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Redband trout density was examined in three forested streams in central Oregon at two scales, pool channel unit and microhabitat. Two streams were in roadless areas and one was in a “highly managed” watershed. At the larger spatial scale, trout displayed a seasonal shift in habitat use from early to late summer. There was a positive correlation between trout density and pool structural complexity during summer base flow. The association was intensified throughout the summer as stream flow continued to drop. The structural complexity of each pool was quantified using an index integrating structural variability and depth. Twenty-two pools were divided into microhabitats, or pool subunits with similar characteristics using a qualitative classification scheme describing different structural elements comprising the pool habitat. Microhabitat was partitioned between fry and older trout throughout the summer: Fry generally used stream margins, backwaters, and shallow areas; whereas, trout one year and older used deep areas (depth greater that 0.5 m) and cover associated with

substrate and wood. The use of cover by trout one year and older doubled from June to August. This change in use was coupled with the increased association with structural complexity at the channel unit scale. The large substrate and wood that provided cover also increased the structural complexity of the pool. As trout increased their use of cover, their densities increased in more complex pools.

Man-made log weir pools in a simplified stream were evaluated for their structural complexity and compared to the shallow natural pools in the same reach. Log weir pools had greater average depth, but were less complex than natural pools, and could maintain a similar density of trout. The structural complexity in natural pools appears to compensate for their shallow depth. Log weir pools enhanced with placement of a rootwad supported higher densities of trout. Addition of a rootwad provided microhabitats associated with cover that were lacking in weir pools without other structures added. When using instream construction to create pool habitat, complex structure that provides microhabitats associated with cover is more effective at holding higher densities of fish under late summer low flow conditions.

Seasonal Shifts in Redband Trout Use of Pools and Their Microhabitats in Three Central Oregon Streams

by

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Christine L. Hirsch, Author

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Seasonal Shifts in Redband Trout Use of Pools and Their Microhabitats in Three Central Oregon Streams

Introduction

Only a small fraction of American rivers have been spared exploitation for hydropower development (Benke 1990). In addition, grazing, logging, agriculture, mining, and urban growth have caused extensive losses of Pacific salmonid habitat (Nehlsen et al. 1991, Meehan 1991). This widespread habitat loss and degradation coupled with heavy fishing pressure has led to the extinction and decline of many anadromous salmonid stocks (Nehlsen et al. 1991). Headwater areas are often less impacted than downstream areas and may provide refugia. Remaining resident and anadromous populations isolated in headwater areas may be key to the preservation of a species as habitat restoration becomes a reality.

The streams of the Ochoco National Forest have been subjected to road building, streamside timber harvest, and a century of intensive grazing (Dean Grover, Ochoco National Forest, Forest Fish Biologist, personal communication). This can result in increased fine sediment production, summer temperatures, and daily and annual temperature fluctuations, and decreased base flows (Meehan 1991). Habitat degradation coupled with drought conditions may result in a bottleneck for redband trout on the Ochoco National Forest during the late summer low flow period.

As instream habitat decreases in availability with decreasing flow, subordinate individuals emigrate and intraspecific competition forces trout to use all available areas (Chapman 1962). This makes summer low flow, which may represent a critical limiting factor, an appropriate time for habitat evaluation. The purpose of this study was to compare habitat use in pools in relation to differences in structural complexity. The second purpose was to determine microhabitat use within pools of two relatively undisturbed forested streams and one highly disturbed forested stream by redband trout and juvenile summer steelhead during the early-summer and the late-summer low flow period. Changes in trout response to pool structural complexity during the summer may be accompanied by changes in microhabitat use associated with structural elements. Understanding patterns of habitat use and structural complexity in relatively pristine systems, provides the technical basis for evaluating man-made, habitat-improvement projects in a badly degraded stream. The specific objectives of this project were:

1. determine the relation between trout density and 1) the structural complexity of pools, and 2) bank complexity throughout the summer. Because flow conditions varied between years of study, these relationships were examined during different patterns of precipitation and flow of average and dry years;

2. determine microhabitat use throughout the summer in Black Canyon Creek, a relatively undisturbed Wilderness stream;
3. examine trout responses to differences in physical structure of man-made log weir pools, with and without rootwads, and natural pools in Trout Creek.

