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Steven R. Hendricks for the degree of Master of Science in Fisheries Science presented on June 6, 2002.

Title: Seasonal Changes in Distribution of Coastal Cutthroat Trout in an Isolated Watershed

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Robert E. Gresswell

In an effort to identify seasonal distribution patterns and habitat requirements of coastal cutthroat trout *Oncorhynchus clarki clarki*, movement of tagged and marked individuals (35 radio-tagged, 753 PIT-tagged, and 5,322 fin-clipped) was monitored over a 14-month period in an isolated watershed in southwestern Oregon. Emigration out of the basin was estimated with a rotating fish trap. Results showed that 70% of recaptured PIT-tagged cutthroat trout and 86% of radio-tagged fish moved among channel units. A smaller proportion of tagged fish moved at the reach- and segment-scale. Greatest movement occurred in April, at the peak of spawning, and the least occurred in October, when discharge was at its lowest. Radio- and PIT-tagged cutthroat trout occupied pool habitat 62-97% of the time, depending on the season. Only 63 (< 1% of tagged and marked fish) coastal cutthroat trout emigrated out of the study area between February and June. Results suggested that unit-scale movement was common throughout the year, and reach- and segment-scale movement was more important during the winter and spring. In addition, habitats (e.g., pool, riffle, and cascade) occupied by coastal cutthroat trout change in concert with discharge, water temperature, and life-history requirements (e.g., spawning, refuge, and feeding).

Seasonal Changes in Distribution of Coastal Cutthroat Trout in an Isolated Watershed

by

Steven R. Hendricks

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APPROVED:

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Major Professor, representing Fisheries Science

Redacted for Privacy

Head of Department of Fisheries and Wildlife

Redacted for Privacy

Dean of Graduate School

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Steven R. Hendricks, Author

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Seasonal Changes in Distribution of Coastal Cutthroat Trout in an Isolated Watershed

CHAPTER 1: INTRODUCTION

Recent work on stream fish movement has suggested that movement is necessary for many populations of potamodromous (migrations limited to freshwater) salmonids (Gowan et al. 1994; Thorpe 1994; Northcote 1997a). Most organisms face the common problem of trying to occupy suitable habitat and persist under changing environmental conditions (Warren and Liss 1981). Organisms must move to adapt to an ever-changing environment and to satisfy life-history requirements, such as spawning, refuge, and feeding. Movement exhibited by salmonids in river systems arises from spatial, seasonal, and ontogenetic separation of optimal habitats for growth, survival, and reproduction (Northcote 1984; Thorpe 1994). Fish move to different habitats in response to changes in habitat quality and as requirements for each ontogenetic stage change. The capacity of potamodromous salmonids to move in relation to seasonal changes in the quality and quantity of habitat is an advantage to the individual and the population (Jonsson 1991; Northcote 1997a).

Despite the knowledge that potamodromous salmonids move throughout the year and can migrate long distances, many research projects are still designed to examine movement over limited spatial (study sections instead of watersheds) and temporal (days instead of seasons) scales (see Gowan et al. 1994; Baxter 2002). Frequent sampling across multiple seasons over large areas has been limited because of the intensive effort involved and logistical constraints. Researchers that have monitored movement over a large area for multiple seasons have found that potamodromous salmonids exhibited spatially extensive movements and temporally diverse patterns of movement (Meyers et al. 1992; Burrell et al. 2000; Hilderbrand and Kershner 2000; Schmetterling 2001; Baxter 2002).

Life-history characteristics, movement patterns, and habitat relationships have been described for many species of potamodromous salmonids (Northcote 1997a), including coastal cutthroat trout (Northcote 1997b; Trotter 1989). Despite the limited information available for above-barrier populations of coastal cutthroat trout (Harvey 1998; Harvey et al. 1999), comparisons to downstream assemblages and to potamodromous subspecies of cutthroat trout can provide a conceptual framework of our current knowledge and help identify gaps in knowledge.

Trophic movement is important for all life-history stages because areas of optimal feeding fluctuate at different times of the year and throughout the life cycle. Shortly after emergence, coastal cutthroat trout fry may make limited (< 100 m) trophic movements, usually in the downstream direction (Wyatt 1959; Fuss 1982). Moore and Gregory (1988) observed cutthroat trout fry moving to lateral habitats during summer and suggested it was for access to food. Wilzbach (1985) found that adult coastal cutthroat trout moved out of an artificial stream channel under conditions of low food availability, possibly in search of areas of higher food abundance.

Refuge movements are an important movement behavior because potamodromous fish must escape harsh environments, such as high flows and low water temperatures during the winter or spring and low flows and elevated water temperatures in late summer, in order to persist. Coastal cutthroat trout in rain-dominated climates have been recorded moving downstream to areas that afford more secure winter habitat (Johnston 1982), and moving upstream into small ephemeral tributaries that are less affected by high flows (Hartman and Brown 1987). In small headwater streams, reduced discharge in late summer may trigger movement to pool habitats as trout seek refuge from low water levels and elevated water temperatures (Schlosser 1995).

Varley and Gresswell (1988) described four different reproductive movement patterns in Yellowstone cutthroat trout *O. c. bouvieri*; fluvial, fluvial-adfluvial, lacustrine-adfluvial, and allacustrine. Lacustrine-adfluvial and allacustrine movement patterns involve fish migrating from a lake into tributaries or outlet streams, respectively. Fluvial populations disperse locally in a stream in the area of their home range for spawning. Fluvial-adfluvial populations move from rivers to small tributaries to spawn. Westslope *O. c. lewisi* and coastal cutthroat trout have been documented moving long distances (up to 72 km) to spawning grounds in tributaries (Moring et al. 1986; Brown and Mackay 1995b; Schmetterling 2001). Depending on the proximity of suitable spawning habitat, reproductive movements can cover short or long distances and be in the up- or downstream direction (Brown and Mackay 1995b).

In isolated watersheds above natural barriers, researchers have argued that salmonids limit movement because of genetic selection against excessive movement and the possibility of moving over a barrier falls and subsequent loss to the upstream population (e.g., Jonsson 1982; Elliot 1987; Northcote 1997b). Researchers have cited this argument when reporting limited movement in isolated populations of brown trout *Salmo trutta* (Elliot 1987), Colorado River cutthroat trout *O. c. pleuriticus* (Young 1996), and Columbia River redband trout *O. mykiss gairdneri* (Mulfeld et al. 2001). In contrast, other researchers have detected extensive and high rates of movement in isolated populations (Harvey 1998; Harvey et al. 1999). Consequently, several questions concerning the role of movement in isolated systems remain unanswered. What are the appropriate spatial scales for examining movement of isolated populations of coastal cutthroat trout? Do movement patterns and habitat use of isolated populations change seasonally? What are the factors that influence movement patterns and habitat use of coastal cutthroat trout in isolated basins?

The purpose of this study is to examine seasonal distribution patterns and habitat use of coastal cutthroat trout in an isolated headwater stream of the Oregon Coast Range. Specific objectives were to: 1) determine the distribution of coastal cutthroat trout at four spatial (unit, reach, segment, and basin) and four temporal (day, week, month, study period) scales, and 2) evaluate environmental and physical variables that may influence distribution, and 3) evaluate ontogenetic (size class) effect on distribution. To address these objectives, distribution of coastal cutthroat trout was assessed in a small watershed isolated above a barrier to anadromous salmonids, and the locations of tagged and marked fish were monitored over a period of 14 months.

CHAPTER 2: STUDY AREA AND METHODS

STUDY AREA

The study was conducted in Camp Creek, a stream that flows west through the Oregon Coast Range for 20 km before joining Mill Creek, a tributary to the Umpqua River. The study area was located above a 4-m waterfall that is approximately 13 km upstream from the confluence of Camp and Mill creeks. The mainstem extended 7 km above the barrier, and there were four fish-bearing perennial tributaries with a cumulative length of approximately 3 km (Figure 1). In addition, there were several small ephemeral tributaries that only flowed during high discharge periods in the winter months. The drainage area was approximately 1,500 ha.

The study area is characterized by steep canyons of sedimentary rock (Bateman formation) and a bedrock dominated stream channel (BLM 1995). Elevation ranges from 40 m (above mean sea level; ABS) at the junction with Mill Creek to 420 m (ABS) at the upper end of the study area. Precipitation is primarily rainfall, occurring from November through March, averaging 100-160 cm annually (BLM 1995). Average annual precipitation measured at Elkton, Oregon (15 km N of the study site) from 1948 to 2001 is approximately 134 cm (Western Regional Climate Center 2001). Runoff patterns in the study area are characteristic of the southern Oregon Coast Range; high flows (>1 $m^3 \cdot sec^{-1}$) associated with rainfall events occur from November through March, and low flow (≈ 0.05 $m^3 \cdot sec^{-1}$) conditions are prevalent from June through October. Although air temperatures are usually moderated by mild maritime weather, maximums can reach 42°C in the summer and occasionally minimums can drop below -17°C in the winter. Fifty-year average (1951 to 2001) maximum and minimum air temperatures are 9.4°C and 2.2°C for January and 28.8°C and 10.7°C for July (Western Regional Climate Center 2001).

Vegetation in the basin consists primarily of red alder *Alnus rubra*, vine maple *Acer circinatum*, bigleaf maple *Acer macrophyllum*, and salmon berry *Robus spectabilis* in the riparian zone (BLM 1995). The dominant overstory species is Douglas-fir *Pseudotsuga menziesii*, but western red cedar *Thuja plicata,* and western hemlock *Tsuga heterophylla*

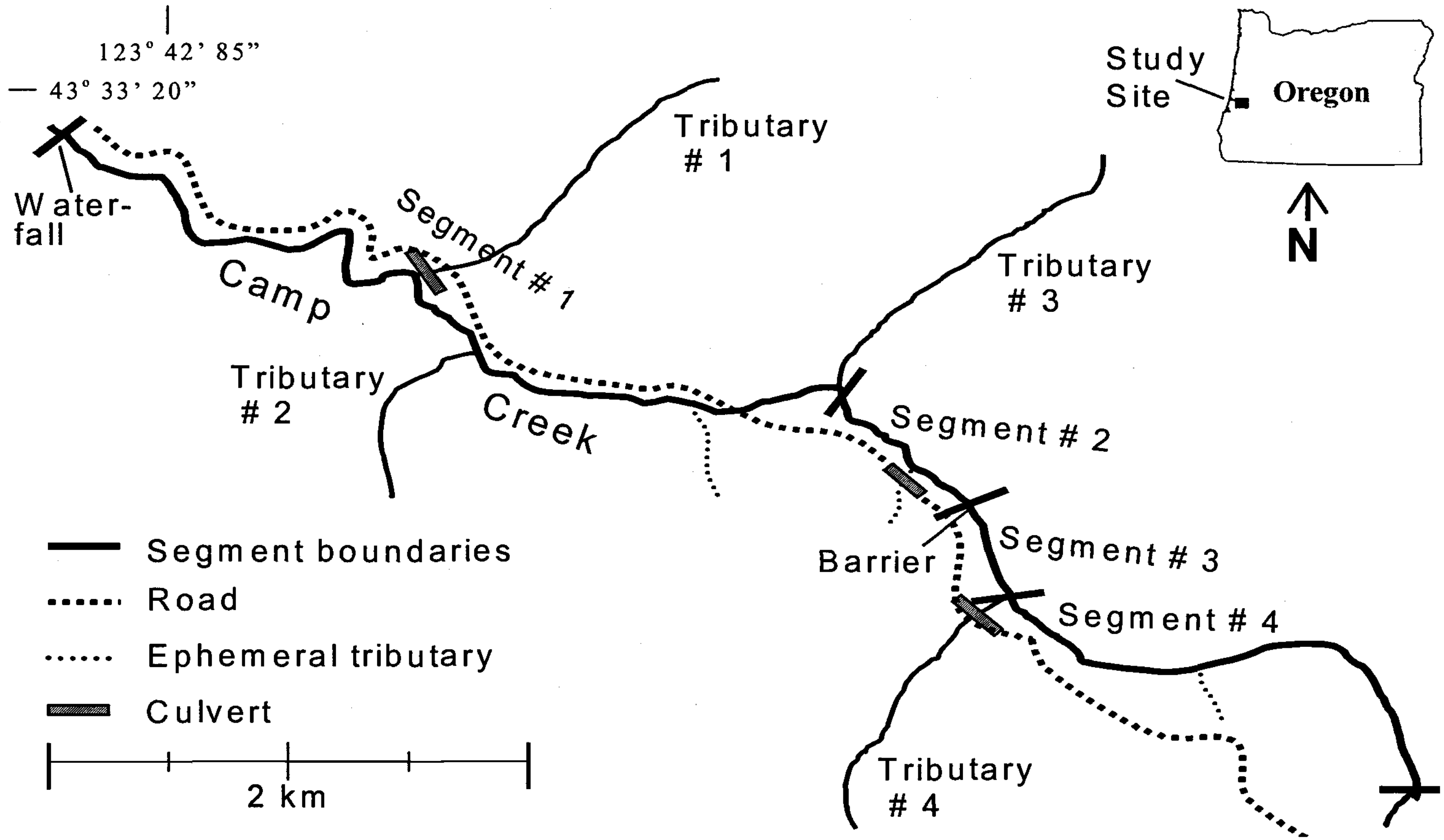

Figure 1. Camp Creek study area, Douglas County, Oregon. Ephemeral tributaries are shown as dotted lines. Dashed line is paved road. Shaded bar indicates tributaries passing through culverts. Solid bars indicates segment boundaries.

also occur (BLM 1995). Coastal cutthroat trout was the only salmonid species present in the study area. Other aquatic vertebrate species included reticulate sculpin *Cottus perplexus* and pacific giant salamander *Dicamphadon tenebrosus*.

