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Title: Persistence of Spatial Distribution Patterns of Coastal Cutthroat Trout in a Cascade Mountain Stream.

Abstract approved:

Robert E. Gresswell Sherri L. Johnson

Previous research in South Fork Hinkle Creek suggested that coastal cutthroat trout exhibit an aggregated spatial pattern across multiple spatial scales. To evaluate the persistence of the observed abundance patterns and identify factors that affect those patterns, half-duplex passive integrated transponders (PIT-tags) were implanted in 320 coastal cutthroat trout ($\geq$ 100 mm, about age 1-plus fish) within our study sections, and in an additional 370 fish throughout the watershed. Nineteen habitat patches of high, or low relative fish abundance were delineated and monitored over a 13-month period. Seasonal habitat surveys quantified channel characteristics in each patch. Immigration and emigration were monitored using stationary and portable PIT-tag antennas along 2 km of stream, including mainstem and tributary habitats. In general, habitat patches that supported a high abundance of coastal cutthroat trout experienced less immigration and more consistent fish abundance. Mainstem study sections maintained the initial relative abundance patterns, but abundances in the tributary sections shifted during the study period. Abundances of PIT-tagged coastal cutthroat trout were consistent over time in mainstem habitats, even though some originally marked fish moved away. In tributary sections relative abundances were much more variable and few originally marked fish remained. The number of instream boulders was positively correlated with fish abundance, pool habitats, and section fidelity of individual fish in mainstem study sections. A majority (70%) of fish detected moving traveled 25 m or less during any season. The greatest number of fish moved during the spring, and the fewest during the winter. Timing of fish movements were not specifically related to high stream discharge or storm events, and fish appeared to move in proportion to the available seasonal discharge.

Persistence of Spatial Distribution Patterns of Coastal Cutthroat Trout in a Cascade Mountain Stream

by
Marc S. Novick

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Marc S. Novick, Author

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

Table | Page

Persistence of Spatial Distribution Patterns of Coastal Cutthroat Trout in a Cascade Mountain Stream

CHAPTER 1: INTRODUCTION

Headwater streams on the western slope of the Cascade Mountains are dynamic, heterogeneous environments subjected to frequent natural and anthropogenic disturbance. These small streams account for the majority of total stream length available to salmonids in most watersheds and are easily altered by forest harvest practices (Chamberlin et al. 1991). Potamodromous coastal cutthroat trout (*Oncorhynchus clarki clarki*) are obligate freshwater inhabitants that are common throughout small streams and are able to exist at the upstream limits of habitable stream (Bryant et al. 2004; Latterell et al. 2003).

Aquatic ecologists working in small streams are challenged with the task of identifying stream habitats, the spatial distribution and temporal persistence (i.e., rate of change) of habitat (Frissell et al. 1986), and the timing and manner in which habitats are used by stream fishes (Schlosser 1995). The temporal variation of stream habitats and the mobility of stream fishes complicate species abundance-habitat association models (Van Horne 1983), and consequently the identification of high quality aquatic habitats is often problematic. Several authors have suggested that habitat-specific movement processes, such as immigration, emigration, and site fidelity can be used to evaluate habitat quality (Winker et al. 1995; Harvey 1998; Belanger and Rodriguez 2001). This assumption implies that habitats of higher quality attract and retain more fish through time.

Studies that include multiple spatial and temporal scales may be necessary to identify the relevant scale for assessing habitat quality. For example, investigation of the spatial scale of habitat use should be relative to the dispersal ability of the organism, and the temporal scale of study should reflect the generation time of the organism or the persistence of available habitats (Warren and Liss 1980; Addicott et al. 1987; Fahrig 1992). Continuous sampling through space or time can yield unique insights that are not detectable with traditional sampling methods, because patterns of natural variability can be observed (Fausch et al. 2002; Gresswell et al. in press). This is particularly true for small forested headwater stream networks, where trout have the capacity to move frequently and over potentially long distances in response to changing environmental or life-history conditions (Gowan and Fausch 1996; Gresswell and Hendricks in review).

Stream discharge is an important environmental factor determining the availability of stream habitat, influencing the movement potential and distribution of stream fishes (Poff and Ward 1989; Trepanier et al. 1996). The timing, magnitude, frequency, and duration of stream discharge determine its effects on stream biota (Poff et al. 1997). For example, low summer flows may reduce available habitat and limit fish movements (Lonzarich et al. 2000). Elevated fall, winter, or spring discharge can alter habitat and displace stream fishes (Matheney and Rabini 1995; Harvey et al. 1999), or facilitate fish movement to newly accessible habitats (Schmitterling 2001; Albanese et al. 2004; Mellina 2005 et al.).

In order to assess habitat quality of a stream network in western Oregon, we evaluated the persistence of abundance patterns and habitat associations of coastal cutthroat trout by monitoring stream sections of high and low relative trout abundance for a period of 13 months. Simultaneous habitat evaluations provided insight into factors affecting distribution patterns in mainstem and tributary streams. Seasonal changes in habitat composition and stream discharge were evaluated in relation to distribution patterns of coastal cutthroat trout. We investigated (1) the consistency of relative abundance patterns of coastal cutthroat trout over time; (2) the underlying habitats associated with areas of high and low relative abundances; and (3) trout movement in a seasonal context, highlighting the role of stream discharge.

CHAPTER 2: METHODS

Study Area

The South Fork of Hinkle Creek, located in the Umpqua River basin at the foothills of the Cascade Mountains, southwestern Oregon (Figure 1), flows through 40-year-old, second-growth conifer forest. The watershed drainage area is about 1,100 ha with a mean annual discharge of 0.20 $m^3 \cdot s^{-1}$. Mean annual precipitation is about 112 cm occurring predominately as rain from October thru April. Snowfall averages < 25 cm annually. Bedrock geology consists of basalt and andesite (Meacham and Steiner 2002). Elevation of the study sections ranges from 499 to 635 m; maximum elevation in the watershed is 1,250 m. Forest vegetation is predominately Douglas-fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*). The forest is managed for industrial timber production. The riparian canopy consists of red alder (*Alnus rubra*), Douglas-fir, and western red cedar. Vine maple (*Acer circinatum*) and sword fern (*Polysticlum munitum*) are common riparian under-story vegetation. Fish species present in the stream include sculpin (*Cottus* spp.), steelhead (*Oncorhynchus mykiss*), and potamodromous coastal cutthroat trout.

Fish Monitoring

During August 2003, a continuous electrofishing survey of all pool and cascade habitats was conducted in the South Fork Hinkle Creek watershed (Gresswell et al. 2003). Coastal cutthroat trout were collected using single-pass electrofishing without block nets. Although this technique underestimates population abundance in a channel-unit, Bateman et al. (2005) demonstrated that it could provide a representative pattern of abundance in a stream network. A half-duplex PIT-tag (23 mm x 4 mm, 0.6 g in air; Texas Instruments, Plano, Texas) was surgically implanted in coastal cutthroat trout $\geq$ 100 mm (fork length), following procedures similar to Zydlewski et al. (2001). Additionally, the adipose fin was removed from each trout implanted with a PIT-tag to indicate that it had previously been captured.

Patterns of relative trout abundance were used to select study section boundaries for subsequent monitoring. A total of 13 mainstem and 6 tributary study sections, ranging in length from 30 m to 298 m, were selected. All study sections were located upstream of the steelhead trout distribution. Study sections consisting of multiple channel-units (i.e., pool, riffle, cascade, and step) were classified into high and low relative abundance categories by graphically interpreting the moving average (window size = 6 channel-units) of coastal cutthroat trout relative abundance patterns obtained from the previous electrofishing survey. Mainstem stream sections having relative abundances of $\leq$ 6 trout and tributary sections with $\leq$ 3 trout were classified as low abundance.

In order to monitor coastal cutthroat trout movement into or out of individual study sections, 24 stationary PIT-tag antennas were installed at the upstream and downstream boundaries of each stream section (Figure 1). Seven stationary PIT-tag antennas were already located at mainstem-tributary junctions throughout the South Fork Hinkle Creek watershed (Gresswell et al. 2003). The stream-width antennas were oriented in a “swim-through” position (Castro-Santos et al. 1996; Barbin-

Zydlewski et al. 2001) perpendicular to stream flow in relatively high-velocity habitats (e.g., riffles or pool tails). Antenna locations within individual channel-units were chosen to minimize multiple PIT-tag detections due to trout remaining in the antenna field for extended periods of time.

Antenna tuning, maximum read range, and detection efficiency were measured weekly. Antenna tuning was checked by calculating wattage (from voltage and amperage measurements) and comparing it to a standard for each stationary antenna. Maximum read range was defined as the furthest distance that a submerged PIT-tag, oriented perpendicular to the antenna, could be detected from the vertical axis of a stationary antenna. Detection efficiency was measured by calculating the proportion of submerged test tags that were detected at each antenna. Neutrally buoyant test tags were released upstream of antennas and allowed to drift through the antenna field at ambient water velocities. Time of each test was recorded so that results could be tested for correlations with stream temperature, stage height, and discharge. Both stage height and discharge were recorded to test for potential effects of water depth and velocity on antenna efficiency.

In addition to fixed monitoring stations, portable PIT-tag antennas (Roussel et al. 2000) were used to relocate trout bimonthly at the channel-unit scale. Portable antennas resembled backpack electrofishing anodes and were operated by a single observer wading upstream. In addition, watershed-scale portable antenna surveys occurred in December 2003, April 2004, and June 2004 (Gresswell et al. 2003). During each survey the PIT-tag code, date, time, channel-unit type, and location were recorded for each trout detected. Portable PIT-tag antennas had an omni directional read range of about 1 m. Sample efficiency was evaluated by using mobile antennas to detect PIT-tagged trout in block-netted stream sections with known numbers of PIT-tagged trout.