Hierarchical scaling of stream habitat

Habitat use by trout can be considered a multiscale hierarchical procedure of selecting landscape features on a regional scale, water quality on a local scale, and physical habitat attributes on a channel-unit scale. On a regional scale, trout can be limited by access. They have never existed in some regions or basins and are now excluded from others by dams and other barriers. On a local scale, trout are limited by reach level attributes. For example, areas with high water temperatures may be inhospitable. On the channel unit scale, trout distribution is related to physical features of the habitat. The microhabitat scale determines which physical features or areas of the environment are being used. These scales are nested (Frissell et al. 1986, Gregory et al. 1991), and should be considered together to fully understand habitat needs. I investigated habitat use at the channel unit and microhabitat scales.

Channel unit scale

Population densities of trout in streams have been associated with habitat quality (Lewis 1969), which has been assessed in a variety of ways. Increased habitat use has been associated with shade or overhead cover (Gibson and Power 1975, Shirvell 1990, Lohr and West 1992, Fausch 1993), woody debris (Tschaplinski and Hartman 1983, Angermeier and Karr 1984, Shirvell 1990), pool depth (Everest and Chapman 1972, Bisson et al. 1988), and abundance of large substrate (Everest and Chapman 1972, Bustard and Narver 1975b).

Steelhead generally occupy high gradient areas at the reach scale, and use channel units with higher velocities. Steelhead in Idaho streams occupied higher gradient reaches than most other salmonids, with relatively few steelhead in low-gradient areas (Everest and Chapman 1972). Juvenile steelhead sympatric with coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*O. clarki clarki*) in western Washington streams occupied lateral scour pools and plunge pools preferentially, and were scarce in low gradient riffles, glides, secondary channel pools and dammed pools (Bisson et al. 1988).

Structural complexity creates a variety of microhabitats within pools. Structural elements in pools provide visual isolation between competing animals, protection from predators, and refuge from high water velocities. Habitat variables have been combined by several investigators to create measures of overall habitat complexity. Complexity has been measured as habitat diversity using the Shannon-Weiner equation on four depth, five velocity, and nine substrate categories (Gorman and Karr 1978, Schlosser 1982, Angermeier and Schlosser 1989). McMahon and Hartman (1989) related fish abundance to four levels of cover complexity (no cover; velocity cover; velocity cover and shade; and velocity cover, shade, and wood debris) in an artificial stream system. Complexity has also been indexed by the hydraulic retention of a stream reach (Pearsons et al. 1992). Reeves et al. (1993) used pieces of large wood and number of pools separately as indicators of habitat complexity. Increases in these measures of complexity have been associated with higher fish densities or diversity and more stable fish communities.

In contrast, salmonid fry are known to use shallow areas often associated with the stream margins and other slow water areas (Lister and Genoe 1970, Everest and Chapman 1972, Moore 1987, Moore and Gregory 1988). However, at the channel unit scale, Bisson et al. (1988) found no significant correlation between habitat use by steelhead fry and velocity or depth during summer low flow in western Washington streams. Channel unit measures may be too coarse to detect the specific needs of fry.

Microhabitat scale

Steelhead and other salmonids use specific velocities, depths, and light intensities on a microhabitat scale. Juvenile salmonids may select feeding focal points based on water velocity and food supply to maximize access to invertebrate drift while minimizing energy expenditures (Chapman 1966, Chapman and Bjornn 1969, Jenkins 1969, Everest and Chapman 1972, Fausch and White 1981, Fausch 1984, Wilzbach 1985). Steelhead distribution during summer was correlated with depth, positively for one year and older trout (Everest and Chapman 1972, Bisson et al. 1988) and negatively for young-of-the-year trout (Everest and Chapman 1972). Juvenile steelhead also displayed a preference for low light intensities (Shirvell 1990, Lohr and West 1992, Fausch 1993).

Many studies have characterized salmonid microhabitat use by measuring habitat characteristics at and around the fish. Water velocities (e.g., focal point, maximum, mean, surface, and difference between maximum velocity and focal point velocity), distances (e.g., from overhead cover, water surface, substrate, and nearest fish), depth (e.g., total, maximum, and relative fish depth), substrate size directly under the fish, and focal point light intensity have all been used to characterize salmonid microhabitat use (Cunjak and Green 1983, Cunjak and Power 1986, Morantz et al. 1987, Dolloff and Reeves 1990, Shirvell 1990, Baltz et al. 1991, Bozek and Rahel 1991, Lohr and West 1992). Two different quantitative models of microhabitat use have been developed: 1) the Instream Flow Incremental Methodology which predicts invariant use patterns based on the distribution of flows (Bovee 1982), and 2) models of net energy intake as influenced by the energetics of drift, water velocity and costs of swimming (Smith and Li 1983, Fausch 1984, Hughes and Dill 1990, Hughes 1992a, 1992b, Hill and Grossman 1993). While they provide a wealth of information about the biology and needs of the animal, they provide limited information to aid managers in providing optimum fish habitat.