The U.S. Bureau of Land Management (BLM) manages the entire watershed above the migration barrier. Timber harvest in the study area did not begin until the 1940s. Approximately 51% of the watershed in the study area has been harvested in the past 60 years, primarily in the upper portions of tributaries and ridge tops (BLM 1995). Old-growth Douglas-fir and red cedar are present throughout the riparian corridor (BLM 1995). Currently, most of the upper 10 km of the Camp Creek watershed, including the study area, is allocated as a late-successional reserve and is being managed to achieve late-successional characteristics (late-successional reserves were created to maintain, increase, or develop old-growth characteristics, and are located where they support regional biological diversity; BLM 1995). A paved road follows Camp Creek through the lower 5 km of the study area. Culverts exist on two perennial tributaries (tributary #1 and #4), and one ephemeral tributary (Figure 1).

METHODS

Habitat and environmental inventory

A nested hierarchical system of stream classification (Frissel et al. 1986) was used to characterize the stream at the segment, geomorphic reach, and channel unit scales. During the summer low-flow period in June 1999, segment boundaries were delineated in the field at (1) junctions with tributaries that were contributing > 15% of mainstem discharge, and (2) geologic barriers to fish migration (waterfalls > 4 m). In each segment, geomorphic stream reaches were classified by major changes in gradient, substrate, bed morphology, and pool spacing (Montgomery and Buffington 1997). Minimum length for geomorphic reaches was ≥ 10 channel-widths. Channel units were categorized as pool, riffle, cascade, or step (Bisson et al. 1982). During field surveys, gradient, wetted width, channel unit length, maximum pool depth, dominant and subdominant substrate type, large wood abundance (> 30 cm diameter and > 3 m in length), riparian vegetation, habitat type, reach type, channel type, and channel and valley form were measured for each unit (Bisson et al. 1982; Platts et al. 1983). Each pool and cascade unit was enumerated and marked for subsequent identification.

Water temperature and stream-discharge data were collected during the study period. Ten temperature data loggers (Optic StowAway, Onset Computer Co.) were placed in the watershed. In June 1999, a staff gage was installed at the lower end of the study site, and the water height was measured on each subsequent visit. Discharge was measured at the staff gage on 12 occasions to establish a stage-discharge relationship (Buchanan and Somers 1969) .

Fish sampling

Coastal cutthroat trout were captured primarily with electrofishing (variable waveform backpack electroshockers); however, from December through March, angling was a more effective means of capture because of high discharge, decreased water clarity, and cold water temperatures. Fish were sampled bimonthly beginning in June 1999, except from December through March when sampling occurred monthly because of the low number of cutthroat trout captured. The adipose fin was removed from all captured fish, and each individual was measured (fork length to the nearest mm) and weighed (to the nearest 0.1 g). Channel unit number and type were recorded at the site of capture. A sub-sample of cutthroat trout > 70 mm received a passive integrated transponder (PIT) tag by injection into the body cavity (70 mm is minimum size limit for PIT tags). These tags allowed identification of individual fish using a hand-held scanner. Fish that did not receive a PIT tag were given a unique combination of fin clips that identified original capture location at the segment scale. Recaptured cutthroat trout were inspected for unique fin clips or scanned for PIT tags, and, if no marks were observed, they received the appropriate segment-scale fin clip.

Because sampling inefficiency during the high-water period (December-March) hindered my ability to recapture PIT-tagged fish, radio telemetry was used to monitor individual fish. From 19-22 January 2000, 20 adult coastal cutthroat trout (> 150 mm) were captured throughout the lower 5 km of the mainstem of Camp Creek by angling, and radio transmitters were surgically implanted in the body cavity. An additional 15 tags were implanted from 9-11 February 2000. Fish were weighed upon capture to insure that all radio-tagged cutthroat trout would have a transmitter-to-body weight ratio of < 5%. Fish were released at their capture site upon recovery from the surgery process. The gender of each fish was determined during surgery. Transmitters recovered from the stream bottom and stream bank were implanted on 7 March (n = 3) and 4 April (n = 2). Surgical techniques were similar to those described by Young (1995), but clove oil was used as the anesthetic and there was no trailing antennae. Transmitters and coiled antennae formed single units sealed in epoxy. Transmitters weighed either 1.9 g or 2.4 g (model 384 and 393, respectively, Advanced Telemetry Systems [ATS], Isante, Minnesota).

An ATS scanning receiver with a hand-held loop antenna was used to locate radio-tagged cutthroat trout. Between 22 January and 19 June 2000, searches were conducted during daylight hours, 3-6 d/week (depending on water and weather conditions). Nocturnal observations were conducted on eight occasions between 24 February and 19 April. Approximate locations were determined from the road paralleling the stream. Subsequently, precise locations were estimated by triangulation while walking the streambank and wading. Pre-study trials revealed that location accuracy was within 1 m of the transmitter. Recovery of transmitters in the stream (n = 2) and on the bank (n = 3) in thick vegetation revealed that locations were accurate to < 1 m. For each relocation, segment, reach, and channel unit number, channel-unit type, fish location in channel unit, cover used by fish and type of cover, and time of observation was recorded. General comments on weather, water conditions, and the individual fish were also recorded.

To estimate the number of coastal cutthroat trout emigrating from the Camp Creek study area, a rotating fish trap (1.5-m orifice) was installed below the waterfall at the lower study boundary. The trap was deployed on 25 February 2000 and operated continuously until 19 June when discharge was no longer adequate for the trap to function. Fish were collected from the trap 5 d each week. Migrating cutthroat trout were counted, measured, weighed, inspected for fin clips or PIT tags, and given a unique "trap" fin clip. To estimate trap efficiency, captured cutthroat trout were released 250 m upstream of the trapping site, and the number of recaptured "trap" fish was divided by the total number of fish released above the trap. Trap efficiency could then be used to estimate total emigration out of the basin.

Data summary and analysis

Relocation data were used to evaluate scales of movement, movement patterns, and direction of movement. Movement of individual fish was defined as the number of channel units moved between relocations and total movement was the sum of all movement for the duration of the study (radio-tagged fish only). Maximum distance between relocations (also defined as "home range" by Young 1996) by an individual was defined as the difference between the most upstream and downstream locations.

The number of channel units was used to measure movement because it was more directly related to habitat use. The maximum distance between relocations was also measured in meters for comparison with previous studies, but interpretation was confounded because of the wide range in channel-unit lengths (range = 2-95 m) in the basin. For example, an individual moving 50 m in one part of the study area may never have left a channel unit, but an individual in another part of the basin moving the same distance may have moved 3-4 channel units. Assessing the number of channel-units between relocations was more ecologically meaningful because it was directly related to the type of habitats that were occupied.

Relocations of radio- and PIT-tagged cutthroat trout were summarized at four spatial scales (channel unit, reach, segment, and basin). Movement of radio-tagged fish was also summarized at four temporal scales (day, week, month, 5 month). To ensure comparability among radio- and PIT-tagged fish, seasonal habitat use and maximum distance moved between relocations was summarized by month. Directional movement was determined by calculating the percentage of cutthroat trout moving upstream, downstream, both up- and downstream, or not moving. Directional movement was then summarized at multiple temporal scales (day, week, month, and 5 month, for radio-tagged fish and recapture period and 14 month, for PIT-tagged fish). The percentage of movements between channel-unit types (e.g., pool-pool, pool-riffle, pool-cascade, and cascade-cascade) was calculated for radio- and PIT-tagged fish. Mean monthly activity (proportion of observations indicating change in location) of all radio-tagged cutthroat trout and activity of individual radio-tagged fish was also calculated. Movement of fin-clipped fish was only detectable at the segment- and basin-scale because fin clips were unique only at the segment scale.

Number Cruncher Statistical Systems (Hintze 1998) was used for all statistical analyses. The relationship between maximum relocation distances measured in channel units and meters were investigated using Pearson's correlation coefficient. Because movement data was not normally distributed, nonparametric tests were used to test for significant differences ($\propto = 0.05$) among groups. Differences in the median relocation distance for four size groups of PIT-tagged cutthroat trout in the mainstem were also examined using this procedure. When a statistically significant difference was detected, the Kruskal-Wallis multiple-comparison test with Bonferroni correction was used to differentiate between groups. Statistical differences in the median distance between relocations of two size groups of radio-tagged cutthroat trout and two size groups of PIT-tagged fish in two tributaries was determined using a Mann-Whitney nonparametric test. In order to define size groups, all fish lengths were plotted in a frequency histogram and groups were determined by natural breaks in the distribution. The Mann-Whitney test was also used to detect differences in the median distance between relocations by male and female radio-tagged fish. A t-test was used to detect differences in habitat characteristics associated with PIT-tagged cutthroat trout that remained in a single channel unit or moved among channel units. A Chi-square test was used to detect differences in observed and expected monthly activity of radio-tagged trout.

CHAPTER 3: RESULTS

HABITAT AND ENVIRONMENTAL INVENTORY

In general, gradient increased and channel-unit length and width, and pool volume decreased as elevation increased in the watershed. Maximum pool depth was variable throughout the watershed and not associated with elevation (Table 1). The length of each reach and segment and the number of channel units in an individual reach or segment varied greatly in the basin. The average reach length was 190 m (range = 66-734 m, SD = 138 m) in the mainstem and 137 m (range = 30-515 m, SD = 126 m) in the tributaries. The average number of channel units per reach was 13 (range = 3-43 channel units, SD = 9 channel units) in the mainstem and 24 (range = 5-86 channel units, SD = 23 channel units) in the tributaries.

The dominant habitat type, by length, was pools (43%) in the mainstem and riffles (46%) in the tributaries (Table 1). The density of pool habitat was 3 pools/100 m in the mainstem and 7 pools/100 m in the tributaries. Approximately 2% of tributary habitat was dry channel and culvert. Bedrock reaches (35%) were the dominant geomorphic reach type in the mainstem by length but only occurred in the lower 4 km of the study area. Step/pool (25%), cascade (20%), and pool/riffle (18%) reach types occurred in similar proportions throughout the mainstem. The dominant geomorphic reach type in the tributaries was step/pool (40%), followed by cascade (22%), bedrock (19%), and pool/riffle (15%).

Water temperature at the lower boundary of the study area remained below 8°C from November through March and then increased to above 10° C from May through September (Figure 2). A high temperature of 17.5° C was recorded on 28 August 1999, and a low of 3.5° C was recorded on 30 December 1999. Average monthly water temperatures in the upper part of the basin (1 km above tributary #4) were warmer than the lowest station from August through November (+ 1-2° C), similar to the lower area from December through February (+/- < 1° C), and cooler from March through July (- 2-4° C).

Table 1. Summary of physical habitat variables in the mainstem and tributaries of Camp Creek, Douglas County, Oregon, June 1999. Mainstem channel segments are delineated by numerals (e.g., 1, 2, and 3), and tributary segments are delineated by tributary number and segment number (e.g., T1-1, T2-1, and T2-2). Numbers in parentheses indicate standard deviations.

			Mean	Total	Mean channel unit			Percent habitat by length		
Segment	Reach	Channel unit no.	Gradient (%)	Length (m)	Length (m)	Width (m)	Maximum pool depth (m)	Pool	Riffle	Cascade
					Main Channel					
1	1-17	1-184	2.9 (1.6)	3479	20.0 (14.9)	5.7 (2.1)	0.67 (0.23)	52.3	39.5	8.2
2	18-20	185-236	5.0 (4.1)	894	18.2 (15.3)	4.6 (2.3)	0.57 (0.15)	31.4	44.7	23.9
3	21-22	237-255	3.6 (1.0)	327	17.2 (11.9)	4.0 (1.9)	0.99 (0.40)	42.4	51.2	6.5
4	23-37	256-488	7.2 (4.3)	2302	11.0 (7.8)	3.7 (1.8)	0.62 (0.23)	34.8	32.4	32.8
5	38	489-503	19.1 (8.7)	229	15.3 (16.8)	3.8 (1.5)	0.53 (0.16)	16.6	14.8	68.6
Mean		100 (101)	5.3 (3.8)	1446 (1406)	15.5 (12.9)	4.6 (2.1)	0.65 (0.24)	42.6	37.6	19.8
					Tributaries					
T1-1	39-48	1-177	9.6 (5.7)	1023	7.3 (5.1)	1.7 (0.7)	0.35 (0.16)	37.8	50.5	9.2
T2-1	49	1-74	11.8 (5.3)	403	6.4 (5.1)	2.1 (0.8)	0.42 (0.53)	31.0	32.5	35.6
T2-2	50	75-96	11.8 (3.9)	99	5.7 (6.3)	1.2 (0.6)	0.30 (0.08)	22.8	73.3	3.9
T3-1	51-57	1-174	7.8 (4.4)	1026	6.5 (5.7)	2.2 (1.0)	0.35 (0.14)	41.4	51.8	6.8

Table 1. (Continued.)