Twice during the study additional trout were marked in each stream section to mitigate for fish mortality and possible tag loss. On June 7 and 8, 2004 trout were captured by angling and PIT-tagged. In August 2004 an electrofishing census was conducted to recapture previously marked trout and PIT-tag additional trout.

Habitat Monitoring

A watershed-scale habitat census was conducted concurrently with the August 2003 electrofishing survey, and channel-units were classified as pool, riffle, cascade, or step habitats (Bisson et al. 1981). To track habitat locations over subsequent sampling, individual channel-units located within study sections were numbered and marked with survey flagging. Furthermore, each channel-unit was linked to an existing watershed-scale geographic reference system comprised of numbered tree tags spaced about 20 m apart. This system was used to locate channel-units and fish positions by estimating the upstream or downstream distance to the nearest visible tree tag.

To evaluate possible physical factors that influence trout abundances, for each channel-unit we measured length, active channel width, substrate composition, canopy cover, shrub cover, stream gradient, pool spacing, boulder abundance, and large wood abundance. We chose these habitat variables based on their association with trout abundance and the observed habitat preference of stream trout as reported previously in the literature (Table 1). Individual channel-unit measurements and counts were averaged for stream sections.

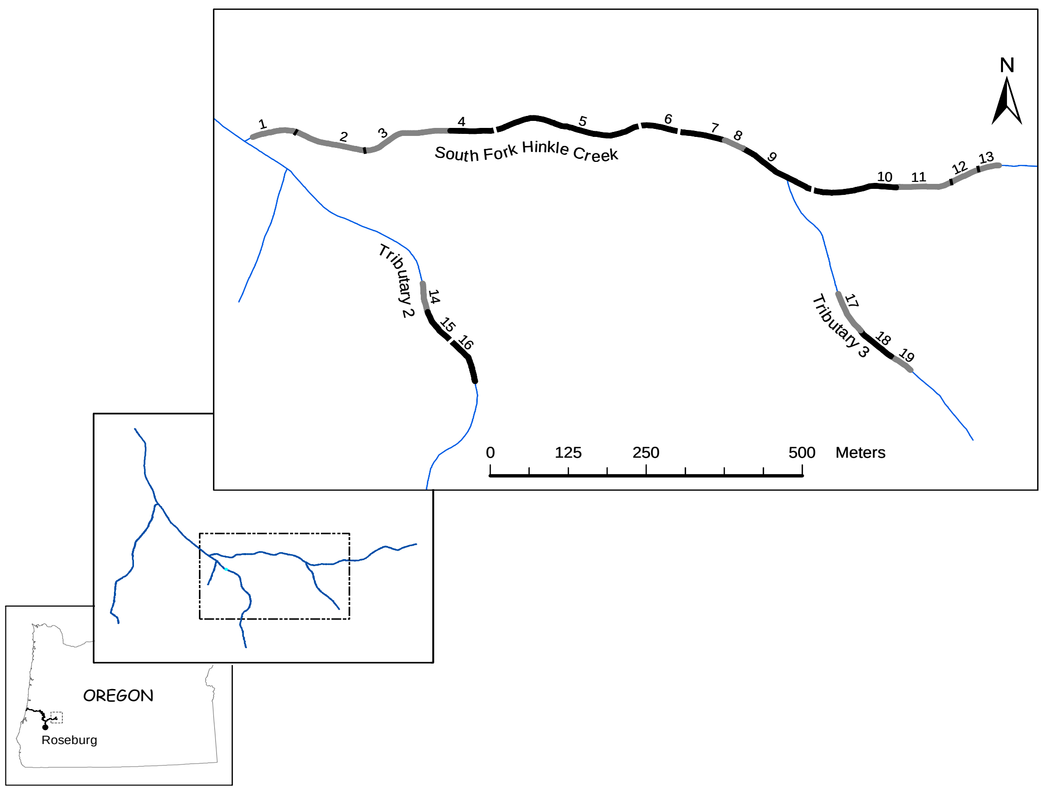

Figure 1. Study sections in South Fork Hinkle Creek, Oregon. Numbers represent individual study sections, black lines indicate high abundance (> 6 trout mainstem, >3 trout tributaries), and gray lines indicate low abundance (≤ 6 trout mainstem, ≤ 3 trout tributaries) sections.

Table 1. Habitat variables measured in South Fork Hinkle Creek, Oregon.

Variable	Method of Estimation	Previous Research
Active channel width (m)	Visual estimation (verified measurements every tenth channel-unit) of the average distance across the channel at bank full flow (Moore et al. 1997).	Laterell et al. 2003; Rosenfeld et al. 2000
Boulder abundance (n)	Count of boulders ≥ 0.61 m diameter located in the active channel of each channel-unit.	Burgess 2001; Warren and Kraft 2003
Canopy cover (%)	Visual estimate (in 10% increments) of the percentage of overhead tree cover above the active channel of each channel-unit (Moore et al. 1997).	Hawkins et al. 1983; Wilzbach and Hall 1985
Shrub cover (%)	Visual estimate (in 10% increments) of the percentage of shrub cover above the active channel of each channel-unit (Moore et al. 1997).	Romero et al. 2005
Channel-unit length (m)	Visual estimation (verified measurements every tenth channel-unit; Moore et al. 1997).	Lonzarich et al. 2002
Wood abundance (n)	Count of individual wood pieces (≥ 10 cm in diameter and ≥ 1 m long) contained in the active channel.	Fausch and Northcote 1992; Harvey 1998; 1999
Pool spacing (m)	The distance between midpoints of sequential pools. Estimated from a dynamic segmentation model of the stream channel.	Buffington et al. 2002; Montgomery et al. 1995; Schlosser 1995
Channel gradient (%)	Slope of the water surface measured for riffles and cascades using a clinometer and statia rod (adjusted for the observer height).	Hicks and Hall 2003; Laterell et al. 2003
Maximum water depth (m)	Maximum water depth of pool habitats measured to the nearest 0.05 m.	Harvey and Stewart 1991; Greenberg et al. 2001
Cobble embeddedness (%)	Visual estimation of percent fine sediments covering cobble substrate (Platt et al. 1983).	Nelson et al. 1992

In order to understand how changes in habitat may have affected coastal cutthroat trout distributions we remeasured specific habitat features in December and April 2003, and August 2004. Each resurvey included identification of discrete channel-units (i.e., pool, riffle, cascade, and step), number of large wood pieces, number of boulders, and the maximum depth of each channel-unit (Table 1).

Another physical variable that we considered important to habitat quality was stream discharge. Stage height was recorded at a gauging station located near the mouth of South Fork Hinkle Creek (about 1 km below the mainstem study section), and discharge was calculated every 0.5 h (USGS station 14319830; http://waterdata.usgs.gov/or/nwis/current/?type=flow). During lapses in data recording, stage height was estimated by simple linear regression between gauges at South Fork Hinkle Creek and Little River near Peel, Oregon (USGS station 14318000; about 15 km southeast of the South Fork Hinkle Creek gauge).

Data Analysis

Data was analyzed using SAS (version 8.1, SAS Institute, Cary, North Carolina) and Number Cruncher Statistical Software (Hintze 2001). Consistency of relative abundance patterns and habitat associations were analyzed separately for mainstem and tributary stream sections. The significance of observed differences between relative abundance categories was initially assessed for August 2003 electrofishing data using one-sided t-tests. Spearman rank correlations were used to examine the initial relationship between coastal cutthroat trout relative abundance and average habitat variables for sections. Those habitat variables that showed the strongest relationship were used as independent variables to model trout abundance in a multiple linear regression. Multiple linear regression models were evaluated based on fit and complexity as indicated by the coefficient of determination (r^2) and Mallow's Cp statistics. The final model represented the most parsimonious use of explanatory variables yielding the greatest explanatory power (Ramsey and Schaffer 2002). Tests of collinearity between correlated predictor variables were evaluated using variance inflation factors (Hintze 2001).

Bimonthly mobile antenna data were analyzed with a repeated measure ANOVA. Relative abundance category (i.e., high or low) was the between factor, individual study sections were subject variables, and bimonthly surveys were the repeated factor. One-sided t-tests of trout abundance in 2004 were used to assess if differences in relative trout abundance between high and low stream sections were present at the end of the study (one year later).

A second component of the observed coastal cutthroat trout distribution was related to the site fidelity of individual trout to individual stream sections. These data were summarized over the entire study period using stationary antenna detections only, and at bimonthly intervals using portable antenna data. Stationary antenna summaries indicated the total number of trout immigrating, emigrating, and remaining in their stream section of initial marking. Site fidelity, assessed using portable antenna data, expressed as the proportion of trout that were in their original section of marking relative to the total number of trout detected in that section. Furthermore, portable antenna data indicated the number of trout detected in each section during a survey that were not detected in that section during the previous survey.

Marked coastal cutthroat trout from all samples (August 2003, June 2004, and August 2004) and detections from stationary and portable antennas were used to analyze spatial movement patterns. Movement extent (the difference between the most upstream and downstream position that a trout was detected) was calculated for each season. Only detections from stationary antennas were used to quantify movement timing and frequency.

Seasonal habitat survey data were analyzed using a one-way ANOVA with repeated measures design to assess habitat change over time. Separate analyses were conducted for the abundance of wood, boulders, and habitat types (i.e., pool, riffle, and cascade). Section category (e.g., high or low relative abundance) was analyzed separately, so there was no between factor, individual section number was the subject variable, and season was the repeated factor. Mainstem and tributary sections were analyzed separately.