Managers need to know which features of the habitat are providing the preferred velocities, light intensities, depths, and substrates, to create or manage for high quality salmonid habitat. In this project, I divided each pool into subunits, or microhabitats, characterized by physical features and determined each microhabitat's use.

Study Area

Ochoco National Forest lies on a southwestern expansion of the Blue Mountains (Baldwin 1959). The bedrock in this area is hard, competent, highly fractured basalts of the Picture Gorge formation (USDA Forest Service 1977). Three third- and fourth-order streams on the Ochoco National Forest were selected for study: Black Canyon Creek, Rock Creek, and Trout Creek (Figure 1). Rock Creek and Black Canyon Creek are on the eastern edge of the Ochoco National Forest in the John Day River Basin. Trout Creek is on the northwest edge of the Ochoco National Forest in the Deschutes River Basin. All study reaches were comprised primarily of pools and riffles with very little glide or side channel habitat. Stream flows ranged from 1.7 to 60 m^3/min during sampling periods. Study site characteristics varied (Table 1). Land uses and stream impacts differed among sites. Rock Creek and Black Canyon Creek are relatively undisturbed and represent the best available trout habitat on the Ochoco National Forest. Trout Creek, in contrast, has been roaded, streamside logged, and grazed, and represents more typical, highly managed streams.

These streams are all considered riparian management areas by the Ochoco National Forest. The management emphasis in these areas is to "manage streamside vegetation and habitat to maintain or improve water quality" (USDA Forest Service 1989). To accomplish this, the Forest initially set aside 100 foot wide "special protection areas" from all perennial streams or 200 foot buffers from streams designated as wildlife connective habitat, including Trout Creek. Current national direction (PACFISH) has since superseded Forest Plan direction on all anadromous streams in the Pacific Northwest and has set aside Riparian Habitat Conservation Areas, 300 feet on each side of all fish bearing streams (USDA Forest Service and USDI Bureau of Land Management 1994).

Table 1. Study site characteristics for Black Canyon Creek, Rock Creek and Trout Creek, Oregon.

Site	1	2	3	4
Stream	Black Canyon	[Lower] Rock Creek	[Upper] Rock Creek	Trout Creek
Number of pools studied	22[a] 15[b]	8	15	15
Elevation (m)	900	1300	1600	1100
Estimated base flow (m^3/min)	32	25	5.5	1.7
Percent pools in reach (by area)	4	3	5	6
Reach width to depth ratio	8.0	12.2	13.6	9.8