Segment	Reach	Channel unit no.	Mean Gradient (%)	Total Length (m)	Mean channel unit			Percent habitat by length		
					Length (m)	Width (m)	Maximum pool depth (m)	Pool	Riffle	Cascade
					Tributaries					
T4-1	58-59	1-77	7.3 (3.9)	576	8.4 (8.3)	2.2 (1.2)	0.44 (0.20)	26.2	44.9	20.0
T4-2	60-61	78-138	8.5 (4.6)	353	6.4 (5.9)	2.3 (0.9)	0.45 (0.14)	30.4	31.8	37.9
T4-3	62	139-177	10.4 (3.9)	217	7.1 (5.3)	1.4 (0.5)	0.26 (0.10)	15.0	34.8	50.2
Mean		87 (60)	9.2 (5.0)	528 (370)	6.9 (5.9)	1.9 (0.9)	0.37 (0.24)	33.8	45.9	18.1

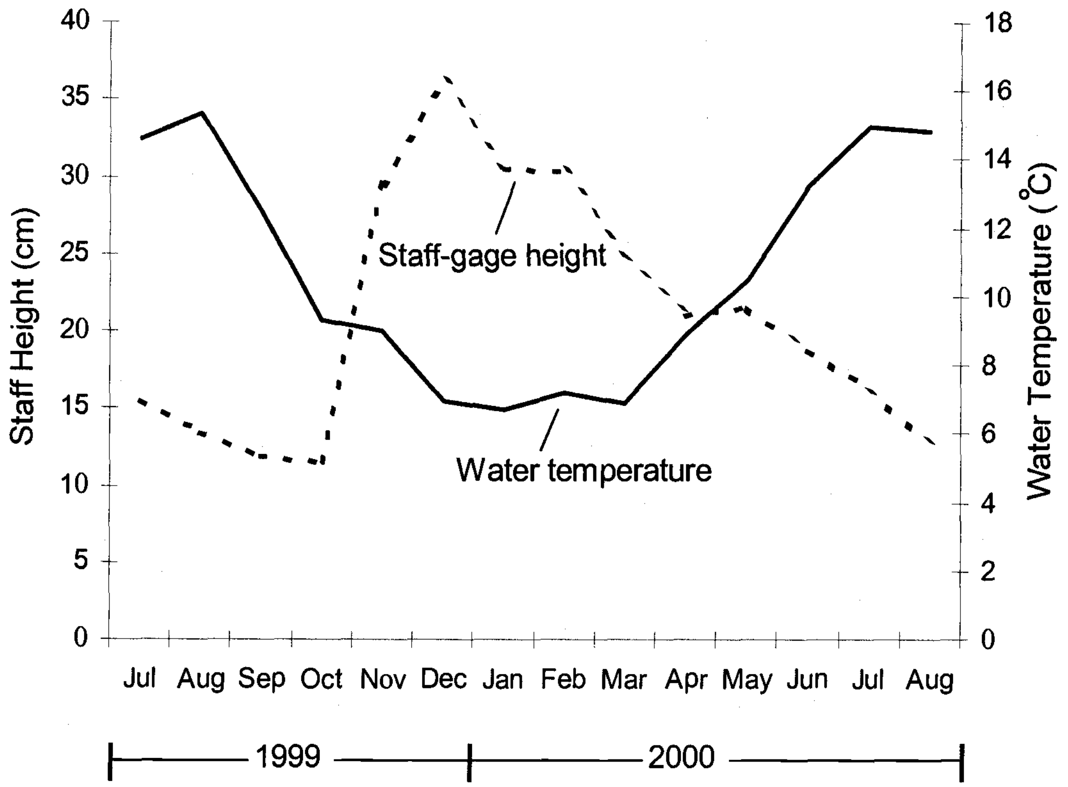

Figure 2. Monthly average staff height (cm) (dotted line) and water temperature (° C) (solid line) recorded above the waterfall at the lower end of the study site in Camp Creek, Douglas County, Oregon, from June 1999 to August 2000.

Staff-gage height in the Camp Creek study area (measured at the lower boundary of the study area) was high from November through May and low from June through October (Figure 2). A high staff-gage height reading of approximately 38 cm (≈ 5 $m^{3} \cdot sec^{-1}$) occurred on 25 November 1999, and a low of 11 cm (≈ 0.014 $m^{3} \cdot sec^{-1}$) occurred on 8 October 1999. Precipitation measured at Elkton, Oregon was 136 cm in 1999 and 101 cm in 2000. Based on the fifty-year average precipitation in Elkton (134 cm), 1999 was slightly above average, and 2000 was below; however, rainfall from January through August of 2000 was normal (Western Regional Climate Center 2001).

SPATIAL MOVEMENT PATTERNS

A total of 8,216 coastal cutthroat trout were captured in the Camp Creek study area from June 1999 through August 2000. Numbered PIT tags were implanted in 753 cutthroat trout (mean FL = 130 mm, range = 72-259 mm, SD = 41 mm); 603 in the mainstem and 150 in tributaries #3 and #4. PIT tags were not inserted into fish in tributaries #1 and #2 because barriers (waterfall and culvert) prevented the movement of fish from the mainstem into the tributaries. A total of 353 (47%) individual PIT-tagged fish were recaptured; 287 of 603 (48%) fish tagged in the mainstem and 66 of 150 (44%) fish tagged in tributaries #3 and #4. Because some individuals were recaptured more than once (range = 1-6 recaptures, mean = 1.7, SD = 1), a total 597 relocations were obtained from this group of fish. A total of 5,322 individuals were also fin-clipped; 4,051 in the mainstem and 1,271 in all four tributaries. A total of 1,902 fin-clipped fish were recaptured; 1,565 (39%) in the mainstem and 337 (27%) in all four tributaries.

Approximately 70% (n = 202) of recaptured PIT-tagged coastal cutthroat trout in the mainstem moved among channel units (> 0 channel units; Table 2). The mean maximum distance between relocations of PIT-tagged cutthroat trout in the mainstem was four times the median (Table 2), indicating a highly skewed distribution (Figure 3). Mean maximum distance between relocations measured in meters was 124 m (range = 0-2,519 m, SD = 346 m), and the median was 28 m. Maximum distance between relocations measured in channel units was highly correlated to maximum distance measured in meters (r = 0.98).

Characteristics of habitat occupied by PIT-tagged fish that changed location in the mainstem differed significantly from habitat of fish that did not move (Table 3). Cutthroat trout that did not change locations inhabited units that were deeper, longer, and had greater volume, than fish moving among channel units.

Approximately 67% (n = 44) of recaptured coastal cutthroat trout originally PIT-tagged in tributaries #3 and #4 moved among channel units (> 0 channel units; Table 2). Eleven fish moved out of the tributaries and into the mainstem, and 2 left the study area and were

Table 2. Summary of movement by coastal cutthroat trout PIT-tagged in the mainstem (n = 287) and tributaries #3 and #4 (n = 66) and by radio-tagged (n = 35) fish in Camp Creek, Douglas County, Oregon, from June 1999 to August 2000. Mean and median channel-units moved, and percent of radio- and PIT-tagged fish moving 0, 1-5, and > 5 channel units are shown. Number in parentheses indicate standard deviation.

	PIT tag - mainstem	PIT tag - tributaries	Radio Tag
Channel-Units Moved		**Percent moving**	
0	30	33	14
1-5	51	39	26
> 5	19	28	60
		Channel units	
Mean	8 (22)	26 (59)	20 (26)
Median	2	2	9

captured in the fish trap. Mean maximum distance between relocations for cutthroat trout that left the tributaries was 116 channel units (median = 133 channel units, range = 21-274 channel units, SD = 88 channel units). Only three fish originally tagged in the tributaries were recaptured more than once in the mainstem, and those fish remained near the previous capture (range = 2-11 channel units). The mean distance between relocations for all cutthroat trout in tributaries #3 and #4 was thirteen times the median (Table 2), indicating a highly skewed distribution (Figure 3). The mean maximum distance between relocations measured in meters was 336 m (range = 0-3,993 m, SD = 869 m), and the median was 22 m. Maximum distance between relocations measured in channel units was highly correlated to maximum distance measured in meters (r = 0.98).

Radio tags were surgically implanted in 40 adult coastal cutthroat trout (> 150 mm) between 26 January and 4 April 2000. The data from five radio-tagged fish were not included in summary or analysis because they were either consumed by predators or shed

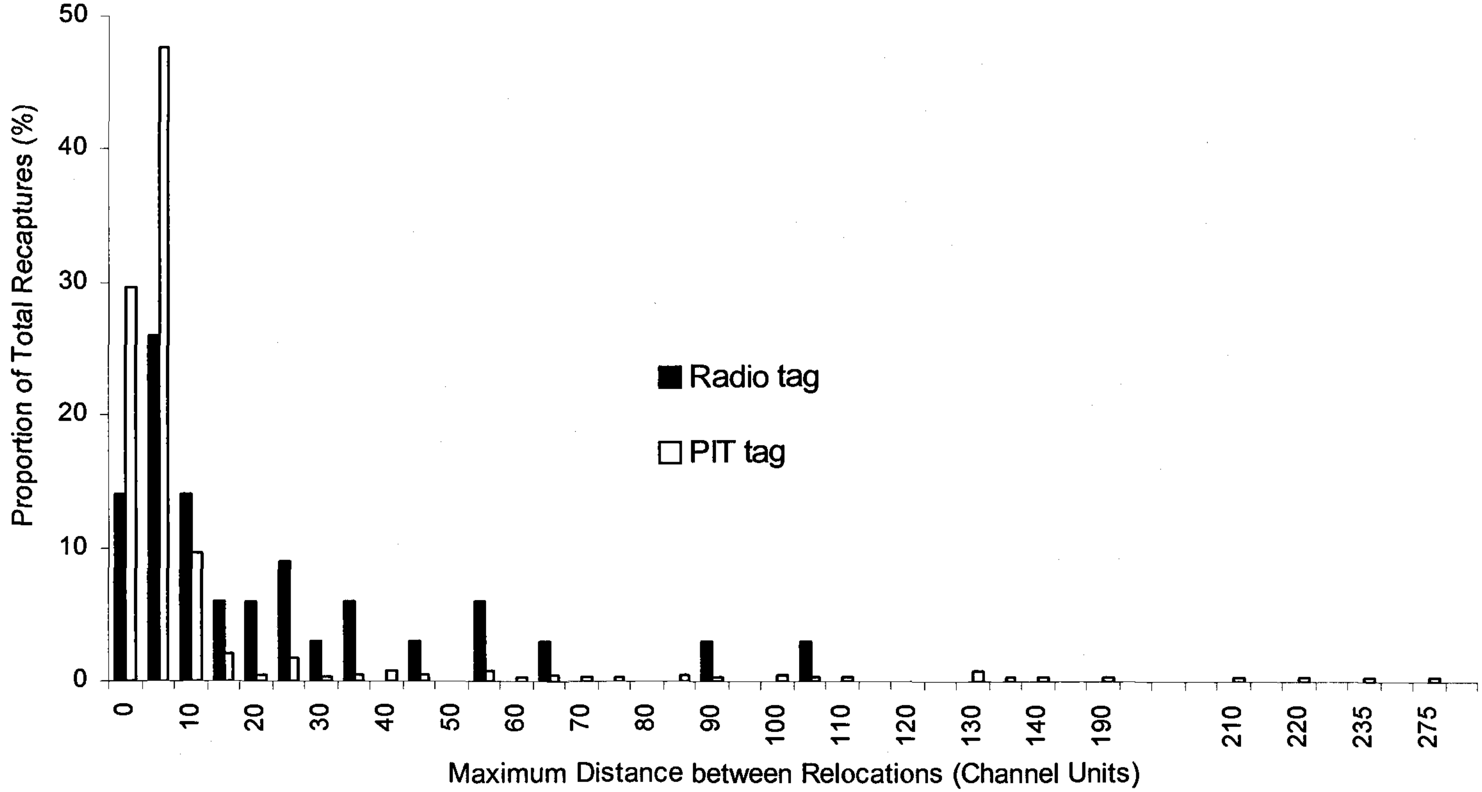

Figure 3. Histogram of the maximum distance moved (channel units) by radio-tagged (n = 35, solid) and PIT-tagged (n = 353, open) coastal cutthroat trout in Camp Creek, Douglas County, Oregon, from June 1999 to August 2000. Maximum distance moved is defined as the number of channel-units moved between the most upstream and downstream location of an individual fish. Intervals are 5 channel-units, except zero stands alone.

Table 3. Habitat characteristics chosen by two groups (0 or ≥ 1 channel units)of PIT-tagged coastal cutthroat trout recaptured in the mainstem of Camp Creek, Douglas County, Oregon, from June 1999 to August 2000.

	Distance between relocations		
Habitat Characteristics	≥ 1	0	P-value
Max Pool Depth (m)	0.65	0.75	< 0.01
Unit Length (m)	21.5	30.1	< 0.001
Pool Volume (m^3)	83.6	142.9	< 0.001

their tag and had fewer than nine relocations. The remaining 35 cutthroat trout were relocated 14-77 times (mean = 59, SD = 16) yielding a total of 2,060 relocations over the 145 d monitoring period (27 January-19 June 2000). On average, fish were relocated about four times per week. Transmitters were surgically implanted into cutthroat trout ranging from 151-229 mm (mean FL = 190 mm, SD = 21 mm) and weighing from 38.1-123.6 g (mean = 71.3 g, SD = 23.3 g). The transmitter-to-body weight ratio of tagged fish ranged from 1.8-4.9% (mean = 3.2%, SD = 0.9%).

Approximately 86% (n = 30) of radio-tagged coastal cutthroat trout moved among channel units (> 0 channel units; Table 2). The mean maximum distance between relocations was more than twice the median (Table 2), indicating a skewed distribution (Figure 3). Mean maximum distance between relocations measured in meters was 281 m (range = 0-1,526 m, SD = 379 m), and the median was 107 m. Maximum distance between relocations measured in channel units was highly correlated with distance in meters (r = 0.96). The total channel units moved by individual radio-tagged cutthroat trout averaged 104 channel units (range = 0-567 channel units, median = 48 channel units, SD = 139 channel units), and 1,411 m (range = 0-7,913 m, median = 868 m, SD = 1,813 m).