The relationship between discharge and coastal cutthroat trout movement was analyzed two ways. First, linear regression was used to predict the number of trout moving using the instantaneous stream discharge occurring during each season as the predictor variable. Second, discharge was summarized seasonally and expressed categorically within each season as high, medium, and low (determined by the 33rd and 66th percentiles of the discharge distribution). We used an electivity analysis (Strauss 1979) to compare the discharge when trout movement occurred to the total available discharge trout were exposed to within each discharge category during each season. A linear index was calculated based on the difference between unweighted proportions of use (i.e., movement) and availability of stream discharge. Electivity index values ranged from +1, indicating that fish movement occurred more frequently at a particular discharge level to -1, indicating that fish movement occurred less frequently at a particular discharge level, with values close to zero indicating fish movement in proportion to available discharge levels (high, medium, and low; Table 5).

CHAPTER 3: RESULTS

Distribution Patterns

A total of 320 coastal cutthroat trout (mean fork length = 122 mm; range = 100 - 190 mm) from the study sections were implanted with PIT-tags. The ratio of PIT-tag weight (0.6 g, in air) to fish body weight varied from <1% to 7% (mean = 3%). Trout were marked during August 2003 (n = 133), June 2004 (n = 37), and August 2004 (n = 150). The longer trout were in the study area the more likely they were to be detected (August 2003: 117/133 or 87%; June 2004: 25/37 or 68%, and August 2004: 39/150 or 26%).

Stationary PIT-tag antennas were operational during 82 - 96% of the study period (mean = 90%). The average maximum read range of antennas was 25 cm upstream and downstream from the vertical axis of the antenna. During field trials of the portable PIT-tag antennas, a mean of 82% (range = 67 - 96%) of PIT-tagged trout were detected. Maximum antenna read range for stationary antennas was not correlated with stream stage height ($r = 0.15$), stream discharge ($r = 0.17$), or water temperature ($r = 0.01$).

During the initial 2003 electrofishing survey, differences in relative abundance between high and low abundance sections were statistically significant (one-sided t-test, $P < 0.01$) in both mainstem and tributary study sections. Mean relative abundance of coastal cutthroat trout in the mainstem was 11 fish in high abundance sections and 3 fish in low abundance sections; mean relative abundances in the tributaries were 7 fish in high abundance sections and 1 fish in low abundance sections. Although the mean relative abundance of trout in mainstem stream sections changed during the subsequent 2004 electrofishing survey, the relative number of trout remained significantly greater (one-sided t-test, $P = 0.03$) in high abundance sections (18 trout) than in the low abundance sections (4 trout). In the tributaries, however, there were no statistically significant differences (two-sided t-test, $P = 0.32$) in mean trout abundance between high (5 trout) and low (4 trout) abundance sections during the 2004 electrofishing survey (Table 2).

Table. 2. Summary statistics of coastal cutthroat trout ≥ 100mm captured during annual electrofishing surveys in mainstem and tributary study sections in South Fork Hinkle Creek, Oregon. N= number of stream sections, Min= minimum, Max= maximum, CV= coefficient of variation.

Year	Stream	Category	N	Mean	Median	Min	Max	CV
2003	mainstem	high	6	15	11	7	31	63
2003	mainstem	low	7	4	4	0	6	55
2003	tributary	high	3	6	6	4	7	27
2003	tributary	low	3	< 1	0	0	1	173
2004	mainstem	high	6	18	13	5	53	100
2004	mainstem	low	7	4	3	1	8	74
2004	tributary	high	3	5	3	3	8	62
2004	tributary	low	3	4	3	2	6	57

During bimonthly surveys with portable antennas relative abundance of marked trout detected in mainstem study sections was always greater than the relative abundance in tributary stream sections (Figure 2). There was also less variation in the relative abundance of marked trout in high abundance sections in the mainstem (CV = 77%) compared to tributaries (CV = 117%). Similarly, low abundance sections in the mainstem exhibited less variation (CV = 98%) than low abundance sections in the tributaries (CV = 166%). Throughout the study, mean bimonthly relative abundance of PIT-tagged coastal cutthroat trout in mainstem study sections was significantly different between high and low abundance sections (repeated measure ANOVA, $F_{1, 91} = 11.62$, $P < 0.01$); however, there were no significant differences in the abundance of PIT-tagged coastal cutthroat trout between high and low abundance sections in tributaries (repeated measure ANOVA, $F_{1, 42} = 2.57$, $P = 0.18$).

According to stationary PIT-tag antenna detections, 38% (50/133) of marked coastal cutthroat trout never left their section of initial marking. In the mainstem, the proportion of coastal cutthroat trout never detected leaving their section of marking was 44% (39/88) in high and 37% (10/27) in low abundance sections. In tributary sections a larger proportion of trout remained in high abundance sections (6%; 1/17) than in the low abundance sections (0%; 0/1).

Over the study period, portable antenna data showed that 33% (35/105) of the marked trout in the mainstem were always relocated in their section of marking, but only about 12% (4/28) of coastal cutthroat trout in tributaries were relocated in their section of marking. More trout in mainstem high abundance sections were detected in their section of marking (46%; 41/88) than in low abundance sections (21%; 6/27). In the tributaries about 25% (4/17) of trout from high abundance sections were never detected elsewhere, but none of the trout in the low abundance sections remained in the same section throughout the study.

Estimates from stationary antennas indicated that the mean proportion of coastal cutthroat trout immigrating into study sections (based on the number of trout marked in each section) throughout the study period was higher in the mainstem (3.8 times more trout than initially marked) than in the tributaries (2.7 times the number initially marked). The mean proportion of immigrants was higher in mainstem low sections (6.1 times the number initially marked there) than mainstem high sections (1.5 times the number initially marked). Likewise, tributary low sections (4.0 times the number initially marked) experienced a greater mean proportion of immigrants than tributary high sections (1.4 times the number initially marked; Table 3). Although average proportions of immigrants were different, the similarity in numbers of trout moving among adjacent high and low abundance sections suggests that trout traveled through multiple study sections. The proportion of untagged coastal cutthroat trout (≥ 100 mm fork length) captured in study sections during the 2004 electrofishing census was about 80% regardless of stream type or section category.

Results from portable antenna surveys suggested that the proportion of coastal cutthroat trout moving among study sections in the mainstem was less than the proportion of trout moving among tributary study sections (Figure 3). The mean percentage of trout moving into mainstem sections was 51% and 37% for high and low abundance sections, respectively. Mean percentages of trout moving into tributary sections were 89% for high abundance sections and 50% for low abundance sections (Figure 3).

Because coastal cutthroat trout were marked with PIT-tags throughout the entire watershed and watershed-scale portable antenna surveys occurred seasonally, it was possible to identify the location of initial marking for trout that entered the study area as well as calculate the extent of movement for coastal cutthroat trout that left the study sections. Thirteen percent (16/128) of trout available for detection downstream of the mainstem study area and 5% (3/64) of trout marked upstream of the mainstem study area entered the study area. Coastal cutthroat trout marked downstream of the study area moved about 30 times farther to reach the study area than did trout immigrating from upstream (275 m and 9 m, respectively). Median extent of movement (i.e., difference between most upstream and downstream locations) was significantly different between trout of mainstem (59 m) and tributary origin (25 m) (Mann-Whitney U-test $P < 0.02$).

Differences in coastal cutthroat trout movement among seasons were evident. The largest number of trout moved during the spring, and fewest during the winter (Table A1; Figure A1). Trout moved farther distances during the fall and moved shorter distances during winter. Although relatively long-distance movements (i.e., kilometers) were observed during all seasons, frequent short-distance movements were common. For example, only about 10% of all trout detected moving traveled farther than 500 m during any given season (Table A1).

The relationship between discharge and the number of coastal cutthroat trout detected moving by stationary PIT-tag antennas was complex, but in general, as discharge increased, the number of trout moving decreased. Closer examination, however, suggests that most detections occurred at or below the median seasonal stream discharge (Figure 4). For example, this relationship (with detection as the response variable and instantaneous discharge as the predictor variable) was best described by a negative exponential function during fall, spring, and summer (Figure 4); the amount of variation in trout movement explained by discharge ranged from 30 to 57%. During winter trout movement was more evenly distributed across a range of discharge values, and the resulting curve was best described by a parabolic nonlinear equation, but only 27% of the variation in movement was explained by the equation. Few trout were displaced or moved during the December 2003 annual bank full event (Figure A2).

Furthermore, comparison of use (i.e., fish movement) to availability of seasonal stream discharge (number of discharge values per category for each season) showed that trout did not move in relation to stream discharge (Table 5). The electivity index values were near zero during most seasons and discharge categories, indicating that trout movement was proportional to seasonal discharge levels (Tables 4 and 5).