[a] 1993
[b] 1994

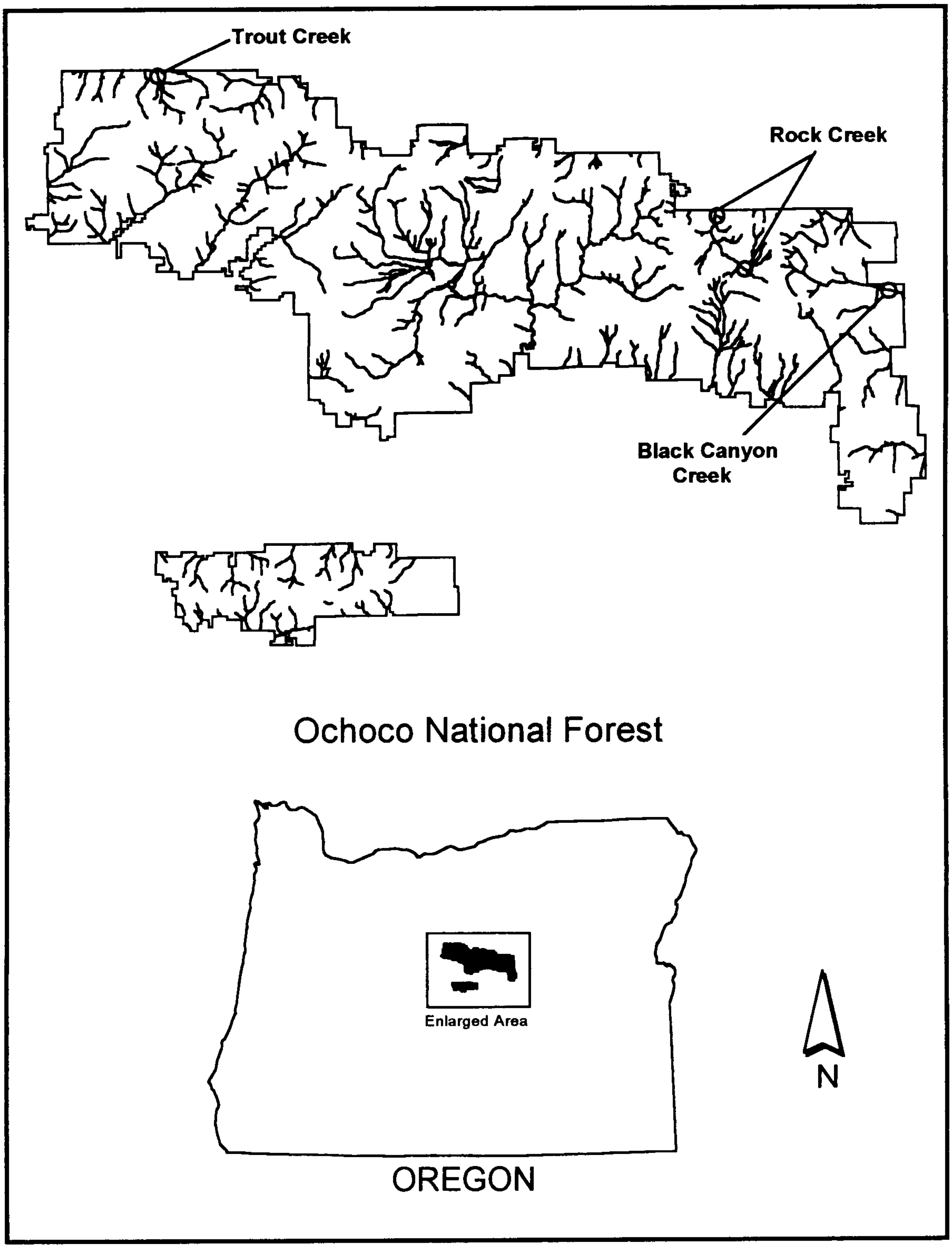

Figure 1. Location of study sites on the Ochoco National Forest, Oregon.

Rock Creek

This stream is a north-facing tributary to Mountain Creek, a tributary to the mainstem John Day River. The headwaters lie within the Ochoco National Forest; the lower reaches lie on private land. The two study sites in Rock Creek are within the Rock Creek/Cottonwood Creek Management Area. This area contains mature and old-growth stands and has had limited human impact. It has very steep side slopes and is relatively inaccessible. Current land uses include cattle and sheep allotments and recreational trails. Current management emphasis in this area is to provide protection to soil, water, and fish; and to encourage nonmotorized recreational use (USDA Forest Service 1989). Upstream of the study area, an unpaved major access road parallels the creek, and grazing and streamside logging are evident impacts. The upper site is just below this area, starting at the confluence with Baldy Creek (1600 m in elevation) and the lower site is just above the Forest boundary (1300 m in elevation) in a relatively unimpacted area. There is, however, a diversion dam in the middle of the lower reach. Fish species observed in Rock Creek include Columbia River redband trout (*Oncorhynchus mykiss gairdneri*) and Paiute sculpin (*Cottus beldingi*). Steelhead are known to spawn throughout both study reaches.

Black Canyon Creek

This stream is an east-facing tributary to the South Fork John Day River. The watershed is entirely encompassed by the Ochoco National Forest. Almost the entire drainage lies within the Black Canyon Wilderness Area. The study site lies within the Wilderness. The management emphasis in this area is to protect the Wilderness ecosystems, maintain a natural setting and preserve solitude (USDA Forest Service 1989). The study site in Black Canyon Creek begins approximately 1 km upstream of its confluence with the South Fork John Day River and extends approximately 1.5 km upstream. The elevation is 900 m at the base. Fish species observed in this study area include Columbia River redband trout, Paiute sculpin, torrent sculpin (*C. rhotheus*), mountain whitefish (*Prosopium williamsoni*), mountain sucker (*Catostomus platyrhynchus*), and long nose dace (*Rhinichthys cataractae*). Steelhead are known to spawn throughout the study reach.