Radio-tagged coastal cutthroat trout in this study exhibited four patterns of spatial movement. Five radio-tagged fish (14%) never left their original tagging location. Eight radio-tagged cutthroat trout (23%) exhibited pulsed movement (i.e., exhibited extended periods of little or no movement punctuated by long distance movements of up to 90 channel units). For example, one fish remained in the same unit in which it was tagged for 63 consecutive days. From 14-19 April 2000, this fish moved upstream 31 channel units and then back to its original location where it remained until the battery expired 34 days later. Nine radio-tagged cutthroat trout (26%) frequently moved 1-5 channel units during the monitoring period. The remaining 13 radio-tagged fish (37%) regularly moved 5-50 channel units on a weekly or even a daily basis. Of 21 fish that moved > 5 channel units, 18 returned to their original capture location (non-reproductive homing) at least once during the study period. In addition, five of these radio-tagged fish entered four different tributaries in the basin, three of which were ephemeral.

Median movement differed among length groups for radio- and PIT-tagged cutthroat trout. For radio-tagged cutthroat trout, larger fish moved longer distances than smaller fish. The median maximum distance between relocations of radio-tagged cutthroat trout > 200 mm (21 channel units) was significantly greater than 151-200 mm fish (4 channel units; Mann-Whitney, $P < 0.05$). Relocation distances did not differ significantly among four size classes (70-100 mm, 101-150 mm, 151-200 mm, and > 200 mm) of coastal cutthroat trout PIT-tagged in the mainstem (1, 2, 2, and 2 channel units, respectively; Kruskal-Wallis, $P = 0.07$). In tributaries #3 and #4, the median maximum distance between relocations of 70-100 mm PIT-tagged cutthroat trout was 6 channel units compared to 1 channel unit for fish > 100 mm; however, this difference was not statistically significant (Mann-Whitney, $P = 0.06$). The gender of 24 radio-tagged cutthroat trout that were tracked > 10 times were identified. Male cutthroat trout (n = 13, 21 channel units) moved longer distances than female fish (n = 11, 7 channel units), but the differences were not statistically significant (Mann-Whitney, $P = 0.10$).

Movement among reaches (reach scale) was more common for radio-tagged fish than for all PIT-tagged fish (Figure 4). Segment-scale movement of PIT-tagged and fin-clipped fish in the mainstem was also less than radio-tagged fish (Figure 4). In addition, 20% (n =

13) of PIT-tagged fish from tributaries #3 and #4 changed segments when recaptured in the mainstem of Camp Creek. All cutthroat trout PIT tagged and recaptured in tributaries #3 and #4 (n = 53) remained in their original segment. Basin-scale movement (defined as fish leaving the isolated basin) was not common for tagged or marked fish. No radio-tagged fish and only a few PIT-tagged (n = 7 or 0.9%) and fin-clipped (n = 19 or 0.4%) fish left the basin (Figure 4).

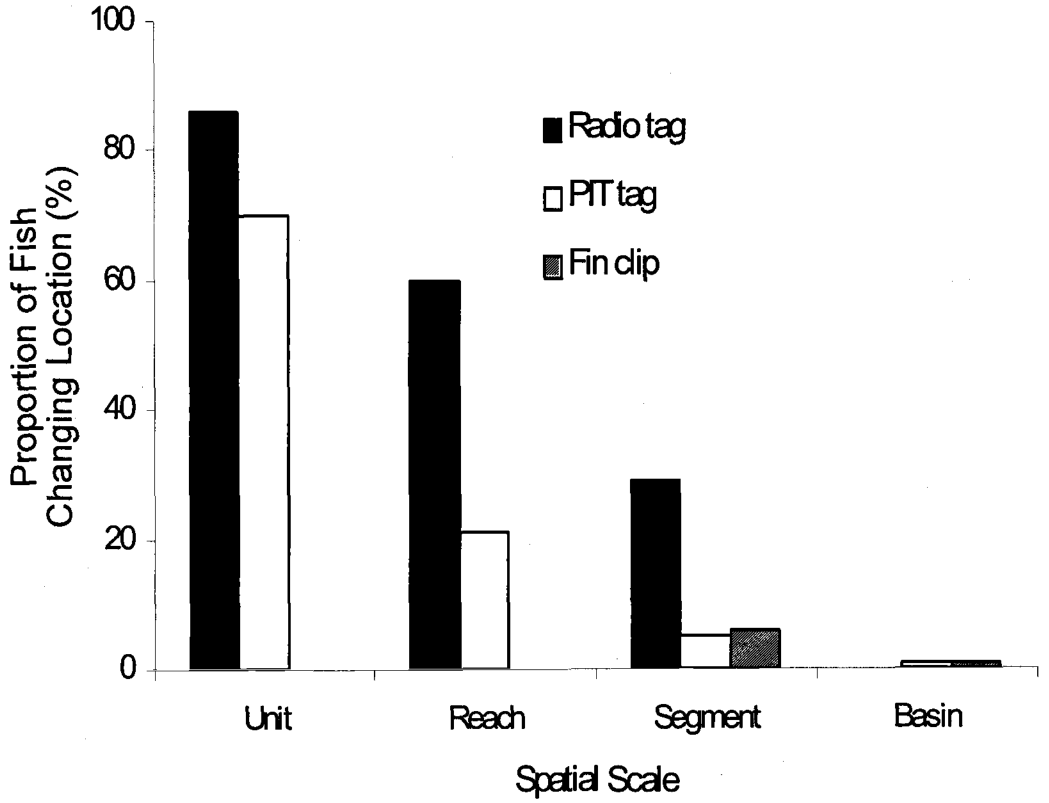

Figure 4. Spatial movement patterns exhibited by radio-tagged (n = 35, solid), PIT-tagged (n = 353, open), and fin-clipped (n = 1,092, shaded) coastal cutthroat trout in Camp Creek, Douglas County, Oregon, from June 1999 to August 2000. The percent of fish moving between channel-units, reaches, segments, and out of the basin are shown. Movement of fin-clipped fish was only detectable at the segment- and basin-scale.

During the period of fish trap operation (25 February-19 June 2000), 63 coastal cutthroat trout moved over the barrier and were captured. Peak emigration occurred in mid-April after water temperatures exceeded 8° C. Adult trout captured in the trap ranged from 94-242 mm (mean = 141 mm). Trout fry (n = 10) from 26-55 mm were first captured on 24 April. No radio-tagged fish moved out of the study area, but 7 PIT-tagged and 19 fin-clipped fish were captured in the trap. Original capture location could be determined to the unit scale for PIT-tagged fish and to the segment scale for fin-clipped fish (Figure 5). Many of these cutthroat trout had moved long distances to leave the basin, a few more than 4 km. Three fish had come from tributaries. Total emigration could not be estimated because few fish were captured in the trap (i.e., few fish were leaving the basin), and there was poor recapture (n = 19 or 30%) of fish released above the trap. In addition, there is evidence that cutthroat trout captured and released above the trap do not continue their

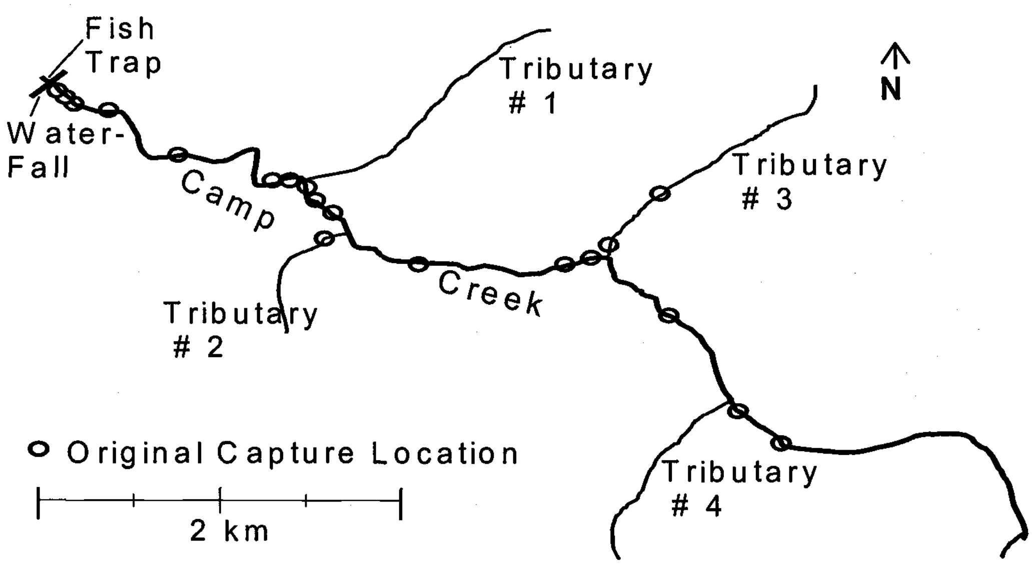

Figure 5. Original capture location (open circles) of PIT-tagged (n = 7) and fin-clipped (n = 19) coastal cutthroat trout captured in the rotary fish-trap in Camp Creek, Douglas County, Oregon, from 25 February to 19 June 2000.

downstream migration. Six of the 63 fish released upstream were recaptured during subsequent electrofishing surveys above the barrier, including a PIT-tagged fish that moved upstream 86 channel units (1,646 m) to its original capture location.

Movement of radio- and PIT-tagged cutthroat trout was also summarized between channel unit types. Most movements (97%, n = 939) of tagged fish were among pools, out of pools, or into pools, and only 3% (n = 28) of movements were between riffles and cascades (Figure 6). Of the 625 movements recorded for radio-tagged fish, 34% (n = 201) crossed reach boundaries, and 4% (n = 25) crossed segment boundaries. Of the 342 movements recorded for PIT-tagged fish, 22.8% (n = 78) crossed reach boundaries, and 6.4% (n = 22) crossed segment boundaries. Tagged fish crossing reach and segment boundaries moved > 5 channel units and > 1 reach type (> 10 channel units), respectively.

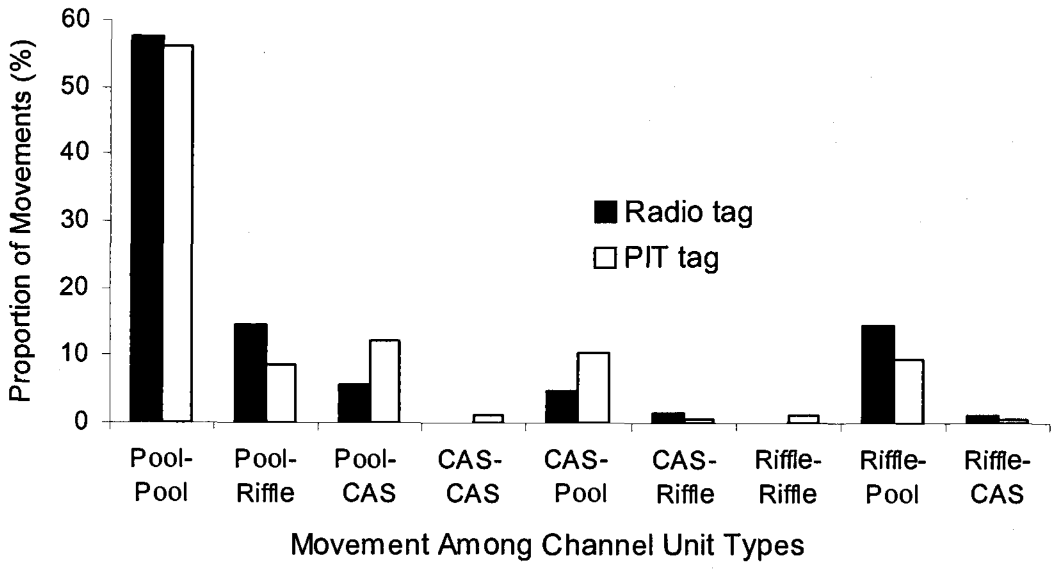

Figure 6. Percent of movements that radio-tagged (n = 625, solid) and PIT-tagged (n = 342, open) coastal cutthroat trout made among channel-unit types in Camp Creek, Douglas County, Oregon, from June 1999 to August 2000. The labels on the x-axis describe the order fish moved between different channel-unit types (e.g., Pool-Pool = fish moved from a pool to another pool, CAS-Riffle = fish moved from a cascade to a riffle).

TEMPORAL PATTERNS OF MOVEMENT AND HABITAT USE

Radio telemetry conducted during daylight hours indicated that 26% (n = 9) of radio-tagged fish did not change locations and were totally hidden under dense cover. Nocturnal observations, however, revealed that these fish were locally active ($\leq$ 2 channel units) at night. These fish emerged from cover at dusk and were active in the same unit, but some occasionally moved 1-2 channel units up- or downstream, before returning to their initial location at dawn. Exclusive nocturnal activity occurred only when water temperatures were below 8° C in January, February, and March. When water temperatures exceeded 8° C in April, all radio-tagged fish were active during the day.

Radio- and PIT-tagged coastal cutthroat trout showed temporal patterns of movement throughout the year. Although most PIT-tagged cutthroat trout in the mainstem were relocated in the same area ($\leq$ 2 channel units) in which they were originally tagged, the proportion of fish moving > 5 channel units per month was low between August and January, increased in February and April, before declining to lower levels in August (Figure 7). Maximum movement of individual PIT-tagged coastal cutthroat trout during each recapture period (Figure 8) was greatest during April when 30% of recaptured fish moved > 20 channel units. Movement patterns of radio-tagged cutthroat trout were similar to PIT-tagged fish during periods when they were monitored simultaneously (February through June). The proportion radio-tagged fish moving > 5 channel units was high from February through April, but by May the proportion had begun to decrease to a low in June (Figure 7). Individual maximum distance between relocations by month for radio-tagged cutthroat trout (Figure 9) also peaked in April when 25% of fish moved > 20 channel units.