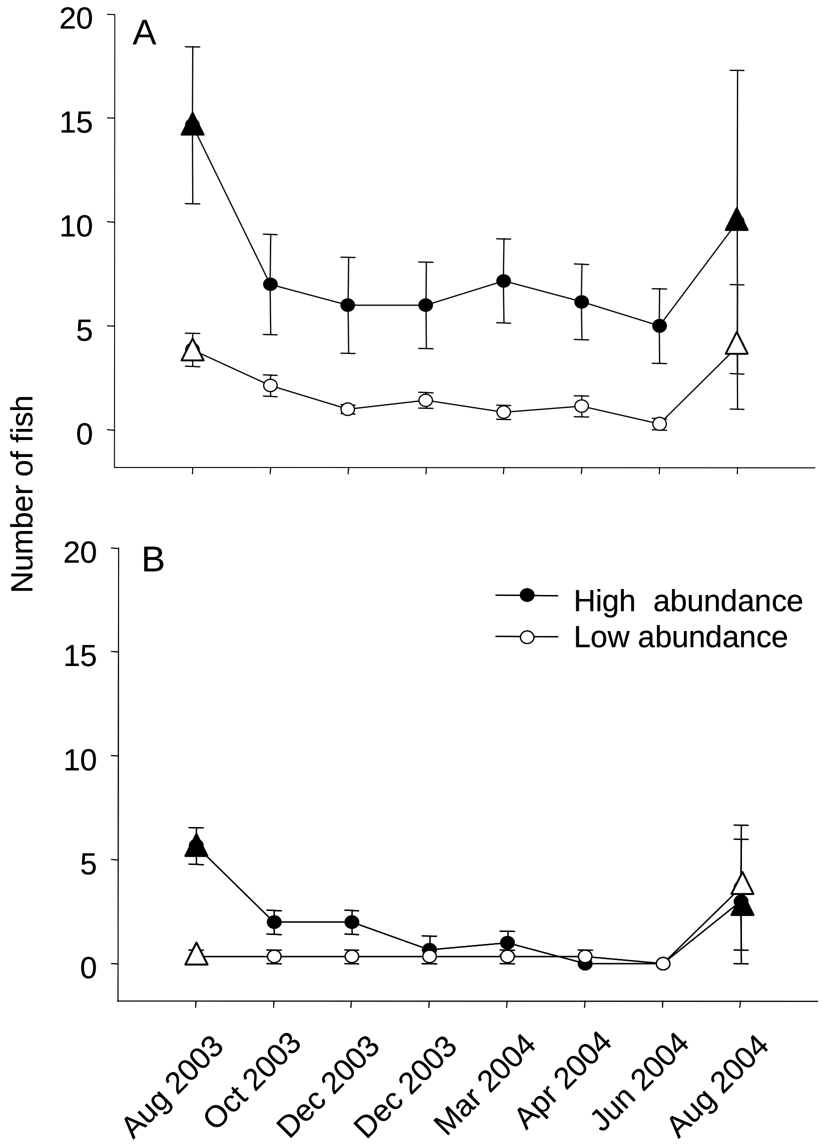

Figure 2. Mean PIT-tagged coastal cutthroat trout abundances in high (black points) and low (white points) relative abundance sections in mainstem (A) and tributary (B) streams in South Fork Hinkle Creek, Oregon. Triangle symbols represent annual electrofishing surveys. Round symbols indicate portable antenna surveys. Vertical lines indicate the standard error of the mean. Two portable antenna surveys occurred in December 2003 (pre and post bank-full discharge event).

Table 3. Summary of PIT-tagged coastal cutthroat trout movements (based on stationary antennas detections) into and out of monitored stream sections in South Fork Hinkle Creek, Oregon, from September 2003 to October 2004. M= mainstem, T= tributary sections.

Section	Abundance category	Length (m)	August 2003 trout	August 2003 (trout/m)	Not detected	Remained	Emigrated	Returned	Immigrated	August 2004 trout
1M	Low	69	0	0.00	0	0	0	0	16	1
2M	Low	161	5	0.03	0	2	3	0	28	9
3M	Low	157	6	0.04	0	3	1	2	29	17
4M	High	47	8	0.17	2	1	2	3	13	5
5M	High	298	31	0.10	4	16	8	3	31	53
6M	High	68	10	0.15	2	3	3	2	16	12
7M	High	73	7	0.10	0	3	1	3	16	6
8M	Low	48	3	0.06	0	0	1	2	20	8
9M	High	105	12	0.11	1	7	1	3	21	13
10M	High	176	20	0.11	6	8	3	3	15	18
11M	Low	87	6	0.07	1	2	2	1	12	3
12M	Low	50	4	0.08	0	2	1	1	15	3
13M	Low	36	3	0.08	0	1	1	1	12	4

Table 3. (Continued)

Section	Abundance category	Length (m)	August 2003 trout	August 2003 (trout/m)	Not detected	Remained	Emigrated	Returned	Immigrated	August 2004 trout
14T	Low	55	1	0.02	0	0	1	0	12	3
15T	High	67	6	0.09	3	0	1	2	9	3
16T	High	53	4	0.08	2	0	2	0	11	3
17T	Low	79	0	0.00	0	0	0	0	3	6
18T	High	72	7	0.10	4	1	0	3	0	8
19T	Low	58	0	0.00	0	0	0	0	5	2

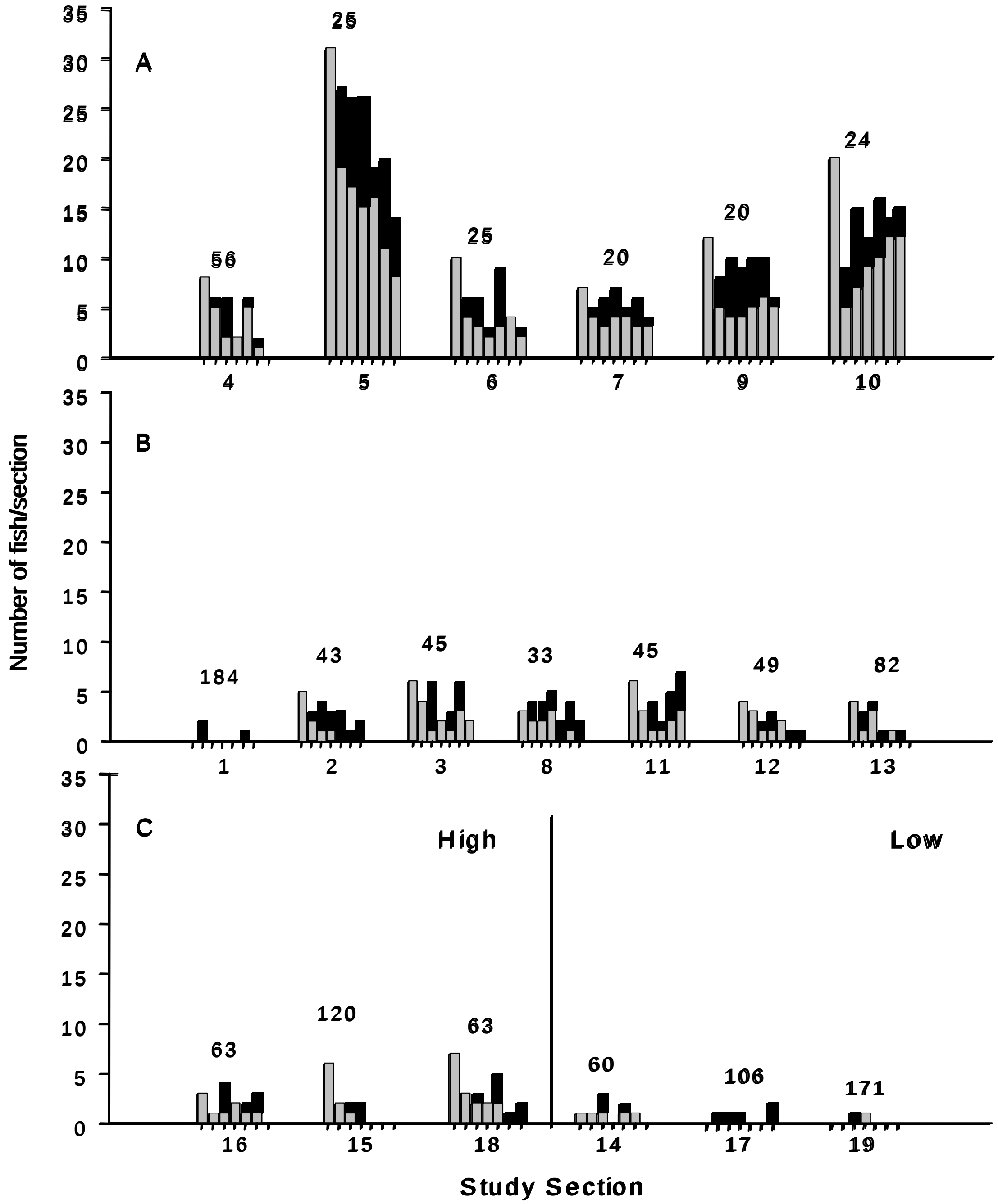

Figure 3. Portable antenna surveys in mainstem high abundance (A), low abundance (B), and tributary (C) stream sections of South Fork Hinkle Creek, Oregon. Gray bars indicate trout that were present during the previous survey. Black bars are numbers of new trout moving into that section. Numbers above bars are coefficients of variation for total trout detected in each section over all surveys. The first tick mark represents the 2003 electrofishing survey subsequent tick marks are portable antenna surveys. A missing bar(above a tick mark) indicates no trout were detected during that survey. Each study section was surveyed seven times (including the initial electrofishing survey).