Trout Creek

This stream is a north-facing tributary to the Deschutes River. The study site is parallel to an unpaved major access road. Twelve log weirs have been constructed within a 0.5 km length of stream as part of a Bonneville Power Administration project to enhance steelhead habitat in the Trout Creek drainage. The elevation at the study site is 1100 m. Domestic livestock grazing began in the Trout Creek area as early as 1860 and was extremely overgrazed until about 1960 (USDA Forest Service 1995). Riparian fencing has excluded livestock grazing from this stream reach throughout the last decade. Upstream land uses include logging, livestock grazing, and roads. Trout Creek is designated as wildlife connective habitat by the Ochoco National Forest, part of a network of wildlife travel corridors across the Forest (USDA Forest Service 1989). Fish species observed in Trout Creek include Columbia River redband trout and speckled dace (*R. osculus*). One unidentified sucker (*Catostomus* sp.) also was observed. Though there was no obvious beaver activity in the other study sites, beaver activity was observed throughout the reach in Trout Creek in conjunction with log weir pools. There were loose brush dams at the tail of log weir pools, often raising the water level and increasing pool depth. No steelhead redds were found in Trout Creek above the Forest boundary during spawning surveys conducted from 1988 through 1995 (Oregon Department of Fish and Wildlife, Ochoco District, unpublished data). Steelhead have historically spawned in this reach.

Inland rainbow (redband) trout

Columbia River redband trout (*Oncorhynchus mykiss gairdneri*) are found east of the Cascade Range in the Columbia and Fraser river basins (Behnke 1992). Redband trout life history patterns include anadromous (steelhead), lacustrine, and resident forms. Resident populations are found throughout this range, although many steelhead populations are extinct as a direct result of dams without fish passage. Both resident redband trout and summer steelhead occur in the John Day River and Deschutes River basins.

Methods

I conducted field studies during the summers of 1993 and 1994. The 2-year study comprised five sampling periods from June through September (Table 2): three surveys were made in 1993, a summer with average rainfall, and two surveys were made in 1994, the driest year on record on the Ochoco National Forest since 1937 (George Taylor, State Climatologist, personal communication). In 1993, Black Canyon Creek and both Rock Creek sites were sampled. In 1994, Trout Creek, the upstream Rock Creek site (site 3, Table 1), and 15 pools in Black Canyon Creek were sampled. Since shallow areas have limited habitat suitable for fish use (Gorman and Karr 1978), habitat evaluation and measurements were restricted to pools. Also, because of greater depth in pools, visual estimates could be more easily and accurately obtained in pools than in riffles. Pools were the experimental unit and the sampling unit. Pools were blocked in groups of four or five, the number that could be surveyed in one day.

Table 2. Dates of sampling periods.

Sampling Period	Year	Dates
1	1993	June 29 - July 22
2	1993	July 26 - August 10
3	1993	August 16 - September 14
4	1994	June 27 - July 15
5	1994	August 22 - September 10

Pools within blocks were surveyed from downstream to upstream to avoid effects of increased turbidity on fish behavior and visibility downstream (Fausch 1993). Study sites were chosen at access points in areas with a high density of pools. Each summer, the streams were surveyed in random order. Blocks within streams were also surveyed in random order each sampling period.

Fish counts were obtained by snorkeling. All surveys were conducted between 0930 and 1630 hours. A diver entered the downstream end of the pool and worked upstream, recording numbers and species of all fish observed. No distinction was made between redband trout and juvenile steelhead trout. Although adult redband trout (length generally less than 400 mm) can be distinguished from adult steelhead trout (length 500 - 800 mm) by the difference in size, there is no definitive method to visually distinguish juvenile steelhead from juvenile or adult redband trout (Thorgaard 1983, Currens et al. 1990, Currens and Schreck 1993). Age-class estimates of trout were also recorded. Recently emerged fry are more effectively sampled by crawling along the bank and searching for fry near the pool margins than by snorkeling (Moore 1987, Moore and Gregory 1988). No bank observations for fry were made, therefore, this group may have been less effectively sampled, especially immediately after emergence. Pool length, area, volume, maximum depth, average depth, and complexity indices were measured or calculated for each pool at each sampling period. Water temperature, pool depths, and stream flow were recorded at each sampling period. Stream flow was estimated using dye. Dye was released through areas of known volume. The time it took the dye to pass through the unit was used to calculate stream flow.