Directional movement of radio- and PIT-tagged cutthroat trout in the mainstem showed no significant directional trends by month or recapture period. There was a trend of downstream movement for radio-tagged cutthroat trout from initial tagging location to last relocation; 14 moved downstream (range = 2-78 channel units, mean = 15.5 channel units), 16 remained in the original unit in which they were marked, and 5 moved upstream (range

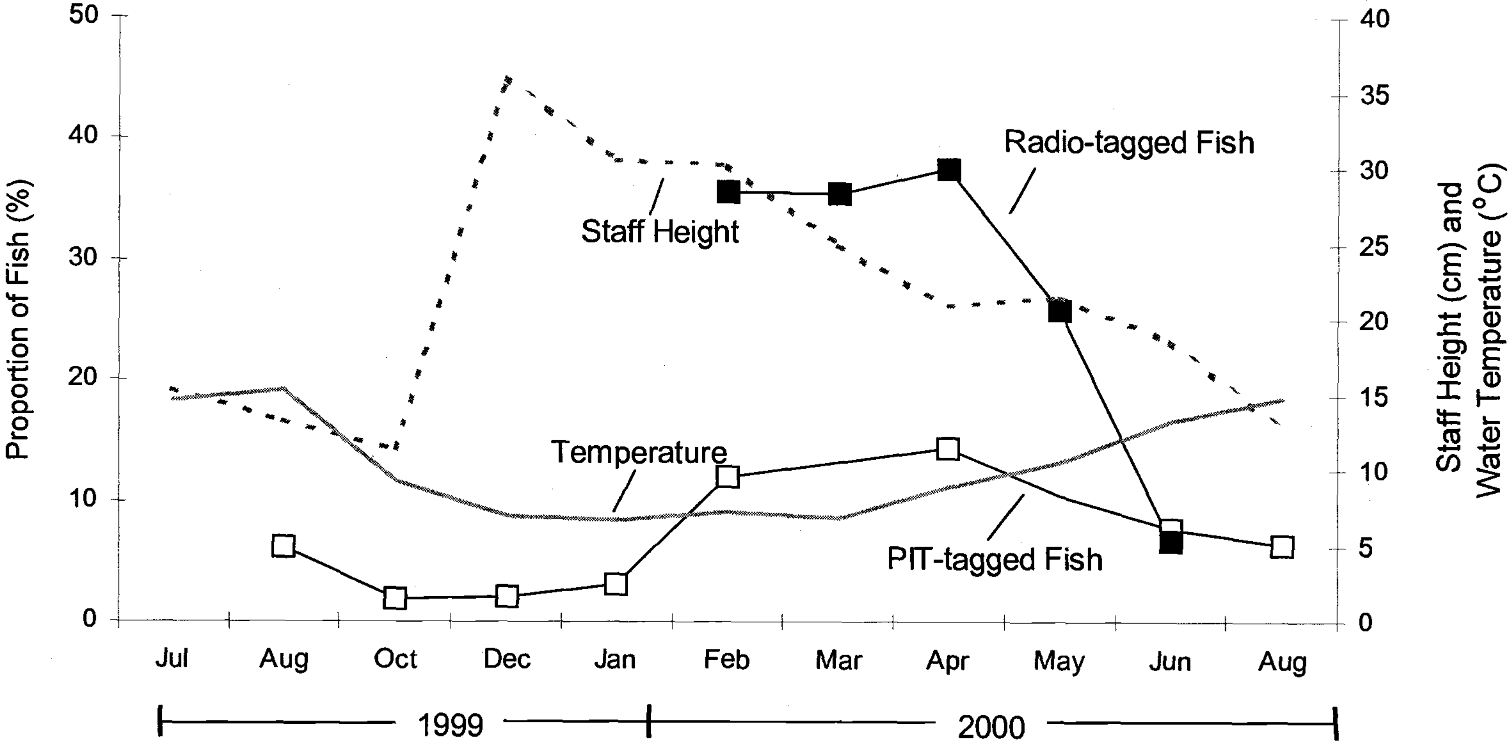

Figure 7. Seasonal movement patterns of radio- and PIT-tagged coastal cutthroat trout in Camp Creek, Douglas County, Oregon, from August 1999 to August 2000. The trend for radio-tagged cutthroat trout (n = 155, solid) is the proportion moving greater than 5 channel units each month. The trend for PIT-tagged cutthroat trout (n=485, open) is the proportion moving greater in than 5 channel units per month for each recapture period. Staff height (cm) and water temperature (° C) are monthly averages measured above the waterfall at the lower end of the study site.

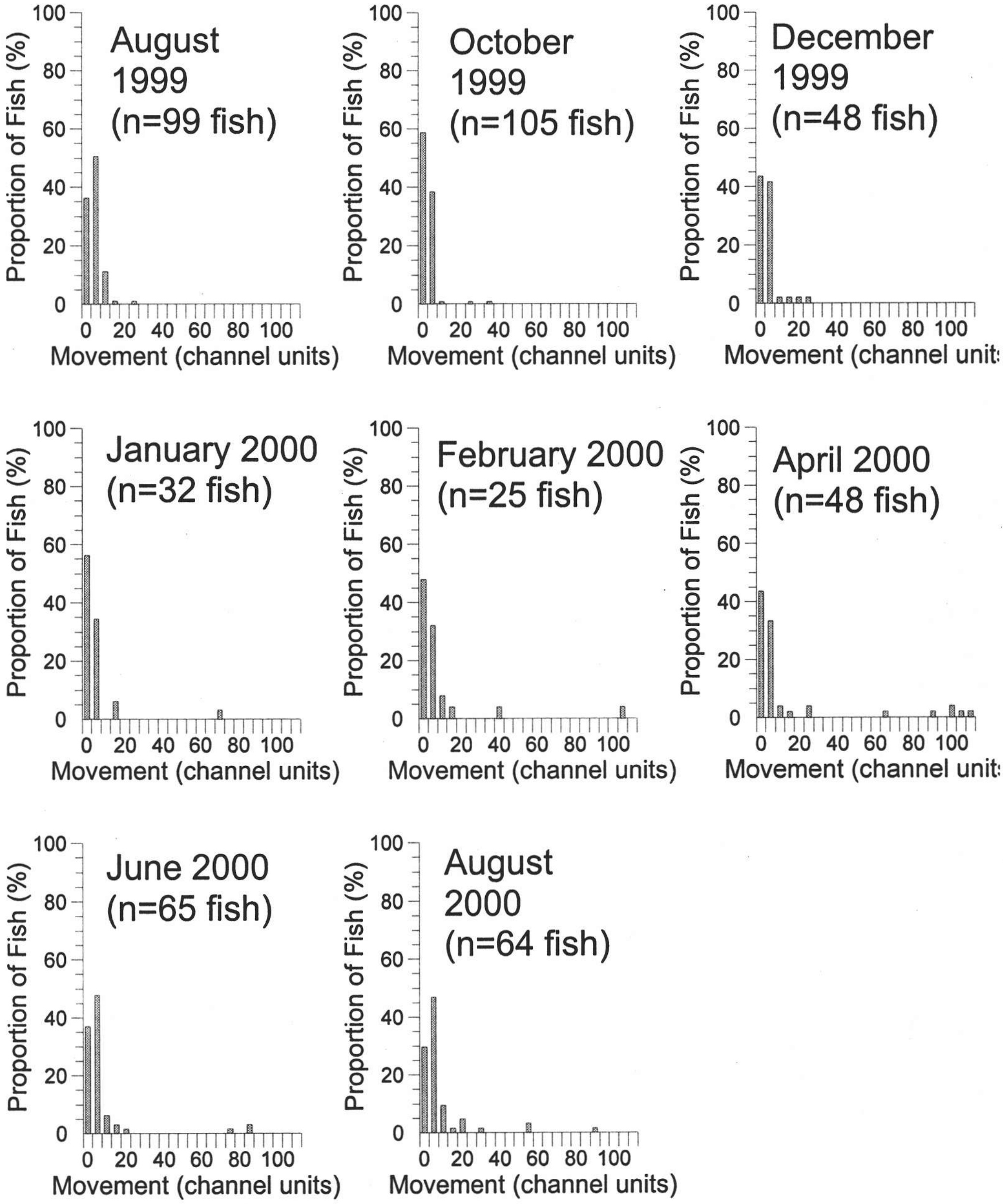

Figure 8. Histogram of distance moved (channel units) for each recaptured period by PIT-tagged coastal cutthroat trout recaptured in the mainstem of Camp Creek, Douglas County, Oregon, from August 1999 to June 2000. Distance moved is the number of channel-units moved by an individual PIT-tagged fish between recapture periods. The x-axis begins with 0 and is in 5 channel-unit intervals (e.g., 0, 1-5, 6-10, 11-15,...,106-110).

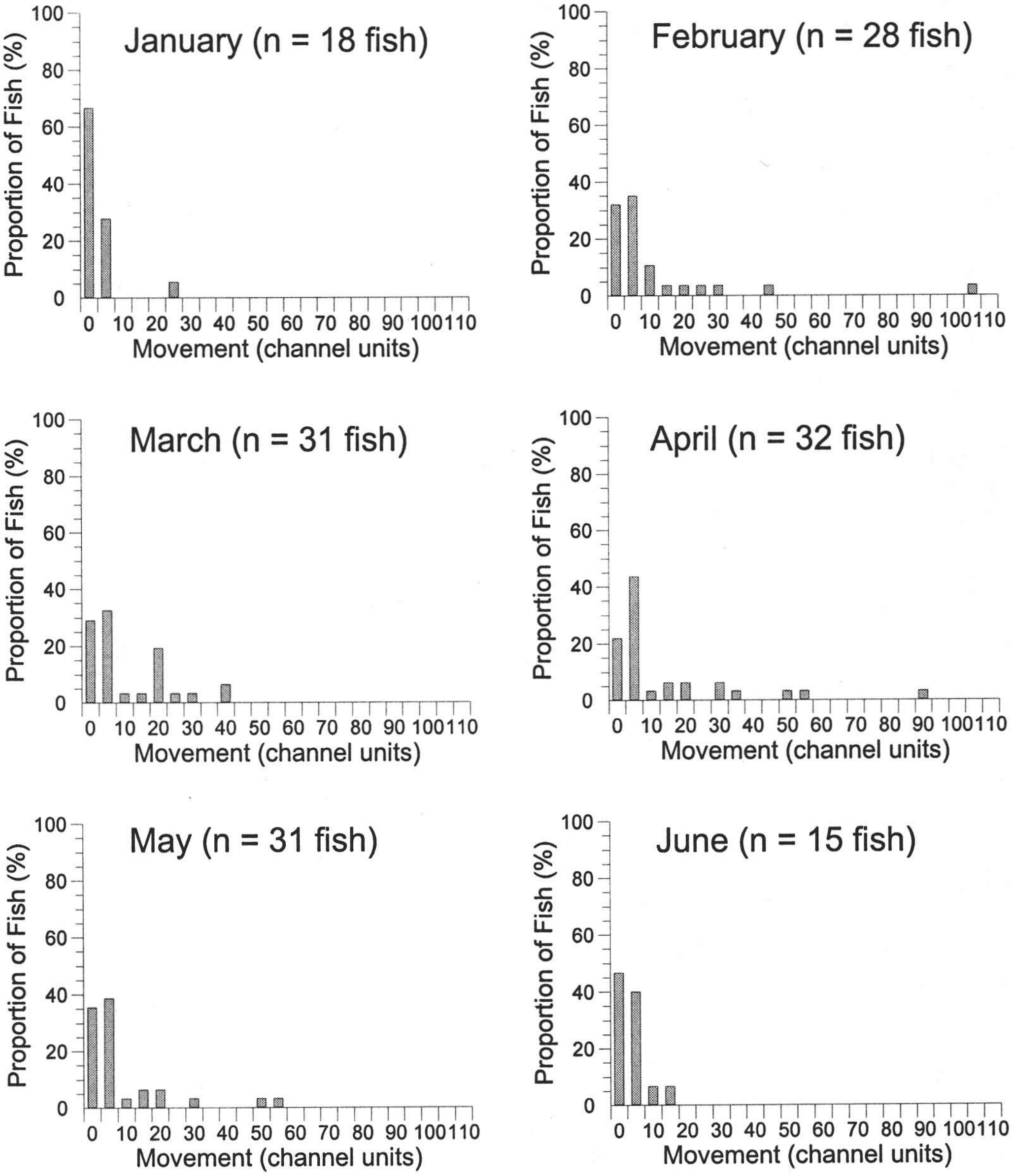

Figure 9. Histogram of maximum distance moved per month (channel units) by radio-tagged coastal cutthroat trout in Camp Creek, Douglas County, Oregon, from January to June 2000. Maximum distance moved is the maximum number of channel-units (distance between most upstream and downstream movements) individual radio-tagged cutthroat trout moved each month. The x-axis begins with 0 and is in 5 channel-unit intervals (e.g., 0, 1-5, 6-10,...,106-110).

1-2 channel units, mean = 1.8 channel units). In contrast, there was a slight upstream trend from first to last capture of PIT-tagged fish; 111 moved upstream (range = 1-113 channel units, mean = 7 channel units), 94 remained in the same unit, and 82 trout moved downstream (range = 1-108 channel units, mean = 11 channel units).

The summary of directional movement (percent moving upstream, downstream, or both) by radio-tagged cutthroat trout at increasingly longer temporal scales (day, week, month, and 5 month) revealed that fish usually move in both directions over longer time periods (Table 4). In addition, summary showed that few radio-tagged fish move over short time periods, and when movement occurred it was equally in the up- and downstream direction. Similar patterns of directional movement were also detected for PIT-tagged fish, although the length of time between recapture samples limited the temporal resolution of summary.

Table 4. Summary of directional movement of radio-tagged coastal cutthroat trout at four temporal scales (day, week, month, 5 month) in Camp Creek, Douglas County, Oregon, from January to June 2000. Directional movement is defined as the percentage of fish moving upstream only, downstream only, both up- and downstream, or not at all. A dash indicates no data at that temporal scale.