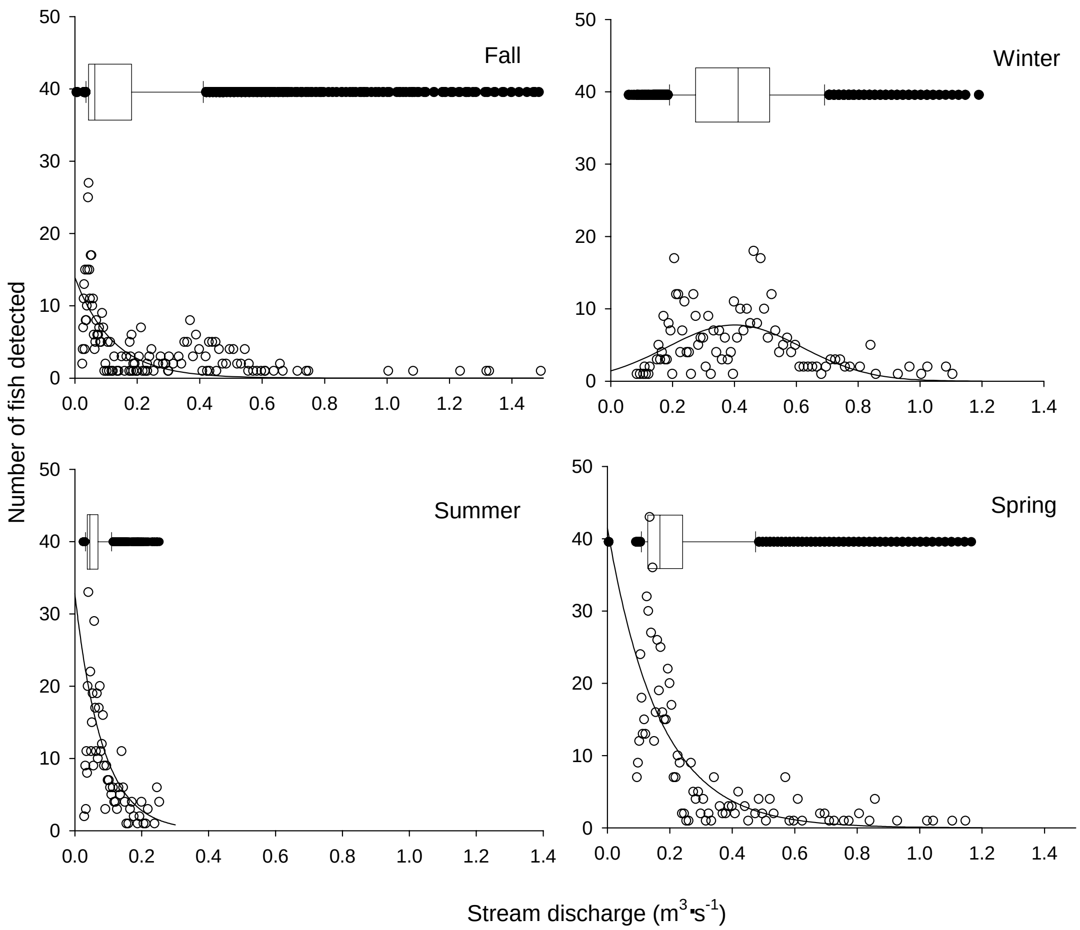

Figure 4. Numbers of coastal cutthroat trout detected by stationary PIT-tag antennas in relation to instantaneous stream discharge in South Fork Hinkle Creek, Oregon. Each white point represents the total number of trout detected moving at a given discharge. Box plots show the distribution of stream discharge during fall (September-December), winter (December-March), spring (March-June), and summer (June-September). Detections during the December 2003 flood are not shown.

Table 4. Seasonal electivity index of coastal cutthroat trout movement detected by stationary PIT-tag antennas in three discharge classes during fall (September-December), winter (December-March), spring (March-June), and summer (June-September). Discharge classes represent the tertiles of the entire discharge distribution in South Fork Hinkle Creek, Oregon. Electivity index values ranged from +1, indicating trout movement occurred more frequently at a particular discharge level to -1, indicating trout movement occurred less frequently at a particular discharge level; values close to zero indicate that movement occurred in proportion to available discharge levels.

Discharge class	Season			
	Fall	Winter	Spring	Summer
High	0.07	-0.02	-0.06	0.11
Medium	0.03	-0.03	0.04	0.03
Low	-0.10	0.04	0.02	-0.14

Table 5. Classes of stream discharge based on the tertiles of the stream discharge ($m^3 \cdot s^{-1}$) distribution during fall (September-December), winter (December-March), spring (March-June), and summer (June-September).in South Fork Hinkle Creek, Oregon.

Discharge class	Season			
	Fall	Winter	Spring	Summer
High	1.00-5.51	0.74-1.19	0.25-1.17	0.08-0.252
Medium	0.04-0.09	0.46-0.73	0.17-0.24	0.06-0.07
Low	0-0.03	0-0.45	0-0.16	0-0.05

Habitat Relationships

During portable antenna surveys, PIT-tagged coastal cutthroat trout were detected most often in pool habitats. For example, during summer and fall 65 - 71% of fish detections occurred in pools, but in winter and spring about 50% of detections occurred in pools. Trout were detected more frequently in riffle habitats during winter (39%) and spring (33%), then during summer or fall. About 20% of the trout were detected in cascades during spring, summer and fall, and in the winter only about 6% of the PIT-tagged trout were detected in cascades (Table 6). PIT-tagged coastal cutthroat trout were rarely detected in side channels or ephemeral tributaries.

In mainstem channels, boulders (66%) were the dominant pool forming agents, followed by root-defended banks (14%), and bedrock (13%). Large wood (7%) was less frequently associated with pool formation in mainstem sections. The majority of pools in smaller tributaries were also formed by boulders (67%), but the influence of bedrock was more pronounced (25%). Large wood only formed 7% of the pools in tributary streams. Differences between the mean length of cascades (16 m and 14 m for mainstem and tributary sections, respectively) and riffles (8 m and 9 m for mainstem and tributary sections, respectively) were not statistically significant ($P > 0.05$); however, the difference in length of pools in the mainstem (5 m) and pools in the tributaries (3 m) was statistically different ($P < 0.01$; Table 7).

Table 6. Summary of portable PIT-tag antenna detections by habitat type during fall (September-December), winter (December-March), spring (March-June), and summer (June-September) in South Fork Hinkle Creek, Oregon.

Channel-unit type	Season			
	Fall	Winter	Spring	Summer
Cascade	21% (73/343)	6% (8/130)	19% (34/178)	17% (18/112)
Pool	66% (207/343)	55% (62/130)	48% (83/178)	71% (79/112)
Riffle	13% (45/343)	39% (51/130)	33% (58/178)	12% (13/112)

Table 7. Descriptive statistics for mainstem and tributary channel-unit lengths (m) located within study sections during summer 2003 in South Fork Hinkle Creek, Oregon

Stream	Channel-unit type	N	Mean	Median	Minimum	Maximum	Coefficient of variation
Mainstem	Cascade	11.0	16.6	15.8	6.3	31.7	43.9
Tributary 2	Cascade	2.0	10.6	10.6	5.3	15.8	70.7
Tributary 3	Cascade	2.0	18.3	18.3	15.7	20.9	20.2
Mainstem	Pool	30.0	4.9	4.5	0.5	11.8	53.6
Tributary 2	Pool	9.0	2.7	2.6	1.1	5.3	51.1
Tributary 3	Pool	9.0	2.5	2.6	1.6	3.1	22.8
Mainstem	Riffle	29.0	9.6	7.4	1.1	23.2	68.0
Tributary 2	Riffle	10.0	9.8	7.9	2.6	26.4	74.2
Tributary 3	Riffle	8.0	11.2	9.8	2.1	26.1	65.4

In August 2003 more boulders were found in high abundance sections (87) of the mainstem than low abundance sections (32), and the differences were statistically significant ($P = 0.03$). None of the other habitat variables differed statistically among study sections (Table 8). Section length and number of boulders were correlated (r = 0.79), but when section length and number of boulders were included as explanatory variables in a multiple linear regression model for predicting coastal cutthroat trout relative abundance, only number of boulders was significant ($P = 0.01$). The simple linear regression model with boulders as the predictor variable explained a high proportion ($r^2 = 0.86$) of the observed variation in relative trout abundance in mainstem study sections. During the August 2004 electrofishing survey the number of boulders accounted for 92% ($r^2 = 0.92$) of the variation in mainstem trout abundance.

Embededness, number of boulders, and number of wood pieces were not measured in all tributaries during the August 2003 sampling period (Table 8), and therefore, regression models of abundance were not directly comparable between mainstem and tributary sections. Percent canopy cover, active channel width, and percent bedrock explained approximately 84% ($r^2 = 0.84$) of variation in trout abundance for tributary sections. During the August 2004 electrofishing survey the number of boulders explained 40% ($r^2 = 0.40$) of the variation in trout abundance in tributary study sections.

The number of boulders and the number of cascade habitats varied among seasons in high and low abundance mainstem sections (Table 9), and the differences were statistically significant ($P \leq 0.05$). The number of pieces of large wood varied significantly among seasons only in mainstem low sections. In contrast, the number of pools and riffles observed in mainstem sections did not differ significantly among seasons (Table 9). In tributary high and low abundance sections only the number of boulders differed significantly among seasons, but data were unavailable for the summer 2003 season. There was no statistically significant seasonal variation in the number of pool, riffle, or cascade habitats in the tributary sections (Table 10).

Table 8. Summary of habitat variables measured during the August 2003 habitat survey of study sections in South Fork Hinkle Creek, Oregon. CA= cascade habitat types, ND= no data for this variable during this survey.

Section	Gradient (%)	Active channel (m)	Wood pieces	Boulders	% Pool	% Riffle	% CA	Pool: riffle ratio	Pool spacing (m)	Cobble embedd-edness	Shrub cover (%)	Bedrock (%)
1M	5	3.4	17	14	33	67	0	0.5	8	0	1.7	0
2M	6	4.3	38	57	38	62	0	0.62	11.4	4	2.2	0
3M	5	4.2	38	110	37	63	0	0.6	9.2	9.1	7.9	0
4M	3	4.5	6	31	59	41	0	1.44	8.2	5	22.5	0
5M	6	3.8	91	239	33	45	22	0.73	11.6	5	8.7	5
6M	9	3.5	13	78	35	22	43	1.62	12.9	2.5	22	0
7M	4	3.6	0	76	19	35	46	0.54	17.4	15	22.2	15.6
8M	6	3.4	5	44	52	48	0	1.1	6.5	6.3	11.8	13.6
9M	5	3.2	5	72	32	41	27	0.77	10.3	9	5.6	0.6
10M	7	3.1	24	124	21	25	54	0.84	13.9	6.7	8.3	5.7
11M	9	3.4	7	49	22	43	35	0.51	18.9	13.3	2.7	0
12M	6	3.2	9	13	27	73	0	0.38	15.1	5	7.1	2.9
13M	14	3.5	2	10	34	22	44	1.56	12.2	0	31.4	40

Table 8. (Continued)

Section	Gradient (%)	Active channel (m)	Wood pieces	Boulders	% Pool	% Riffle	% CA	Pool: riffle ratio	Pool spacing (m)	Cobble embedd-edness	Shrub cover (%)	Bedrock (%)
14T	7	2.8	ND	ND	26	35	39	0.74	8.3	ND	2.0	0.0
15T	7	2.9	ND	ND	25	75	0	0.33	13.1	ND	6	39
16T	7	3	ND	ND	19	81	0	0.24	9.6	ND	0	44.5
17T	11	2.2	10	32	22	52	27	0.42	10.7	14	10.8	10.8
18T	11	2.1	23	25	21	57	22	0.37	11.7	33.8	4.5	0
19T	9	3.5	21	19	12	88	0	0.13	15.4	22.5	11.4	0

Table 9. Mean counts of boulders, wood, pools, riffles, and cascades by season and between abundance categories in mainstem study sections in South Fork Hinkle Creek, Oregon. Sum03= summer 2003, Win= winter, Spg= spring, Sum04= summer 2004, and F_{stat} = F-statistic from an ANOVA, H= high, and L= low relative fish abundance sections.