Visual observation by snorkeling is a quick, low-cost, low-impact method to sample stream fishes. Its effectiveness varies under different conditions. Visual observations are most effective during June through September, avoiding cold, wet weather (Gardiner 1984, Rodgers et at. 1992). Effectiveness varies with substrate size, water velocity, and habitat complexity (Heggenes et al. 1990). In addition, visual observation are less effective at colder temperatures (Gardiner 1984, Hillman et al. 1992). Gardiner (1984) observed fish hiding in the rocks, therefore lowering snorkeling efficiency, at water temperatures below 15 °C. Hillman et al. (1992) reported snorkeling efficiency of about 70 percent at water temperatures above 14 °C. Snorkel surveys were conducted at water temperatures ranging from 7.2 to 18.3 °C. Fry are easily underestimated in shallow water (Griffith 1981, Moore 1987).

Snorkeling efficiency was determined in nineteen pools by comparing snorkel counts to estimates made by electrofishing. To calibrate, the pool was isolated with block nets and snorkeled. Without removing the nets, the pool was electrofished three or more times. All fishes were retained separately for each pass. Trout observed while electrofishing, but not captured, on the final pass were noted. Pool density was estimated using the removal summation method of Carle and Strub (1978). The total trout captured plus trout observed but not captured on the final pass was used as the pool estimate if it was greater than the removal estimate. To assess bias, I ran a multiple regression on the ratio of the snorkel count to the electrofishing estimate.

Measuring complexity

I used an index integrating structural variation and depth to quantify the structural complexity of each pool in the sample reaches. I calculated the pool complexity index value by dividing each pool into five equal longitudinal segments separated by four latitudinal transects (Figure 2). Along each transect, a light chain was draped along the bottom of the pool from bank to bank, with care taken to guide the chain along the shape of the bottom and over any

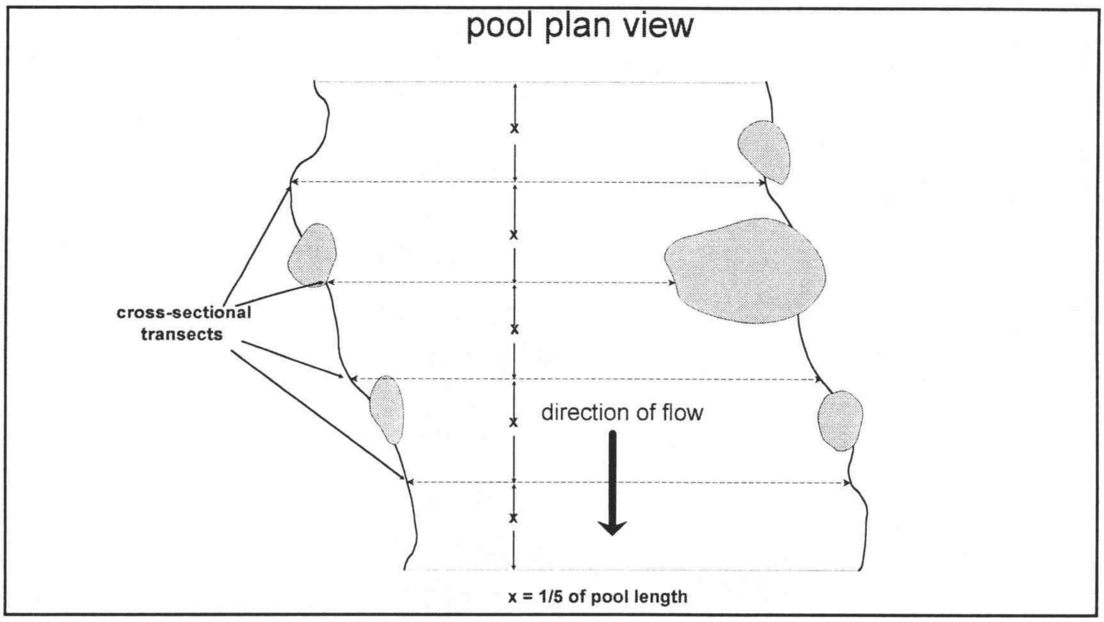

Figure 2. Locations of cross-sectional transects used for measurement of the pool structural complexity index.

obstacles. Wood was included in the measurement. If the wood was within 25 cm of the bottom, the chain was drawn up from the substrate around the wood and back down; if more than 25 cm, the circumference of the wood was included in the chain measurement, but not the distance from the substrate. Stream wetted width was measured at each transect. The measured chain length was divided by the transect length, the wetted width, (Figure 3) and these values were averaged per pool to obtain the pool complexity index value. Structural complexity increases with index values.