	Temporal Scale			
	Day	Week	Month	5 month
Number of observations	2060	502	155	35
Number of observations per fish	2	3-6	9-27	14-77
Percent Moving				
Downstream	15	9	5	0
Upstream	15	10	4	3
Up- and downstream	-	32	56	83
No movement	70	49	35	14

Frequent observations of individual radio-tagged cutthroat trout allowed movement to be summarized at four temporal (day, week, month, and 5 month) and four spatial (unit, reach, segment, and basin) scales (Figure 10). The proportion of fish moving decreases with increasing spatial scale, regardless of the temporal scale of analysis. As temporal scale increased from day to 5 month, the spatial extent of movements also increased.

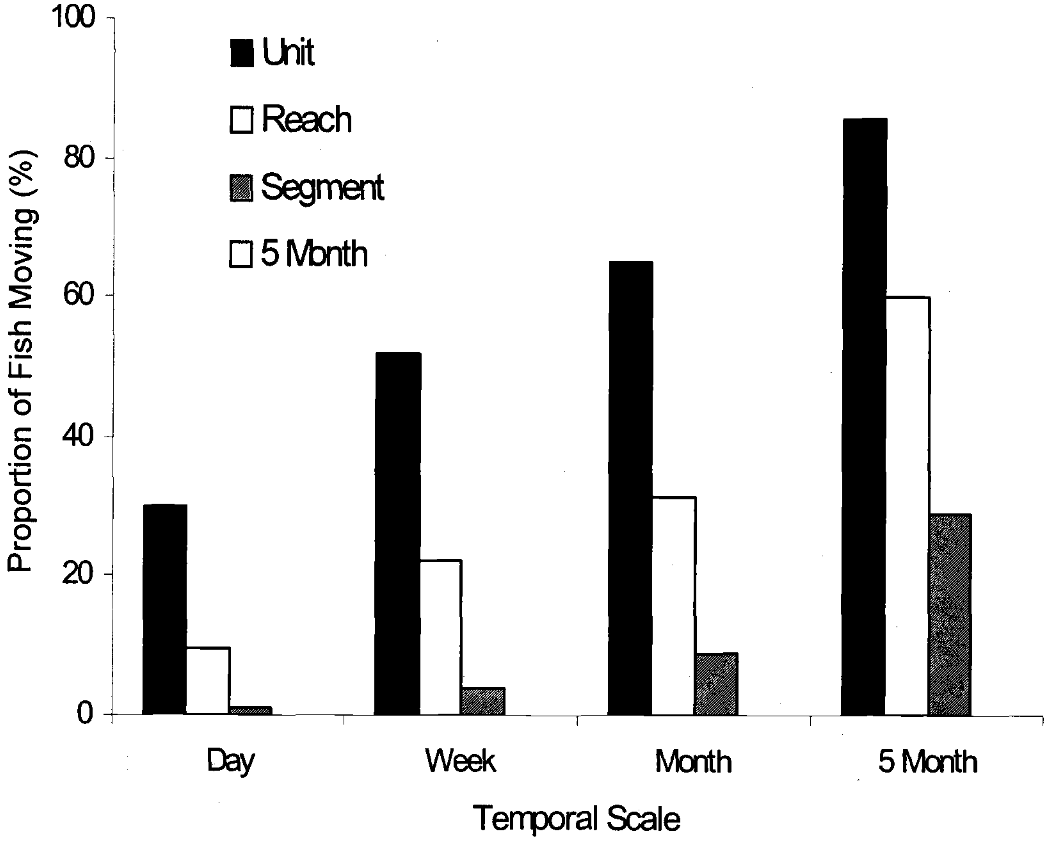

Figure 10. Percent of radio-tagged coastal cutthroat trout moving at each spatial (unit, reach, segment, and basin) and temporal (day, week, month, and 5 month) scale in Camp Creek, Douglas County, Oregon, from January to June 2000. Day temporal scale is a summary of all radio tagged observations (n = 2060). Week is all observations summarized for each week (n = 502), month is all observations summarized for each month (n = 155), and 5 month is all observations summarized for the study period (n = 35).

Pool habitat was used more than cascade or riffle habitat by both radio- and PIT-tagged cutthroat trout (Figure 11). Pool habitats were used 82% of the time by PIT-tagged coastal cutthroat trout and 86% of the time by radio-tagged fish. From January through June 2000, patterns of habitat use were similar for radio- and PIT-tagged fish. In general, cutthroat trout occupied pool habitats almost exclusively from December through March, moved into riffles and cascades from April through June, and moved back into pools from June through October, but in lower proportions than from December through March.

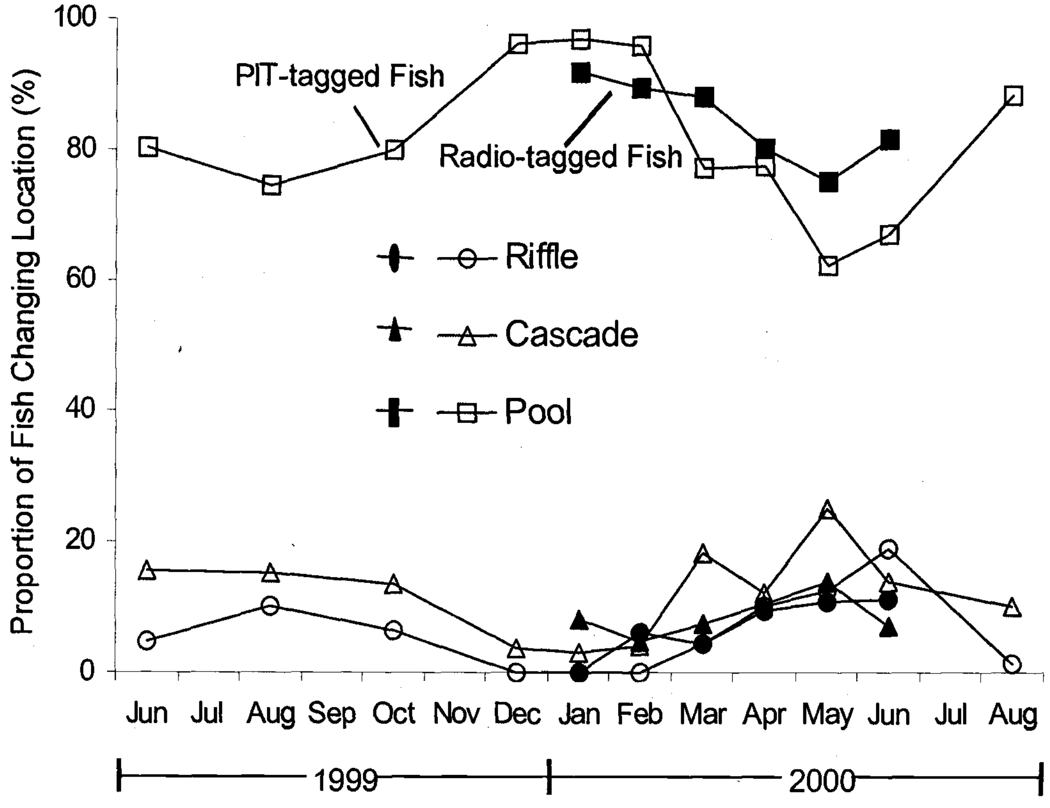

Figure 11. Seasonal habitat use by PIT-tagged (n = 597, open) and radio-tagged (n = 2060, solid) coastal cutthroat trout in Camp Creek, Douglas County, Oregon. The proportion of fish in riffles (circle), cascades (triangle), and pools (square) are shown from June 1999 to August 2000.

Average monthly activity (percent of observations that all fish were found in different locations) of radio-tagged cutthroat trout ranged from a high of 34% in April to a low of 26% in May (mean = 30%); however, there was no significant difference between months (Chi-square = 7.8, $P = 0.10$). Activity of individual fish ranged from 0-69% (mean = 28%, SD = 20%) throughout the study, and more fish were active > 20% (n = 21) of the time than active < 20% (n = 14) of the time.

CHAPTER 4: DISCUSSION

By examining a population of coastal cutthroat trout for a 14-month period in an isolated watershed I was able to describe patterns of movement and habitat use. In the past, most research focused only on short sections of stream, over a limited time, and rarely used multiple techniques. Intensive sampling, along with multiple marking and capture techniques, revealed both fine- and broad-scale spatial and temporal patterns.

Local (unit scale) movement by radio- and PIT-tagged coastal cutthroat trout was common during the study. Many fish also moved between reaches and segments, but few left the basin. Based upon the number of radio- and PIT-tagged fish moving across reach and segment boundaries, it appeared reach boundaries did not restrict movement, but segment boundaries, especially the 4-m waterfall at the lower end of the study site, did act as a filter to fish movement.

The fish trap revealed that only a small percentage of coastal cutthroat trout emigrated from the basin; however, several fish did emigrate long distances in the basin. The continued downstream movement of some marked individuals suggests emigration by a small portion of this population. Previous research has also detected movement over barrier falls in small, isolated streams (Elliot 1987, Northcote and Hartman 1988, Harvey 1998). Unfortunately, these studies did not attempt to quantify movement or determine the distance fish had moved. Although I could not accurately quantify the number of downstream migrants, 63 fish moved up to 4 km to leave the study area. Michael (1983) concluded that the coastal cutthroat trout that left his study area were probably random drifters, few in number, and made no contribution to anadromous populations. I am uncertain what contribution this small number of migrants make to downstream populations in Camp Creek; however, genetic research on above/below barrier populations reveals that there is some downstream flow of genetic information (Chapman and May 1986; Griswold et al. 1997).

Comparisons of PIT-tagged fish that moved and did not move among channel units indicated that habitat characteristics affected movement. Cutthroat trout that did not change channel units occupied deeper and larger pools, longer units, and units and reaches with higher gradients. Heggenes et al. (1991b) found that coastal cutthroat trout that moved < 1 m selected deeper stream areas than fish that moved > 1 m. Kahler et al. (2001) found that coho salmon remaining in a channel unit occupied deeper habitats and habitats with greater area than fish that moved among channel units. In an artificial stream experiment, Lonzarich and Quinn (1995) found that yearling coastal cutthroat trout never occupied shallow pool habitat, even when cover was present. In Camp Creek, individuals that did not move among channel units were smaller than those that moved. Titus (1990) argued that smaller fish are forced to move because they are competitively inferior to larger fish. It is possible that fish that remained in a channel unit occupied suitable habitat that fulfilled all life-history requirements, making movement unnecessary.

Radio- and PIT-tagged cutthroat trout in Camp Creek exhibited at least four spatial movement patterns; 1) no movement (0 channel units), 2) local movement (1-5 channel units), 3) longer distance movements (> 5 channel units), and 4) pulsed movement (shifting between no or local movement and longer movement). In the past, researchers have described two patterns of movement for stream salmonids, sedentary and mobile, and most fish were assumed to be sedentary (e.g., Solomon and Templeton 1976; Hesthagen 1988; Heggenes 1991b). The movement of most (79%) PIT-tagged cutthroat trout in this study is limited (0-5 channel units) and was similar to other mark/recapture studies of salmonids (e.g., Miller 1957; Shetter 1968; Rinne 1982) and non-game fish (Hill and Grossman 1987; Smithson and Johnston 1999) that found limited movement. In an attempt to correct the bias toward restricted movement associated with mark/recapture techniques, I tagged and marked a large number of fish, sampled > 8 km of mainstem and tributary stream repeatedly over 14 months, and attempted to monitor fish emigrating out of the study area. Unfortunately, < 50% of PIT-tagged fish were recaptured and, consequently, I was unable to determine the movement of fish not recaptured. Therefore, the movement of PIT-tagged recaptures probably represents the minimum amount of movement in the study area.

In contrast, radio telemetry in this study may have overestimated movement because only fish > 38 g (≈ > 150 mm) could be tagged, and there was a positive relationship between movement and size for both radio- and PIT-tagged fish. In addition, the telemetry study took place from January through June, a period increased movement was expected, especially for larger fish, because of spawning. Finally, regular observations of radio-tagged fish enabled me to capture frequent and long distance movements more effectively. Telemetry may indicate the maximum amount of movement in the basin and provide specific descriptions on different life-history types. The two methods probably provide a bounded estimate of the upper and lower limits of movement when combined.

I do not believe that movement of radio-tagged cutthroat trout was affected by an average transmitter-to-body weight ratio of 3.2%. Winter (1983) suggested that fish should not be equipped with transmitters that weigh more than 2% of their body weight (out of water). Empirical evidence suggests, however, that the "2% rule" may be unneccesarily conservative. For example, Brown et al. (1999) found that swimming performance of rainbow trout was not altered by transmitters weighing 6-12% of the fish's weight. Researchers conducting field investigations on small potamodromous salmonids concluded that fish were not affected by transmitters weighing up to 5% of their body weight (Waters 1993; Jakober et al. 1998; Muhlfeld et al. 2001).

Frequent observations of radio-tagged fish suggested a pattern of non-reproductive homing. Gerking (1959) defined non-reproductive homing as the choice to return to a place formerly occupied instead of going to other equally probable places. Most radio-tagged cutthroat trout (18 of 21) that moved > 5 channel units returned to a formerly occupied place (a channel unit) at least once, but usually repeatedly. In addition, two radio-tagged fish that did not appear to exhibit homing had PIT tags implanted earlier in the study which revealed they had returned to their original site of PIT tagging.

Researchers have found salmonids will return to their original site of capture when artificially displaced (Miller 1954; Harcup et al. 1984; Halvorsen and Stabell 1990), but this phenomenon also appears to occur more generally. Burrel et al. (2000) observed that brown trout often returned to their original capture location shortly after spawning. Brown and Mackay (1995a) found cutthroat trout returning to the same winter refuge areas in consecutive years. Bachman (1984) discovered that brown trout returned to the same feeding areas over three successive years. Results suggest that coastal cutthroat trout in Camp Creek may move to new areas for feeding or refuge, but then return to a formerly occupied area.

