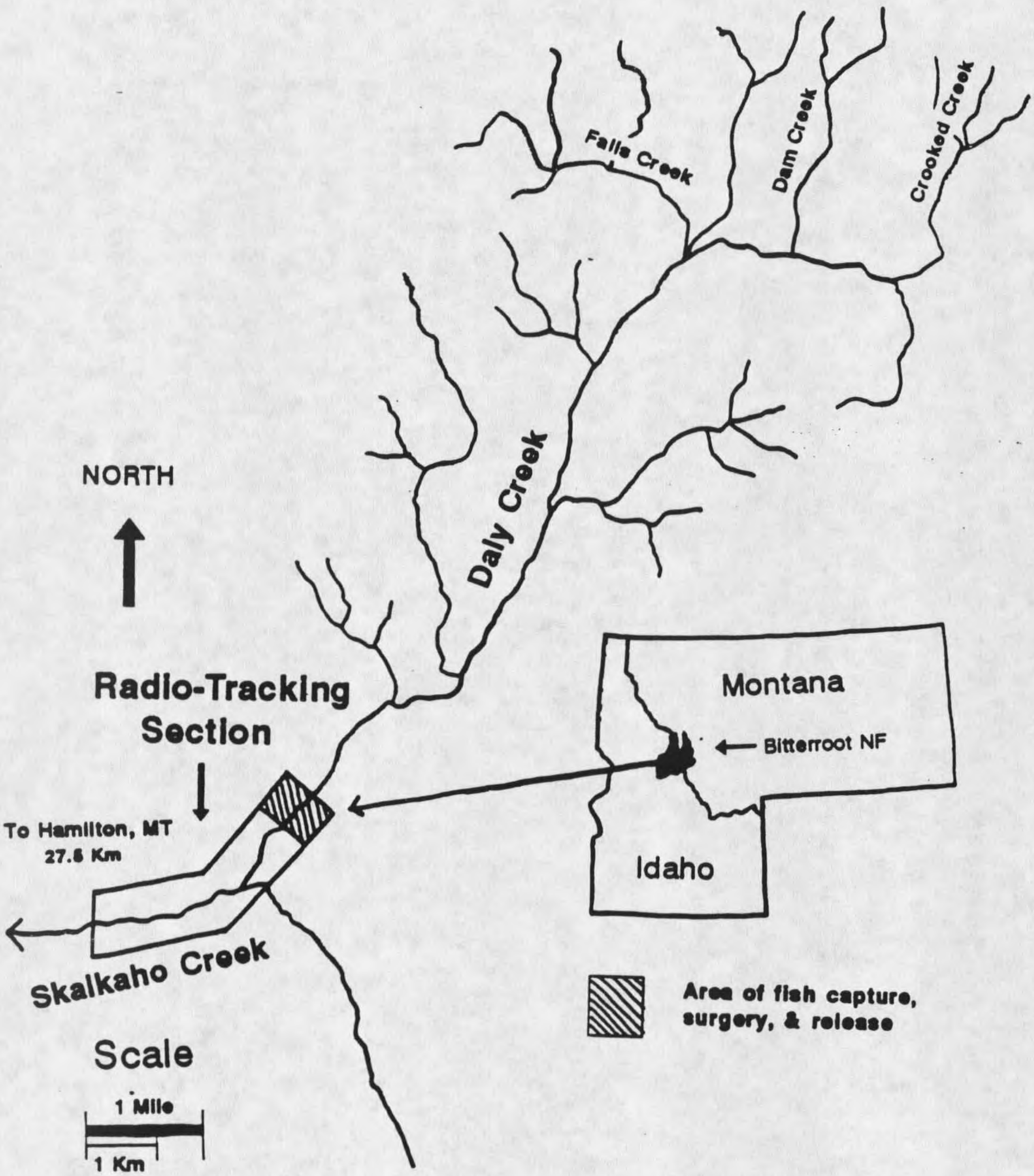

Figure 2.2. Map of the Daly Creek drainage and radiotracking section, Bitterroot National Forest, Ravalli County, Montana.

conducted. Mixed stands of Engelmann spruce and Douglas fir (*Pseudotsuga menziesii*) heavily shade riparian areas. The Daly Creek watershed is used for limited timber harvest and recreation, with moderate angler use (C. Clancy, MDFWP, personal communication). Mean annual precipitation in lower Daly Creek is about 50 cm, 70% of which falls as snow between October and May, and the discharge pattern is similar to Meadow Creek. During autumn and winter study periods, flows ranged from 0.40-0.90 m^3/s. Peak summer water temperatures rarely exceed 13.0 C and winter water temperatures range between 0.0-1.0 C. Surface ice cover in Daly Creek is highly dynamic, ranging from 60-90% depending on air temperature. Ice thickness commonly exceeds 40 cm and is generally insulated with 20-50 cm of snow. Sub-surface ice formation is extensive throughout winter in open water leads, and anchor ice dams are common. The Daly Creek fish fauna is identical to that of Meadow Creek: bull trout, westslope cutthroat trout, and slimy sculpin. Brook trout are not present in Daly Creek, but are present in low numbers in Skalkaho Creek several kilometers downstream.