Abundance	Sum03	Win	Spg	Sum04	F_{stat}	*P*-value
Boulder (H)	87	74	90	65	4.60	< 0.01
Boulder (L)	32	31	46	28	5.24	< 0.01
Wood (H)	11	8	7	6	1.94	0.17
Wood (L)	12	8	7	6	4.80	0.01
Pool (H)	10	9	10	10	0.38	0.76
Pool (L)	9	8	8	7	1.38	0.28
Riffle (H)	6	5	6	8	1.76	0.19
Riffle (L)	7	5	7	7	0.51	0.68
Cascade (H)	3	5	3	2	5.42	< 0.01
Cascade (L)	1	3	2	1	7.27	< 0.01

Table 10. Mean counts of boulders, wood, pools, riffles, and cascades by season and between abundance categories in tributary study sections in South Fork Hinkle Creek, Oregon. Sum03= summer 2003, Win= winter, Spg= spring, Sum04= summer 2004, and F_{stat} = F-statistic from an ANOVA, H= high, and L= low relative fish abundance sections.

Abundance	Sum03	Win	Spg	Sum04	F_{stat}	*P*-value
Boulder (H)	--	19	19	35	96.93	< 0.01
Boulder (L)	--	31	31	47	7.4	0.04
Wood (H)	--	4	4	8	3.37	0.13
Wood (L)	--	8	8	10	1.32	0.36
Pool (H)	6	6	6	7	1.51	0.31
Pool (L)	6	6	6	7	0.52	0.68
Riffle (H)	6	6	6	7	1.50	0.30
Riffle (L)	5	6	6	6	0.38	0.77
Cascade (H)	1	2	1	1	0.73	0.57
Cascade (L)	2	2	2	2	1.00	0.45

CHAPTER 4: DISCUSSION

In this study we assessed relative abundance patterns of coastal cutthroat trout through time. Our study examined annual and bimonthly distributions of hundreds of trout, including uniquely identified individuals, and assessed seasonal variation in habitat and trout abundances. We focused on sections of stream (i.e., patches) that were initially defined by the relative abundance patterns of coastal cutthroat trout. By using relative trout abundance (a bottom up approach) as opposed to selecting habitat criteria (a top down approach) we were able to quantify areas for study based on the distribution of trout, and not a human classification of habitat quality. Essentially spatial variability in trout abundance was used to classify study sections. We found that relative trout abundance in the mainstem of South Fork Hinkle Creek remained high in high abundance sections and low in low abundance sections throughout the 13-month study period. Although abundance of PIT-tagged coastal cutthroat trout in mainstem sections remained similar over time, the locations of individual trout changed. The persistence of trout distributions and trout movements observed in mainstem and tributary streams were markedly different and could be related to differences in physical habitat.

The mainstem stream supported more coastal cutthroat trout than either of the two tributaries, but both stream types exhibited distinctive patterns of relative high and low trout abundance. The initial distribution patterns of coastal cutthroat trout were markedly different between adjacent stream sections in mainstem and tributary habitats; however, as time progressed the high abundance patterns in tributary streams began to diminish until the number of trout in high and low abundance sections was indistinguishable. Conversely, mainstem sections supported high, or low relative trout abundances consistently over time.

The differences in the persistence of relative abundance patterns between mainstem and tributary habitats were not explained by measured habitat variables. These differences were also not attributable to differences in stability of habitats over time between mainstem and tributary streams. It is likely that the persistent boulder habitats associated with high trout abundance are simply the legacy of a larger scale geomorphic process (i.e., debris flow or landslide) that has resulted in temporally stable habitats expressed at the multiple channel-unit scale in the mainstem. Small tributary catchments are located high in the stream network where the magnitude of disturbance is often large (Montgomery 1999; Benda et al. 2004), consequently, the potential capacity (sensu Warren and Liss 1980) to retain habitat forming sediments that result in temporally stable habitats is low, especially in the absence of keystone pieces of large wood (May and Gresswell 2003). Although no habitat-altering disturbances occurred during the study period, tributaries of South Fork Hinkle Creek had steep gradients, frequent cascades, and disorganized substrates indicative of newer less developed habitat.

In the mainstem and tributary patches, a higher relative proportion of trout were detected moving into low abundance sections than high abundance sections. At the bimonthly temporal scale it was evident that low abundance sections experienced a relatively larger turnover (i.e., original trout leaving and new trout moving in) of individual trout than did high abundance sections. This trend was most evident in tributaries. Moreover, section fidelity (i.e., the association over time of trout with their initial marking section) was greater in high abundance sections in mainstem and tributary habitats. In the absence of explicit measures of growth, food availability, survival, or reproductive success we used the stability of relative trout abundance over time, the fidelity of individual trout, and the number of immigrants to evaluate habitat quality between high and low abundance sections. Based on these criteria, low abundance sections may represent poorer quality habitats used transiently by trout; whereas, high abundance patches may provide higher quality habitat, and retain more trout. Furthermore, there was a strong correlation between boulders and high abundance stream sections in the mainstem, and boulders were associated with the formation of pools that are required habitat for adult coastal cutthroat (Rosenfeld and Boss 2001).

Coastal cutthroat trout marked in mainstem and tributary streams exhibited different movement patterns. Although quantifying movement distance was not an explicit objective of our study design we were able to compare movement differences in a relative sense. The overall movement of trout marked in tributaries was less than trout marked in the mainstem habitats. Several reasons for reduced movement are plausible. Tributary and upper mainstem habitats typically had a higher gradient producing more of a stepped bed profile (Grant et al. 1990) that may act as a filter to movement (Kosik and Ferreri 1998). Alternatively the limited movement extent of trout in these habitats could be related to the spatial structure or juxtaposition of habitats (Schlosser 1995). Simply, individual channel-units in tributaries or sections of the upper mainstem are shorter in length than downstream habitats, so that a trout moving 25 m may travel through multiple channel-units and have an increased probability of finding the preferred habitat. In contrast, a trout traveling the same distance through downstream sections may never encounter a different channel-unit (Hendricks 2002).

Coastal cutthroat trout in this study were able to move freely between high and low abundance sections, possibly sampling changes in resource quality (i.e., demographic and physical conditions; Power 1984; Gowan and Fausch 2002) or using habitat patches in a complementary manner (Schlossor 1995). Trout movement was typically short distance high frequency movement, although infrequent long distance movements were observed in some individuals. Interestingly, most trout did not make long-distance spawning migrations, but instead increases in the total number of trout moving and the frequency of those movements were observed during spring. Localized spawning supports observations of decreased genetic diversity among small partially independent populations of coastal cutthroat trout, although not explicitly due to barriers in this case (Wofford et al. 2005).

The frequency and timing of coastal cutthroat trout movement appeared to be unrelated to changes in stream discharge. Trout were not selecting a specific discharge level, and generally moved in relation to the most common seasonal discharge patterns. Furthermore, trout movement did not appear to increase appreciably during bank full discharge events. For example, trout movement in winter was occurring at higher discharges than any other season, but within the winter season trout were not moving during the highest flows (Heggenes 1988; Waters 1993; Harvey 1999). Increases in the frequency of movement may have been related to other environmental factors (i.e., variation in macroinvertebrate availability or local water temperature) or ontogenetic factors (i.e., reproduction)

Analysis of mainstem habitat variables associated with stream sections supporting high and low abundance of coastal cutthroat trout suggested that abundance and the section fidelity of individual trout were positively correlated to the number of instream boulders. Large boulders provided pool habitat, increased water depth, and surface turbulence (i.e., cover) in mainstem and tributary streams in the South Fork Hinkle Creek watershed. During all seasons coastal cutthroat trout were detected most often in pool habitats, and boulders, not large wood, formed the majority of pools in tributary and mainstem sections. This may partially explain the relationship between boulders and trout abundance. In the absence of large wood, boulder substrates may provide similar structural benefits to the stream ecosystem as large wood pieces (Burgess 2001) or at least retain sediment and provide morphological variation at the channel-unit scale (Faustini and Jones 2003).

Seasonal habitat surveys provided a frame of reference for understanding how changes in available habitat may influence the distribution of the PIT-tagged coastal cutthroat trout population. Although statistically significant changes in the number of boulders or wood pieces were noted in mainstem and tributary stream sections these differences did not affect the number or spatial arrangement of habitat units contained within study sections. Changes in the distribution of wood or boulders could have influenced the structural complexity of individual channel-units, but these changes were not concordant with fluctuations in relative trout abundance and did not alter the location or spatial arrangement of channel-units within mainstem or tributary study sections.