I believe that the non-reproductive homing of radio-tagged fish may explain the limited movement recorded for PIT-tagged fish because, with PIT-tagged fish, it is impossible to distinguish between individuals that did not move and individuals that moved and later returned to their original point of capture (Hilderbrand and Kershner 2000). Furthermore, PIT-tagged fish were recaptured a minimum of 30 days apart, averaging more than 100 days between recapture. In contrast, radio-tagged fish were monitored several times a week, enabling me to capture the frequent, and often extensive, up- and downstream movements.

From February through May, five radio-tagged and two PIT-tagged cutthroat trout were relocated in two perennial (tributaries #3 and #4) and three ephemeral tributaries in the basin. Ephemeral tributaries were < 1 m wide (wetted width) and were only flowing during rainy periods. The use of perennial tributaries is common among potamodromous salmonids (e.g., Wyatt 1959; Brown and Mackay 1995b; Schmetterling 2001), but the use of ephemeral tributaries has been less well documented (Erman and Leidy 1975; Hartman and Brown 1987). Salmonids usually enter tributaries for reproduction (e.g., Erman and Hawthorne 1976; Jonsson and Sandlund 1979; Moring et al. 1986) but can also use these areas as refuge from high water events (Harvey et al. 1999), warm water temperatures (Kaya 1977), and feeding (Brown and Hartman 1988). Harvey (1998) suggested that the use of first- and second-order tributaries is important in the basin-scale population dynamics of coastal cutthroat trout, especially in small, isolated watersheds.

Despite the potential importance of these habitats, ephemeral tributaries are often overlooked during land management activities because they are usually dry from late spring through early fall when presence/absence surveys are conducted. These streams receive little protection from logging, and, if roads are being built, culvert passage is often not considered (Hartman and Brown 1987; Rosenfeld et al. 2000) or is inadequate at moderate to high flows (Schmetterling 2001). For instance, habitat is fragmented in the Camp Creek watershed by three culverts that prevent or impede passage. Habitat fragmentation can reduce the ability of salmonids to move among habitat patches and, thus, diminish their persistence (Rieman and McIntyre 1995; Kruse et al. 2001). Limited access to critical habitats, whether for spawning, rearing, refuge, or feeding, could also reduce fish abundance throughout the basin.

Nocturnal telemetry revealed a diel pattern of fish movement. When water temperatures were < 8° C some radio-tagged fish that were inactive during the daylight hours were locally active at night. Diurnal concealment has been observed in other salmonids during the winter (Cunjak 1988a; Contor and Griffith 1995; Harvey et al. 1999) and during the summer (Fraser et al. 1995; Gries et al. 1998) when water temperatures are < 8° C. Grunbaum (1996) examined coastal (Coast Range) and inland (Cascade Range) populations of rainbow trout in western Oregon during the winter and found that all inland fish, but only some coastal fish were concealed during the day. The author attributed the difference in diel behavior to milder water temperatures in the coastal region.

Nocturnal activity during winter by salmonids has been attributed to increased risk of predation during the day from endothermic predators because of poor swimming capacity by salmonids in cold water (Fraser et al. 1995; Cunjak 1996). I observed many predator scars on fish captured during the study, and three radio-tagged fish were consumed. Piscivores such as garter snake *Thamnophis spp.*, great blue heron *Ardea herodias*, common merganser *Mergus merganser*, raccoon *Procyon lotor*, and mink *Mustela vison* were observed in the basin. Nocturnal activity has also been attributed to salmonids exploiting increased drift rates of aquatic insects at night (Cunjak 1988b; Heggenes et al. 1993; Riehle and Griffith 1993). I observed fish feeding actively in open water at night.

Seasonal movement patterns exhibited by coastal cutthroat trout in Camp Creek reflect responses of fish to changes in discharge and water temperature, and to life-history requirements (e.g., feeding, refuge, and spawning; Figure 7). Cutthroat trout movements decreased from August through October, increased moderately from October through February, peaked in April, and declined in June and August. Hilderbrand and Kershner (2000) reported similar seasonal movement patterns except that movement was low during the winter. There are several possibilities why I recorded increased movement in winter. Hilderbrand and Kershner (2000) only tracked fish once per month during winter and may have missed the frequent and extensive movements that I captured by tracking fish numerous times each week. In addition, water temperatures in the Coast Range of Oregon are warmer than those found in northeastern Utah during the winter, and coastal cutthroat trout would be expected to feed actively during the winter. Angling was the primary means of capturing fish during the winter and all radio- and PIT-tagged fish grew during this period, indicating that fish were feeding during the winter. Movement recorded in February and March could be related to spawning activity as coastal cutthroat trout can begin spawning in January (Trotter 1989). In support of this, the greatest number of redds were observed in April, when distances moved by radio- and PIT-tagged cutthroat trout and activity of radio-tagged fish was greatest. Decreased discharge, increased water clarity, and increased water temperatures (> 8°C) may have also accounted for the increased movement observed in April and May. Fish may have been moving from winter habitats to spring feeding areas since productivity increases in headwater streams with a deciduous canopy in the spring (Connolly 1996).

The limited movement from August through October may be attributed to low discharge ($0.02\ m^3 \cdot sec^{-1}$) that impeded movement among habitats. In addition, PIT-tagged fish lost weight from August through October, suggesting that fish were not meeting food requirements for growth. Increased movement recorded from October through December may be related to rising water levels that allowed cutthroat trout to move out of low-water refuge areas and into habitats with better resources or less competition.

It appears that the perception of movement by fish depends on the temporal scale of observations. At different scales, the probability of fish movement changes and so does the ability to detect movement. Most (70%) radio-tagged fish do not change channel units on a daily basis, however, when movement occurred, it was equally in the up- and downstream direction. At coarser time scales (week and month), more fish moved in both directions and the probability of only up- or only downstream movement was equal. Movement was frequent (86%) at the study period time scale (5 month), and fish usually (83%) moved in both directions. Although movement was not frequent at the finest temporal scale, if I had not been tracking fish 3-6 d/week I may have missed the cumulative movement that occurred over extended periods. In addition, I could have missed recording different behaviors (e.g., homing, nocturnal activity, and pulsed movement), and the frequent occurrence of fish moving both up- and downstream. In order to correctly perceive movement and movement patterns, biologists need to consider these temporal complexities when determining the appropriate temporal resolution and scope of a research project.

The importance of pool habitat in this study is consistent with other populations of coastal cutthroat trout (e.g., Glova 1987; Bisson et al. 1988; Heggenes et al. 1991a). Research has shown that growth rates of young of year coastal cutthroat trout were higher in pools than riffles and adult fish consistently lost weight in riffles (Rosenfeld and Boss 2001). In Camp Creek, radio- and PIT-tagged cutthroat trout occupied pool habitats 85% of the time, although pools made up only 43% of the habitat in the basin by length. Although pool habitat was important to coastal cutthroat trout throughout the year, results show that radio- and PIT-tagged cutthroat trout shift between pool, riffle, and cascade habitat during the year. From fall to winter, fish moved from cascade and riffle habitat to large pools. Cutthroat trout were likely seeking refuge from high water velocities and low water temperatures, similar to winter habitat shifts described for other salmonids (e.g., Cunjak and Power 1986; Baran et al. 1997; Bonneau and Scarnecchia 1998). Harvey et al.

(1999) suggested that coastal cutthroat trout may move into complex pools during the winter when the risk of predation is particularly severe.

As discharge decreased and water temperatures warmed over 8°C in April, many cutthroat trout moved from large-deep pool habitats into riffles and cascades. This habitat shift may have been for foraging because the largest increase in monthly growth of PIT-tagged fish was recorded in April. A greater proportion of cutthroat trout occupied pool habitats during the low-water period (July-October) than in the spring (April-June). Saunders and Gee (1964) observed marked juvenile Atlantic salmon *Salmo salar* moving from riffles to pools when water levels became low and then return to the same riffles once water levels rose. Pools may provide cutthroat trout refuge from low water levels (Thorpe 1994) as stream discharge becomes increasingly reduced before the first fall rains. This condition is common in small coastal streams on the West Coast and results in disconnected habitats in the mainstem and dry channels in the tributaries (Northcote 1992; Northcote and Hartman 1988; Connolly 1996).

The almost exclusive use (97%) of pool habitat in the movements of radio- and PIT-tagged cutthroat trout coincides with the high use of pool habitat during the study. Although radio- and PIT-tagged fish occupied riffle and cascade habitats throughout the year, it is surprising that no radio-tagged and few PIT-tagged cutthroat trout moved only between cascade habitats or riffle habitats. Cutthroat trout use riffle and cascade habitats, but only secondarily to pool habitats. Most cutthroat trout occupy pool habitats, move between pools, and occasionally made short-term forays into riffles and cascades. Some cutthroat trout occupied cascades for extended periods, but when movement occurred it was usually into pool habitats, occasionally into riffles, and rarely into other cascades. It appears that adult cutthroat trout did not occupy riffle habitat for extended periods, but used riffle habitat as migration corridors between pools and cascades, or for short-term feeding opportunities.

Coastal cutthroat trout in Camp Creek do not use any single habitat throughout the year, but move among a series of habitat units (pools, riffles, and cascades), and occasionally at larger spatial scales, to meet all of their life history and habitat requirements. Kocik and Ferreri (1998) defined a series of habitat units that contain the necessary habitat elements to support all life history stages as functional habitat units (FHU). A FHU is a natural partition of a river system, and boundaries are defined by the spatial arrangement of discrete (spawning, fry, parr, seasonal, etc.) habitat elements, dispersal capabilities, and by filters (barriers or impediments) to dispersal (Kocik and Ferreri 1998). It appears that an FHU for coastal cutthroat trout in Camp Creek would involve at least three consecutive channel units (e.g., pool-riffle-pool or pool-cascade-pool), because most movements by radio- and PIT-tagged cutthroat trout were ≤ 3 channel units. However, at certain times of the year, it appears that movements may occur at larger spatial scales. For example, trophic and refuge movements may occur at the reach scale during particularly severe, stressful or opportunistic periods, and reproductive movements may occur at reach- and segment-scales to access patchily distributed spawning habitat in the basin.

The movements of radio- and PIT-tagged cutthroat trout underscore the complexity of coastal cutthroat trout habitat relationships and movement patterns in small headwater streams. Preliminary information suggests that changes in movement patterns and habitat use is linked to physical changes in the stream (discharge and temperature); however, ontological factors (size-class) and life-history requirements (reproduction, refuge, and feeding) also influence how much fish move and where fish are located during particular portions of their life and at particular seasons of the year. In addition, there were pronounced seasonal patterns to movement and movement was largely within and among pool habitats.

The data suggest that most fish commonly move at the unit scale, with larger fish and males moving the furthest. The perception of extent, frequency, and duration of residence at various spatial and temporal scales is influenced substantially by the methods used to monitor fish location. Although each marking, monitoring, and capture technique has its limitations, these tools can be complimentary by providing a more accurate and complete view of movement and habitat use in a population under study. It is critical that managers are aware of these complex patterns of movement and habitat use and that future management strategies include maintenance of stream network connectivity as a priority consideration.

BIBLIOGRAPHY

Bachman, R.A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society 113:1-32.

Baran, P., M. Delacoste, and J.M. Lascaux. 1997. Variability of mesohabitat used by brown trout populations in the French central Pyrenees. Transactions of the American Fisheries Society 126:747-757.

Baxter, C.E. 2002. Fish movement and assemblage dynamics in a Pacific northwest riverscape. Doctoral dissertation. Oregon State University, Corvallis.

Bisson, P.A., J.L. Nielsen, R.A. Palmason, and L.E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. In Armantrout, N.B., ed., Proceedings of a Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information: Portland, Oregon. Western Division of the American Fisheries Society. P. 62-73.

Bisson, P.A., K. Sullivan, and J.L. Nielsen. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout. Transactions of the American Fisheries Society 117:262-273.

BLM (Bureau of Land Management). 1995. Mill Creek watershed analysis. Coos Bay District of BLM, Coos Bay, Oregon.

Bonneau, J.L., and D.L. Scarnecchia. 1998. Seasonal and diel changes in habitat use by juvenile bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarki*) in a mountain stream. Canadian Journal of Zoology 76:783-790.

Brown, R.S., and G.F. Hartman. 1988. Contribution of seasonally flooded lands and minor tributaries to the production of coho salmon in Carnation Creek, British Columbia. Transactions of the American Fisheries Society 117:546-551.

Brown, R.S., and W.C. Mackay. 1995a. Fall and winter movements of and habitat use by cutthroat trout in the Ram River, Alberta. Transactions of the American Fisheries Society 124:873-885.

Brown, R.S., and W.C. Mackay. 1995b. Spawning ecology of cutthroat trout (*Oncorhynchus clarki*) in the Ram River, Alberta. Canadian Journal of Fisheries and Aquatic Sciences 52:983-992.

Brown, R.S., S.J. Cooke, W.G. Anderson, and R.S. McKinley. 1999. Evidence to challenge the "2% Rule" for biotelemetry. North American Journal of Fisheries Management 19:867-871.

Buchanan, T.J., and W.P. Somers. 1969. Discharge measurements at gaging stations. U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Washington, D.C.

Burrel, K.H., J.J. Isely, D.B. Bunnell, D.H. Van Lear, and C.A. Dolloff. 2000. Seasonal movement of brown trout in a Southern Appalachian river. Transactions of the American Fisheries Society 129:1373-1379.

Chapman, D.W., and B. May. 1986. Downstream movement of rainbow trout past Kootenai Falls, Montana. North American Journal of Fisheries Management 6:47-51.