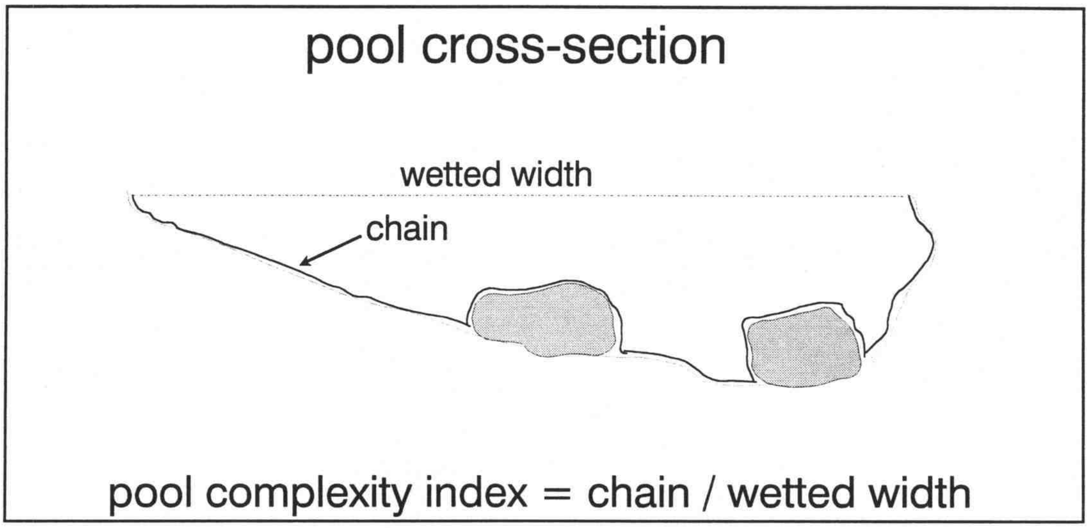

Figure 3. Pool cross-section demonstrating the calculation of the pool complexity index taken at each transect.

I used a similar index to measure bank complexity. The wetted edge of each bank was measured, as was the straight pool length along each bank (Figure 4). Each wetted edge length was divided by the pool length and these values were averaged to calculate the bank complexity index value for each pool. Again, bank complexity increases with higher index values.

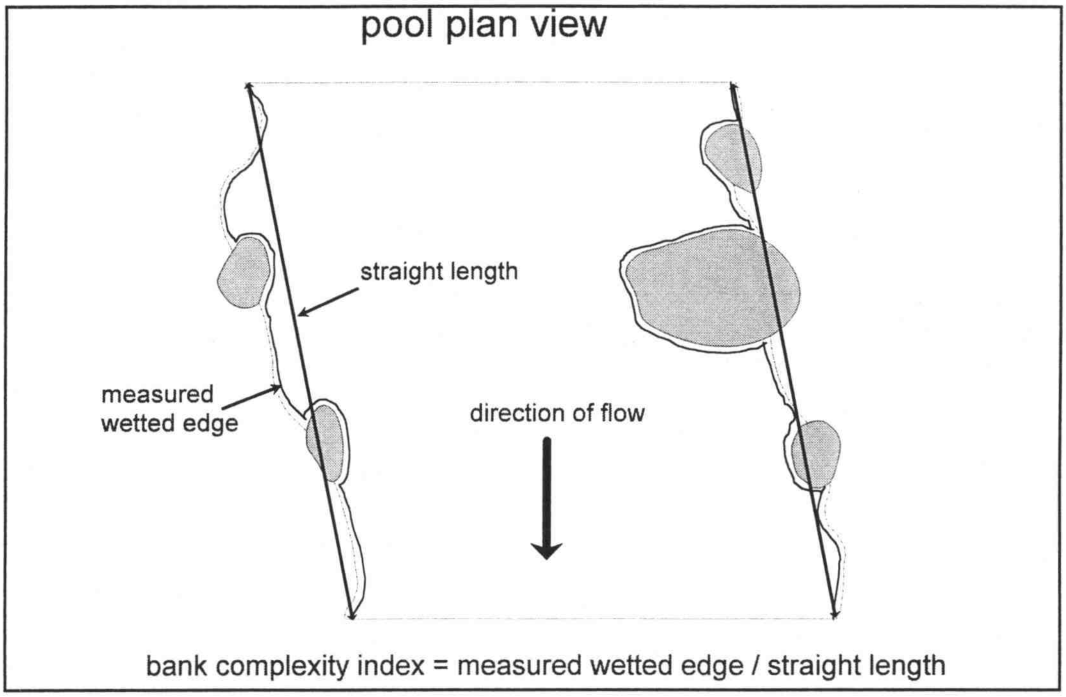

Figure 4. Pool plan view demonstrating measurement of the bank complexity index.