Methods

Radiotelemetry was used to measure the autumn and winter movements and habitat use of 18 bull trout and six westslope cutthroat trout from late August 1992 through February 1993. Due to the small size of fish (range 231-434 mm total length/TL), I was limited to using small transmitters with short (90 d) battery lives. Thus, movements were monitored during two different time periods (autumn phase & winter phase) using different sets of radiotagged fish. During the autumn phase, only bull trout were radiotagged in order to assess spawning movements whereas both species were monitored during winter.

Radiotagging

Four bull trout > 231 mm TL were radiotagged in both streams in late August 1992. Fish were captured with a Coffelt Mark-10 backpack electrofishing unit or a boat-mounted Coffelt Mark-22M electrofishing unit. In late October 1992, additional bull trout (Daly Creek N=6; Meadow Creek N=4) and westslope cutthroat trout (Daly Creek N=2; Meadow Creek N=4) were radiotagged in each stream to assess winter movements.

Following capture, fish were anesthetized with a 200 mg/L solution of MS-222, weighed (g), and measured (mm). Radio transmitters were surgically implanted using standard procedures reported for fish of similar size (Schrader 1989). The surgical procedure involved placing the fish ventral side up in a V-shaped PVC trough padded with wet sponges with the head and gills submerged in anesthetic. A 1.5-2.0 cm incision was made through the ventral abdominal wall immediately anterior and slightly dorsal to the pelvic girdle. Incisions were made only large enough to gently slip the transmitter into the peritoneal cavity. After inserting the transmitter, the incision was closed with a single row of three to four sutures through the peritoneum and dermis using a curved cutting needle (FS-1; 1/2 in) with absorbable Ethicon 2-0 chromic gut suture material. Sutures were firmly cinched using two double surgical knots separated by a single knot. Fish were tagged with different colored Floy tags to facilitate visual identification of radiotagged individuals. Fish were released approximately one hour later in the exact location where they were captured. All fish were active when released and surgery and anesthesia did not have any obvious negative effects.

Capsule-shaped, beeswax-coated transmitters (Custom Telemetry and Consulting, Athens, Georgia) with internal loop antennas were used in this study. Transmitters were approximately 30 mm long by 14 mm in diameter, and operated on unique, individual frequencies ranging between 40.4112 MHz to 40.5612 MHz. Guidelines suggest that the transmitter weight in water should make up no more than 2% of the fish's body weight (Brown, in press). Transmitter weights in my study ranged between 3.6 to 4.0 g or 0.7 to 3.5% of the fish's body weight.

Radiotracking Protocol

A 40-MHz receiver with 16 operational channels (Advanced Telemetry Systems Inc., Isanti, Minnesota) and a hand-held bi-directional loop antenna (60 cm by 65 cm) mounted on a 3-m pole were used to triangulate fish locations to within 1.0 m^2. Headphones were used with the receiver when locating fish. On approximately 25% of the locations, I was able to visually observe the radiotagged fish using the fish's uniquely colored Floy tag.

Radiotracking equipment was extensively checked prior to data collection. Transmitter strength and performance were tested in air, stream water, and under ice in a cooler. All transmitters were operated for 24 h in ice water prior to implantation. Receiver accuracy was calibrated by tracking the location of a hidden transmitter located on the ground. Transmitter signals were initially detected at a distance of approximately 100-150 m and signal strength was not attenuated by the presence of snow or ice.

Fish were located twice weekly during autumn and once weekly during winter. A minimum of 48 h elapsed between locations to meet the assumption of independence for radiotracking studies (Alldredge and Ratti 1986). Most locations were made during the day (0900-1600 h); however, each fish was also located at night (1900-0400 h) on at least two occasions. Transmitter duration averaged 67 d in autumn (range 53-82 d) and 112 d (range 56-119 d) in winter.

Movement and Habitat Use

For each relocation, the distance (m) and direction (up or downstream) moved from the original point-of-release and last location, the habitat type occupied (Table 2.1), and the cover type used (Table 2.2) within a 1 m radius were recorded. Thermographs were used to record temperature. Percent ice cover was visually estimated during each sampling period to assess possible effects of ice on timing and magnitude of movements.

To compare habitat use with availability, I classified all habitat units positioned between the uppermost and lowermost fish locations and calculated the percent composition of each habitat unit type. All units between those two points were assumed to be available to radiotagged fish (White and Garrott 1990).