In this study habitat selection at the multiple channel-unit scale was not random and appeared to influenced by the presence of physical habitat provided by boulders. These observations provide important implications for sampling and monitoring of trout populations in small streams. For example nonrandom variation in the spatial distribution of trout or habitats may yield distorted patterns when trout are not sampled continuously (Ganio et al. 2005).

Indeed these abundance patterns appear real and cannot be explained away as sampling artifacts. Instead the nonrandom distribution and temporal persistence of these trout abundance patterns should be acknowledged and further explored in hopes of elucidating the underlying causal mechanisms. Others have described these nonrandom spatially aggregated distributions of coastal cutthroat trout (Gresswell et al. in press), and even developed techniques for sampling (Bateman et al. 2005) and data analysis (Ganio et al. 2005) that account for these spatial relationships. The next practical step in exploring these spatiotemporal patterns would be to further elucidate the demographic mechanisms underlying the observed persistence of habitat and trout abundances. Are these high abundance areas acting as source or sink habitats (Van Horne 1983)? Are there differences in growth, survival, food resources, and reproductive success between patches of high and low trout abundance? Exploring these questions has wide-reaching implications for understanding the role of spatial patterning, temporal variation, the structure and function of stream networks, and the long-term survival of potamodromous coastal cutthroat trout in small streams. Recognition that the spatial pattern and temporal persistence associated with specific habitat types (at a variety of spatial scales) can affect local population size, persistence of populations, and behavior of individual trout may assist resource managers challenged with monitoring trout population dynamics, setting angling rules, and regulating forest harvest activities in headwater ecosystems.

LITERATURE CITED

Addicott, J. F., J. M. Aho, M. F. Antolin, D. K. Padilla, J. S. Richardson, and D. A. Soluk. 1987. Ecological neighborhoods: scaling environmental patterns. OIKOS 49:340-346.

Albanese, B., P. L., Angermeier, and S., Dorai-Raj. 2004. Ecological correlates of fish movement in a network of Virginia streams. Canadian Journal of Fisheries and Aquatic Sciences **61**:857-869.

Barbin-Zydlewski, G., A. Haro, K.G. Whalen and S.D. McCormick. 2001. Performance of stationary and portable passive transponder detection systems for monitoring fish movements. Journal of Fish Biology 58:1471-1475.

Bateman, D. S., R. E. Gresswell, and C. E. Torgersen. 2005. Evaluating single-pass catch as a tool for identifying spatial pattern in fish distributions. Freshwater Ecology 20:335-345.

Belanger, G., and M. A. Rodriguez. 2002. Local movement as a measure of habitat quality in stream salmonids. Environmental Biology of Fishes 64:155-164.

Benda, L., L. N., Poff, D. Miller, T. Dunne, G. Reeves, G. Pess, and M. Pollock. 2004. The network disturbance hypothesis: how channel networks structure riverine habitats. Bioscience 54:413-427.

Bisson, P. A., J.L. Nielsen, R.A. Palmson, and L.E. Grove. 1981. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. Pages 62-73 in N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Portland, OR.

Bryant, M. D., N.D., Zymonas., and B. E., Wright. 2004. Salmonids on the fringe: abundance, species composition, and habitat use of salmonids in high-gradient headwater streams, southeast Alaska. Transactions of the American Fisheries Society 133:1529-1538.

Buffington, J. M., T. E. Lisle, R. D. Woodsmith, and S. Hilton. 2002. Controls on the size and occurrence of pools in coarse-grained forest rivers. River Research and Applications In press.

Burgess, J. A. 2001. Response of trout, sculpins, and salamanders to experimental manipulation of large wood in cascade mountain streams. Master of Science. Oregon State University, Corvallis, Oregon.

Castro-Santos, C., A. Haro, and S. Walk. 1996. A passive integrated transponder (PIT) tag system for monitoring fishways. Fisheries Research 28:253-261.

Chamberlin, T. W., R. D., Harr, and F. H. Everest. 1991. Timber harvesting, silviculture, and watershed processes. *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Fahrig, L. 1992. Relative importance of spatial and temporal scales in a patchy environment. Theoretical Population Biology 41:300-314.

Fausch, K. D., and T. G. Northcote. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia Stream. Canadian Journal of Fisheries and Aquatic Sciences 49:682-693.

Fausch, K. D., C. E. Torgersen, C. V. Baxter, and H. W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. Bioscience 52:483-498.

Faustini, J. M., and J. A. Jones. 2003. Influence of large woody debris on channel morphology and dynamics in steep, boulder-rich mountain streams, western Cascades, Oregon. Geomorphology 51:187-205.

Frissell, 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.

Ganio, L. M., C. E. Torgersen, and R. E. Gresswell. 2005. A geostatistical approach for describing spatial pattern in stream networks. Front. Ecol. Environ. **3**:138-144.

Gowan, C. a. K. D. F. 1996. Mobile brook trout in two high-elevation Colorado streams: re-evaluating the concept of restricted movement. Canadian Journal of Fisheries and Aquatic Sciences 53:1370-1381.

Gowan, C., and K.D. Fausch. 2002. Why do foraging stream fish move during summer? Environmental Biology of Fishes 64:139-153.

Grant, G. E., F. J. Swanson, and M. G. Wolman. 1990. Pattern and origin of stepped-bed morphology in high-gradient streams, Western Cascades, Oregon. Geological Society of America Bulletin 102:340-352.

Greenberg, L. A., T. Steinwall, and H. Persson. 2001. Effect of depth and substrate on use of stream pools by brown trout. Transactions of the American Fisheries Society 130:699-705.

Gresswell, R. E, and S. R. Hendricks. In review. Population-scale movement of coastal cutthroat trout in a naturally isolated stream network. Transactions of the American Fisheries Society.

Gresswell, R. E., C. E. Torgersen., D. S. Bateman, T. J. Guy, S. R. Hendricks, and J. E. B. Wofford. In press. A spatially explicit approach for evaluating relationships among coastal cutthroat trout, habitat, and disturbance in small streams. *in* R. Hughes, L. Wang., and P. Seelbach, editors. Influences of landscapes on stream habitats and biological assemblages. American Fisheries Society.

Gresswell, R. E., D. S. Bateman, J. Li, M. S. Novick,, C. E. Torgersen, and D. Hockman-Wert. 2003. Cumulative effects of timber harvest on fish abundance and distribution. Cooperative Forest Ecosystem Research Program Annual Report: 42-45.

Harvey, B. C. and A. J. Stewart. 1991. Fish size and habitat depth relationships in headwater streams. Oceologia 87:336-342.

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 wooded debris and a 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.

Hawkins, C. P., M. L. Murphy, N. H. Anderson, and M. A. Wilzbach. 1983. Riparian canopy and substrate composition interact to influence the abundance of salmonids, sculpins, and salamanders in streams. Canadian Journal of Fisheries and Aquatic Sciences 40:1173-1185.

Heggenes, J. 1988. Effects of short-term flow fluctuations on displacement of, and habitat use by, brown trout in a small stream. Transactions of the American Fisheries Society 117:336-344.

Hicks, B. J., and J. D. Hall. 2003. Rock type and channel gradient structure salmonid populations in the Oregon Coast Range. Transactions of the American Fisheries Society 132:468-482.

Hintze, J. 2001. Number cruncher statistical systems. in, Kaysville, Utah.

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 55:191-200.

Latterell, J. J., R. J. Naiman, B. R. Fransen, and P. A. Bisson. 2003. Physical constraints on trout (Oncorhynchus spp.) distribution in the Cascade Mountains: a comparison of logged and unlogged streams. Canadian Journal of Fisheries and Aquatic Sciences 60:1007-1017.

Lonzarich, D. G., M.R. Lonzarich, and M.L. Warren Jr. 2000. Effects of riffle length on the short term movement of fishes among stream pools. Canadian Journal of Fisheries and Aquatic Sciences 57:1508-1514.

May, C. L., and R. E., Gresswell 2003. Processes and rates of sediment and wood accumulation in headwater stream of the Oregon Coast Range, USA. Earth Surface Processes and Landforms 28:409-424.

Matheney, M. P., and R. C. F. 1995. Patterns of movement and habitat use by northern hog suckers in an Ozark stream. Transactions of the American Fisheries Society 124:886-897.

Meacham, J. E., and E. B. Steiner. 2002. Atlas of Oregon, CD version. *in*. University of Oregon Press; UO InfoGraphics Lab; Department of Geography, Eugene, Oregon.

Mellina, E., S. G., Hinch, K. D., MacKenzie, and G. Pearson. 2005. Seasonal movements of stream-dwelling rainbow trout in north-central British Columbia, Canada. Transactions of the American Fisheries Society 134:1021-1037.

Montgomery, D. R., J.M. Buffington, R.D. Smith, K.M. Schmidt, and G. Press. 1995. Pool spacing in forest channels. Water Resources Research 31:1097-1105.

Montgomery, D. R. 1999. Process domains and the river continuum. Journal of the American Water Resources Association 35 (2):397-410.

Moore, K. M. S., K. K. Jones, and J. M. Dambacher. 1997. Methods for stream habitat surveys. Information Report 97-4, Oregon Department of Fish and Wildlife, Portland, Oregon. 59 pp.

Nelson, R. L., W. S. Platts, D. P. Larson, and S. E. Jensen. 1992. Trout distribution and habitat in relation to geology and geomorphology in the North Fork Humboldt River Drainage, Northeastern Nevada. Transactions of the American Fisheries Society 121:405-426.

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

Poff, N. L., and J. V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. Canadian Journal of Fisheries and Aquatic Sciences 46:1805-1818.

Poff, N. L., D. Allan, M.B. Bain, J.R. Karr, K.L. Prestgaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The Natural Flow Regime: A paradigm for river conservation and restoration. Bioscience 47:769-784.