Contor, R.C., and J.S. Griffith. 1995. Nocturnal emergence of juvenile rainbow trout from winter concealment relative to light intensity. Hydrobiologia 299:179-183.

Connolly, P.J. 1996. Resident cutthroat trout in the central Coast Range of Oregon: logging effects, habitat associations, and sampling protocols. Doctoral dissertation. Oregon State University, Corvallis.

Cunjak, R.A. 1988a. Physiological consequences of overwintering in streams: the cost of acclimization. Canadian Journal of Fisheries and Aquatic Sciences 45:443-452.

Cunjak, R.A. 1988b. Behaviour and microhabitat of young Atlantic salmon (*Salmo salar*) during winter. Canadian Journal of Fisheries and Aquatic Sciences 45:2156-2160.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 53:267-282.

Cunjak, R.A., and G. Power. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). Canadian Journal of Fisheries and Aquatic Sciences 43:1970-1981.

Elliot, J.M. 1987. Population regulation in contrasting populations of trout *Salmo trutta* in two lake district streams. Journal of Animal Ecology 56:83-98.

Erman, D.C., and G.R. Leidy. 1975. Downstream movement of rainbow trout fry in a tributary of Sagehen Creek, under permanent and intermittent flow. Transactions of the American Fisheries Society 104:467-473.

Erman, D.C., and V.M. Hawthorne. 1976. The quantitative importance of an intermittent stream in the spawning of rainbow trout. Transactions of the American Fisheries Society 105:675-681.

Fraser, N.H.C., J. Heggenes, N.B. Metcalfe, and J.E. Thorpe. 1995. Low summer temperatures cause juvenile Atlantic salmon to become nocturnal. Canadian Journal of Zoology 73:446-451.

Frissel, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. Environmental Management 10:199-214.

Fuss, H.J. 1982. Age, growth, and instream movement of Olympic Peninsula coastal cutthroat trout (*Salmo clarki clarki*). Master's Thesis. University of Washington.

Glova, G.J. 1987. Comparison of allopatric cutthroat trout stocks with those sympatric with coho salmon and sculpin in small streams. Environmental Biology of Fishes 20:275-284.

Gerking, S.D. 1959. The restricted movement of fish populations. Bio. Rev. 34:221-242.

Gowan, C., M.K. Young, K.D. Fausch, and S.C. Riley. 1994. Restricted movement in resident stream salmonids: a paradigm lost? Canadian Journal of Fisheries and Aquatic Sciences 51:2626-2637.

Gries, G., and F. Juanes. 1998. Microhabitat use by juvenile Atlantic salmon (*Salmo salar*) sheltering during the day in summer. Canadian Journal of Zoology 76:1441-1449.

Griswold, K.E., K.P. Currens, and G.H. Reeves. 1997. Genetic and meristic divergence of coastal cutthroat trout residing above and below barriers in two coastal basins. Pages 167-169 in J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis.

Grunbaum, J.B. 1996. Geographical and seasonal variation in diel habitat use by juvenile (age 1+) steelhead trout (*Oncorhynchus mykiss*) in Oregon coastal and inland streams. Master's thesis. Oregon State University, Corvallis.

Halvorsen, M., and O.B. Stabell. 1990. Homing behaviour of displaced stream-dwelling brown trout. Animal Behaviour 39:1089-1097.

Hartman, G.F., and T.G. Brown. 1987. Use of small, temporary, floodplain tributaries by juvenile salmonids in a West Coast rain-forest drainage basin, Carnation Creek, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 44:262-270.

Harcup, M.F., R. Williams, and D.M. Ellis. 1984. Movements of brown trout, *Salmo trutta* L., in the River Gwyddon, South Whales. Journal of Fish Biology 24:415-426.

Harvey, B.C. 1998. Influence of large woody debris on retention, immigration, and growth of coastal cutthroat trout (Oncorhynchus clarki clarki) in stream pools. Canadian Journal of Fisheries and Aquatic Sciences 55:1902-1908.

Harvey, B.C., R.J. Nakamoto, and J.L. White. 1999. Influence of large woody debris and bankfull flood on movement of adult resident coastal cutthroat trout (*Oncorhynchus clarki*) during fall and winter. Canadian Journal of Fisheries and Aquatic Sciences 56:2161-2166.

Heggenes, J., T.G. Northcote, and A. Peter. 1991a. Seasonal habitat selection and preference by cutthroat trout (*Oncorhynchus clarki*) in a small, coastal stream. Canadian Journal of Fisheries and Aquatic Sciences 48:1364-1370.

Heggenes, J., T.G. Northcote, and A. Peter. 1991b. Spatial stability of (*Oncorhynchus clarki*) in a small, coastal stream. Canadian Journal of Fisheries and Aquatic Sciences 48:757-762.

Heggenes, J., O.M.W. Krog, O.R. Lindas, J.G. Dokk, and T. Bremnes. 1993. Homeostatic behavioural responses in a changing environment: brown trout (*Salmo trutta*) become nocturnal during winter. Journal of Animal Ecology 62:295-308.

Hesthagen, T. 1988. Movements of brown trout, *Salmo trutta*, and juvenile Atlantic salmon, *Salmo salar*, in a coastal stream in northern Norway. Journal of Fish Biology 32:639-653.

Hilderbrand, R.H., and J.L. Kershner. 2000. Movement patterns of stream-resident cutthroat trout in Beaver Creek, Idaho-Utah. Transactions of the American Fisheries Society 129:1160-1170.

Hill, J., and G.D. Grossman. 1987. Home range estimates for three North American stream fishes. Copeia 2:376-380.

Hintze, J.L. 1998. Number Cruncher Statistical Systems, version PASS 6.0. Jerry L. Hintze, Kaysville, Utah.

Jakober, M.J., T.E. McMahon, R.F. Thurow, and C.G. Clancy. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society 127:223-235.

Jonsson, B. 1982. Diadromous and resident trout *Salmo trutta*: is their difference due to genetics? Oikos 38:297-300

Jonsson, N. 1991. Influence of water flow, water temperature and light on fish migration in rivers. Nordic Journal of Freshwater Research 66:20-35.

Jonsson, B., and O.T. Sandlund. 1979. Environmental factors and life histories of isolated river stocks of brown trout (*Salmo trutta* m. *fario*) in Sore Osa river system, Norway. Environmental Biology of Fish 4:43-54.

Johnston, J.M. 1982. Life histories of anadromous cutthroat with emphasis on migratory behavior. Pages 123-127 in E.L. Brannon and E.O. Salo, editors. Salmon and trout migratory behavior symposium. School of Fisheries, University of Washington, Seattle.

Kahler, T.H., P. Roni, and T.P. Quinn. 2001. Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:1947-1956.

Kaya, C.M. 1977. Reproductive biology of rainbow and brown trout in a geothermally heated stream: the Firehole River of Yellowstone National Park. Transactions of the American Fisheries Society 106:354-361.

Kocik, J.F., and C.P. Ferreri. 1998. Juvenile production variation in salmonids: population dynamics, habitat, and the role of spatial relationships. Canadian Journal of Fisheries and Aquatic Sciences 55(supplement 1):191-200.

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 2001. An assessment of headwater isolation as a conservation strategy for cutthroat trout in the Absaroka Mountains of Wyoming. Northwest Science 75:1-11.

Lonzarich, D.G., and Quinn, T.P. 1995. Experimental evidence for the effect of depth and structure on the distribution, growth, and survival of stream fishes. Canadian Journal of Zoology 73:2223-2230.

Meyers, L.S., T.F. Thuemler, and G.W. Kornely. 1992. Seasonal movements of brown trout in northeast Wisconsin. North American Journal of Fisheries Management 12:433-441.

Michael, J.H. 1983. Contribution of cutthroat trout in headwater streams to the sea-run population. California Fish and Game 69:68-76.

Miller, R.B. 1954. Movements of cutthroat trout after different periods of retention upstream and downstream from their homes. Canadian Journal of Fisheries and Aquatic Sciences 11:550-558.

Miller, R.B. 1957. Permanence and size of home territory in stream-dwelling cutthroat trout. Canadian Journal of Fisheries and Aquatic Sciences 14:687-391.

Montgomery, D.R., and J.M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 105(5):596-611.

Moore, K.S., and S.V. Gregory. 1988. Summer habitat utilization and ecology of cutthroat trout fry (*Salmo clarki*) in Cascade Mountain stream. Canadian Journal of Fisheries and Aquatic Sciences 45:1921-1930.

Moring, J.R., R.L. Youker, and R.M. Hooton. 1986. Movements of potamodromous coastal cutthroat trout, *Salmo clarki clarki*, inferred from tagging and scale analyses. Fisheries Research 4:343-354.

Muhlfeld, C.C., D.H. Bennett, B. Marotz. 2001. Fall and winter habitat use and movement by Columbia River redband trout in a small stream in Montana. North American Journal of Fisheries Management 21:170-177.

Northcote, T.G. 1984. Mechanisms of fish migration in rivers. Pages 317-355 *in* J.D. McCleave, G.P. Arnold, J.J.Dodson, and W.H. Neill, editors. Mechanisms of migration in fishes. Plenum Press, New York.

Northcote, T.G. 1992. Migration and residency in stream salmonids - some ecological considerations and evolutionary consequences. Nordic Journal of Freshwater Research 67:5-17.

Northcote, T.G. 1997a. Potamodromy in salmonidae - living and moving in the fast lane. North American Journal of Fisheries Management 17:1029-1045.

Northcote, T.G. 1997b. Why sea-run? An exploration into the migratory/residency spectrum of coastal cutthroat trout. Pages 20-26 in J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis.

Northcote, T.G., and G.F. Hartman. 1988. The biology and significance of stream trout populations (Salmo spp.) living above and below waterfalls. Polskie Archiwum Hydrobiologii 35:409-442.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S. Forest Service General Technical Report INT-138, Ogden, Utah.

Riehle, M.D., and J.S. Griffith. 1993. Changes in habitat use and feeding chronology of juvenile rainbow trout (*Oncorhychus mykiss*) in fall and the onset of winter in Silver Creek, Idaho. Canadian Journal of Fisheries and Aquatic Sciences 50:2119-2128.

Rieman, B.E., and J.D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habtat patches of varied size. Transactions of the American Fisheries Society 124:285-296.

Rinne, J.N. 1982. Movement, home range, and growth of a rare southwestern trout in improved and unimproved habitats. North American Journal of Fisheries Management 2:150-157.

Rosenfeld, J., M. Porter, and E. Parkinson. 2000. Habitat factors affecting the abundance and distribution of juvenile cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 57:766-774.

Rosenfeld, J.S., and S. Boss. 2001. Fitness consequences of habitat use for juvenile cutthroat trout: energetic costs and benefits in pools and riffles. Canadian Journal of Fisheries and Aquatic Sciences 58:585-593.

Saunders, R.L., and J.H. Gee. 1964. Movements of young Atlantic salmon in a small stream. Canadian Journal of Fisheries and Aquatic Sciences 21:27-36.

Schlosser, I.J. 1995. Critical landscape attributes that influence fish population dynamics in headwater streams. Hydrobiologia 303:71-81.

Schmetterling, D.A. 2001. Seasonal movements of fluvial westslope cutthroat trout in the Blackfoot River drainage, Montana. North American Journal of Fisheries Management 21:507-520.

Shetter, D.S. 1968. Observations of movements of wild trout in two Michigan stream drainages. Transactions of the American Fisheries Society 97:472-480.

Smithson, E.B., and C.E. Johnston. 1999. Movement patterns of stream fishes in a Ouachita Highlands stream: an examination of the restricted movement paradigm. Transactions of the American Fisheries Society 128:847-853.

Solomon, D.J., and R.G. Templeton. 1976. Movements of brown trout *Salmo trutta* L. in a chalk stream. Journal of Fish Biology 9:411-423.

Thorpe, J.E. 1994. Salmonid flexibility: responses to environmental extremes. Transactions of the American Fisheries Society 123:606-612.

Titus, R.G. 1990. Territorial behavior and its role in population regulation of young brown trout (*Salmo trutta*): new perspectives. Ann. Zool. Fenn. 27:119-130.

Trotter, P.C. 1989. Coastal cutthroat trout: a life history compendium. Transactions of the American Fisheries Society 118:463-473.

Varley, J.D. and R.E. Gresswell. 1988. Ecology, status and management of Yellowstone cutthroat trout. American Fisheries Society Symposium 4:13-23.

Warren, C.E., and W.J. Liss. 1980. Adaptation to aquatic environments. Pages 15-40 in R. T. Lackey, and L. Nielsen, editors. Fisheries management. Blackwell Scientific Publications, Oxford.

Waters, E. 1993. Winter habitat utilization of radio-tagged coastal cutthroat trout. Master's Thesis. North Carolina State University, Raleigh.

Western Regional Climate Center. "Elkton 3 SW, Oregon: Period of record general climate summary - temperature." 4 June 2001. http://www.wrcc.dri.edu/cgi-bin/cliGCStT.pl?orelkt (12 Nov. 2001).

Wilzbach, M.A. 1985. Relative roles of food abundance and cover in determining the habitat distribution of stream-dwelling cutthroat trout (*Salmo clarki*). Canadian Journal of Fisheries and Aquatic Sciences 42:1668-1672.

Winter, J.D. 1983. Underwater biotelemetry. Pages 371-395 in L.A. Neilsen and D.L. Johnson. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Wyatt, B. 1959. Observations on the movements and reproduction of the Cascade form of cutthroat trout. Master's thesis, Oregon State College, Corvallis.

Young, M.K. 1995. Telemetry-determined diurnal positions of brown trout (*Salmo trutta*) in two south-central Wyoming streams. American Midland Naturalist 133:264-273.

Young, M.K. 1996. Summer movements and habitat use by Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) in small, montane streams. Canadian Journal of Fisheries and Aquatic Sciences 53:1403-1408.