Autumn habitat availability was measured at base flow in both streams during late September-early October 1993. Although flows were higher (0.28 m^3/s in Daly Creek; 0.17 m^3/s in Meadow Creek) in autumn 1993 than in 1992,

Table 2.1. Habitat types designated in Daly Creek (D) and Meadow Creek (M) as modified from Bisson et al. (1981).

Riffle (D & M) - Stream unit with moderate current velocity (20-50 cm/s) and moderate turbulence.

Glide (D & M) - Stream unit lacking pronounced turbulence characterized by moderately shallow water with an even flow.

LWD-formed pool (D & M) - Stream unit in which LWD has caused scouring water to carve out a hole in the channel bed and provides the dominant cover type (contains > 20 cm of submerged LWD/m^2 pool area).

Boulder-formed pool (D) - Stream unit in which boulders have caused scouring water to carve out a hole in the channel bed and boulder crevices and ledges provide the dominant cover.

Pocket water (D) - Stream unit with moderate-to-fast current velocity (20-100 cm/s) and moderate turbulence interspersed with numerous boulder-formed pocket pools.

Beaver pond (M) - Stream unit formed by the damming activities of beaver characterized by deep water (> 50 cm), low velocity (< 5 cm/s), and fine sediment (< 8 cm).

Pool lacking LWD (M) - Stream unit formed by scouring flow impinging against one streambank due to a meander bend in the channel (contains < 20 cm of submerged LWD/m^2 of pool area).

Table 2.2. Cover type classification as modified from Dolloff and Reeves (1990).

Cover type	Description
No Cover	No cover within a 30 cm radius
Cobble	Rock crevices (diameter 64-256 mm)
Boulder	Rock crevices (diameter > 256 mm)
Large woody debris	> 1 woody piece (diameter > 10 cm)
Fine woody debris	> 1 woody piece (diameter < 10 cm)
Undercut bank	Earth bank (< 45 cm from water)
Aquatic vegetation	Submerged aquatic macrophyte capable of hiding > 75% of a fish's body
Surface ice	Ice used as overhead cover

there were no noticeable changes in habitat composition between years in either stream.

Winter habitat unit availability could not be measured with the same procedure in each stream. Sub-surface ice was uncommon in Meadow Creek due to the rapid formation of surface ice. This prevented the formation of anchor ice dams necessary for altering habitat composition; therefore, autumn and winter habitat composition were assumed to be similar. In Daly Creek, winter habitat composition differed depending on dynamic surface and sub-surface ice conditions. I classified winter habitat conditions into two categories:

(1) Moderate ice cover - Surface ice covers < 75% of the wetted stream area and sub-surface ice and anchor ice dams are not present.

(2) Extensive ice cover - Surface ice covers > 75% of the wetted stream area and sub-surface ice and anchor ice dams are common.

I then measured habitat availability at each condition during December 1993 and averaged the two measurements to calculate a baseline winter habitat composition. I also measured the amount of pool habitat at three different winter ice conditions (none, moderate, extensive).

<u>Data Analysis</u>

A chi-square goodness-of-fit test (Zar 1984) was used to test the null hypothesis that habitat unit use occurred in proportion to availability (Alldredge and Ratti 1986). If the null hypothesis was rejected, simultaneous Bonferroni confidence intervals (Byers et al. 1984) were calculated to determine whether a habitat type was preferred, avoided, or used in proportion to availability. Fish preferred or avoided habitat types when percent availability did not overlap the confidence interval (Byers et al. 1984).

Winter survivorship of radiotagged fish in Daly Creek in relation to water temperature and percent ice cover was estimated with the Kaplan-Meier procedure (Cox and Oates 1984). This procedure computes the percentage of radio-tagged fish dying on each day of the study from all radio-tagged fish at risk at the beginning of that day. The STATGRAPHICS statistical program (1991) was used to perform all statistical computations. Significance was defined as $P < 0.05$.

Results

Autumn Movement

Meadow Creek bull trout conducted relatively long distance movements downstream during autumn. Three fish exhibited the resident life history form, whereas one fish displayed movements typical of a fluvial bull trout. I defined a fluvial bull trout as one which moved out of Meadow Creek and into the East Fork during the tracking phase. Consult Appendix Table 1 for specific data on the net movements of individual fish in both streams.

Resident bull trout in Meadow Creek moved downstream (range 731-1,478 m) into a large beaver pond complex (9 contiguous ponds) between mid September and early October 1992 (Figure 2.3). On several occasions, more than one radiotagged fish was located within the same pond.

One Meadow Creek bull trout was observed spawning. On September 2, a radiotagged male (434 mm TL) spawned with a much smaller female (250 mm TL) in the tailout of a lateral scour pool. Appendix Table 2 presents habitat parameters measured at bull trout redds in Daly and Meadow Creeks. The fluvial bull trout (242 mm TL) moved 337 m upstream following capture, possibly spawned on September 17 (not observed) and then rapidly moved 11.9 km downstream, including a movement of 4.9 km in < 3 d (Figure 2.3).