Power, M. E. 1984. Habitat quality and the distribution of algae-grazing catfish in a Panamanian stream. Journal of Animal Ecology 53:357-374.

Ramsey, F. L., and D. W. Schafer. 2002. The Statistical Sleuth: A course in methods of data analysis, 2nd edition. Duxbury, Pacific Grove, CA.

Romero, N., R. E. Gresswell, and J. L. Li. 2005. Changing patterns in coastal cutthroat trout (Oncorhynchus clarki clarki) diet and prey in a gradient of deciduous canopies. Canadian Journal of Fisheries and Aquatic Sciences 62:1797-1807.

Rosenfeld, J. S., 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.

Roussel, J. M., A. Haro, and R. A. Cunjak. 2000. Field test of a new method for tracking small fishes in shallow rivers using passive integrated transponder (PIT) technology. Canadian Journal of Fisheries and Aquatic Sciences 57:1326-1329.

Schlosser, I. J., and P. L. Angermeir. 1995. Spatial variation in demographic processes of lotic fishes: conceptual models, empirical evidence, and implications for conservation. Pages 392-401 in American Fisheries Society Symposium.

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.

Trerpanier, S., R. M.A., and P. Magnan. 1996. Spawning migrations of landlocked Atlantic salmon: time series modeling of river discharge and water temperature effects. Journal of Fish Biology 48:925-936.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893-901.

Warren, C. E., and W. J. Liss. 1980. Adaptation to aquatic environments. Pages 15-40 in R. T. a. L. A. N. Lackey, editor. Fisheries Management. John Wiley and Sons, New York.

Warren, D. R., and C. E. Kraft. 2003. Brook trout (Salvelinus fontinalis) response to wood removal from high-gradient streams of the Adirondack Mountains (N.Y., U.S.A.). Canadian Journal of Fisheries and Aquatic Sciences 60:379-389.

Waters, E. 1993. Winter habitat utilization of radio-tagged coastal cutthroat trout. Masters Thesis. North Carolina State University, Raleigh, North Carolina. 43pp.

Wilzbach, M. A., and J.D. Hall. 1985. Prey availability and foraging behavior of cutthroat trout in an open and forested section of stream. Verh. International Verein. Limnol. 22:2516-2522.

Winker, K., R. J.H., and R. M.A. 1995. The use of movement data as an assay of habitat quality. Oceologia 101:211-216.

Zydlewski, G. B., C. Winter, D. McClanahan, J. Johnson, and J. Zydlewski. 2001. Evaluation of fish movements, migration patterns, and population abundance with streamwidth PIT tag interrogation systems. Completion report 2001-012-00, Abernathy Fish Technology Center, Longview, WA.

APPENDICES

Table A1. Seasonal summary statistics for spatial and temporal movements of PIT-tagged coastal cutthroat trout in South Fork Hinkle Creek.

Variable	**Season**			
	Fall	Winter	Spring	Summer
Median movement extent (m)[a]	5 (0- 2221)	0 (0-2664)	1 (0-2096)	4 (0-2688)
Median net distance moved (m)[a]	112 (0-2221)	62 (0-1471)	45 (0-1446)	69 (0-2685)
Fish moving > 100 m net distance (%)[b]	54 (37/69)	37 (14/38)	26 (14/54)	47 (22/47)
Median distance of a single movement (m)[a]	63 (1-2221)	40 (3-1309)	45 (1-1612)	45 (1-2688)
Percent of movements (upstream)	52	44	57	51
Fish detected not moving (%)[b]	34 (71/210)	67 (82/123)	42 (71/170)	38 (74/195)
Fish moving > 500 m (%)[b]	4 (8/210)	5 (6/124)	2 (4/70)	9 (17/195)
Fish moving > 25 m (%)[b]	28 (58/210)	22 (27/124)	25 (43/170)	30 (58/195)
Mean fish detected (fish• day^{-1})[a]	4.0 (0-17)	4.7 (0-15)	6.7 (0-20)	3.8 (0-16)

[a] Numbers in parentheses are the range of the distribution.
[b] Numbers in parentheses are sample sizes used to calculate percentages.

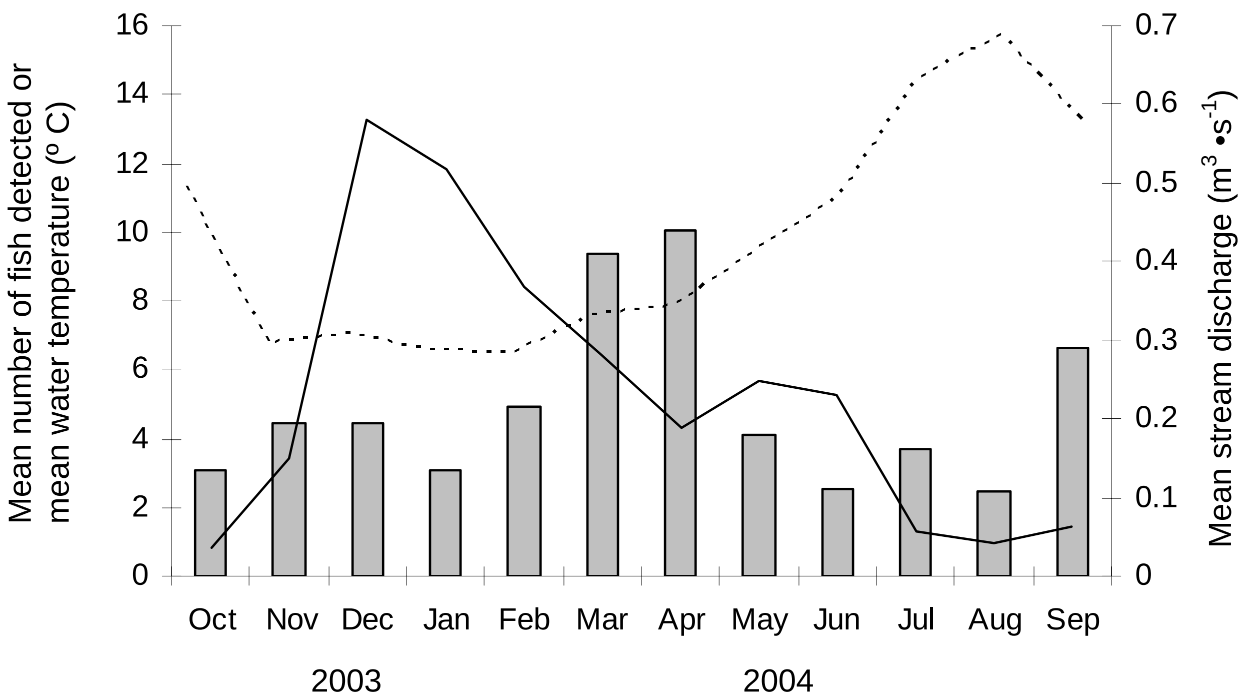

Figure A1. Monthly mean number of coastal cutthroat trout detected at stationary PIT-tag antennas, mean water temperature, and mean stream discharge for South Fork Hinkle Creek, Oregon. Bars represent fish detections, dotted line is stream temperature, and the solid line is stream discharge.

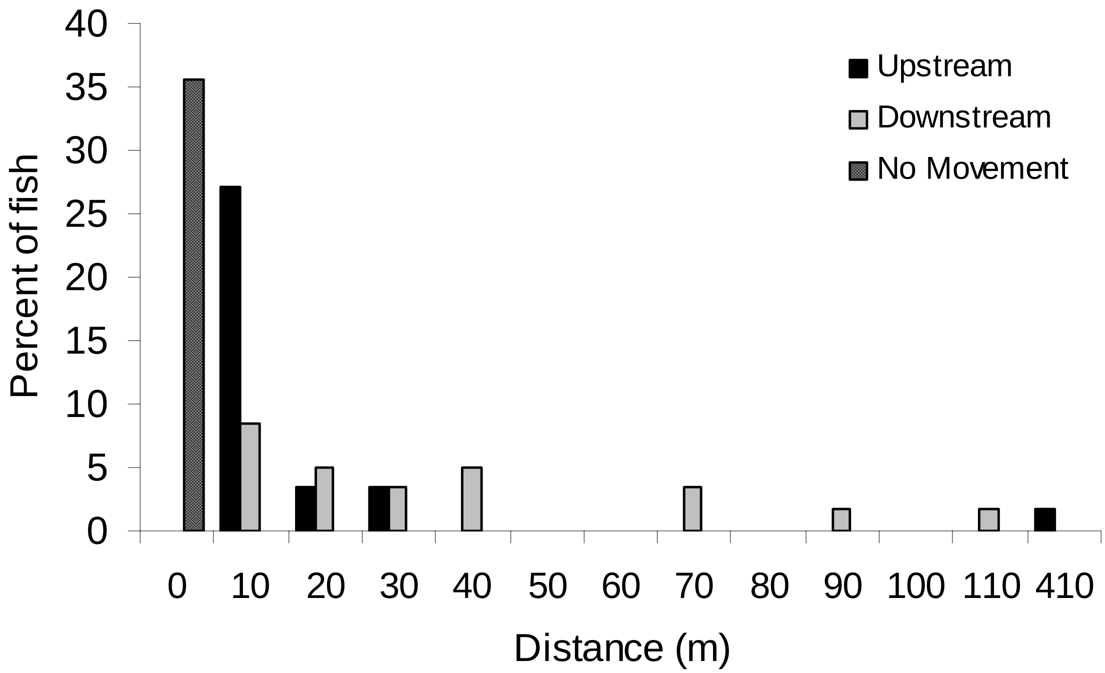

Figure A2. Distribution of movement distance and direction for the 59 coastal cutthroat trout that remained in the mainstem study area before and after the December 15, 2003 annual flood event.