Statistical analysis

Data were analyzed by using multiple linear regression on trout one year and older density (trout/m^2) to answer the question: "Is trout density correlated to complexity after accounting for other habitat variables?" To be conservative, I initially ran the stepwise procedure without including either the pool complexity or the bank complexity variables on trout density measured as trout per length, trout per area, and trout per volume. Although three types of density were analyzed, I focused on density as trout per area. Trout exist in a three dimensional environment, but pool volumes can be difficult to accurately assess. Measuring density as trout per volume tends to equalize the densities present in deep and shallow areas, while measuring density as trout per area emphasizes the importance of deep areas. Variables used in the stepwise procedure included: pool length, pool area, pool volume, maximum depth, average depth, and water temperature while snorkeling. After selecting the best model, the pool complexity variable and the bank complexity variable were each added to the final model separately to determine if they were correlated to trout density after accounting for other covariates. Study sites were included as block variables in the stepwise model to account for the possibility that each site contained animals from separate populations or had a different carrying capacity.

To compensate for biases associated with the snorkeling technique, I initially created a quadratic equation. The equation included temperature, the square of temperature, and pool structural complexity. Though data were not corrected using this equation, I did include water temperature as a potential variable in the stepwise regression analysis in case the temperature bias was significant.

Stepwise regression was done on total fry per pool and on fry density (fry/m) using the following variables: pool length, area, volume, maximum depth, average depth, pool structural complexity, bank complexity, water temperature while snorkeling, density of trout one year and older (trout/m^3), and number of trout one year and older per pool. Since emergence occurred at different times in each site, regressions were run separately for each site to account for different fry needs at different ages.

Microhabitat assessment

For this study, I defined a microhabitat as a subsection of a channel unit (pool) with specific depths and flows, associations with physical structures (i.e., the stream edge, rocks, or large woody debris), or other specific characteristics (i.e., turbulence or backwater) (Table 3). Microhabitat was quantified by drawing a detailed map of each pool unit to scale, including a depth profile. The percent area occupied by each microhabitat was visually-estimated during the 1993 late July sampling period after the pool had been snorkeled. Microhabitat locations were noted on the maps. Microhabitat area was determined by multiplying the percent area occupied by each microhabitat by the measured pool surface area.

Microhabitat use was determined during three snorkel surveys of 22 pools in Black Canyon Creek from June 29, 1993, through August 19, 1993. All surveys were conducted between 1000 and 1600 hours. Location, orientation, and estimated age of each fish in the pool were recorded on the pool map at each visit.

Microhabitat availability was estimated once, therefore changes in microhabitat availability over the summer are unknown. Calculating electivity indices is only appropriate for the mid-July sampling period. The method proposed by Neu et al. (1974) was used to test electivity. A Chi-square goodness-of-fit test was first done to determine whether microhabitat use was other than random for both fry and older trout. The Bonferroni Z-statistic was used to determine whether each microhabitat was used more or less frequently than expected.

Table 3. Definitions of microhabitats identified in pools of Black Canyon Creek.

Microhabitat	Description
Edge	Within 0.5 m of bank
Under Rocks	In the space under rocks/substrate
Under Debris	In, under or associated with woody debris
Backwater	Very still water, silt substrate
Turbulence	Under or in turbulent (white) water
Shallow current	Depth < 0.25 m, flow predominantly downstream
Moderate depth current	Depth 0.25 - 0.5 m, flow predominantly downstream
Deep current	Depth > 0.5 m, flow predominantly downstream
Shallow eddy	Depth < 0.25 m, flow other than downstream
Moderate depth eddy	Depth 0.25 - 0.5 m, flow other than downstream
Deep eddy	Depth > 0.5 m, flow other than downstream

Results

Channel unit scale

I surveyed 45 pools from Black Canyon Creek, lower Rock Creek, and upper Rock Creek during three sampling periods from June through September 1993, and 45 pools from Black Canyon Creek, upper Rock Creek, and Trout Creek during two sampling periods from June through September 1994. Stream flows were highest in Black Canyon Creek and lowest in Trout Creek, and decreased in all sites over the summer (Table 4). Density of one year and older trout observed per pool ranged from 0.1 to 3.3 trout/m^3. In 1993, trout density was greatest in the upper Rock Creek site during early summer and highest in Black Canyon Creek during late summer (Table 5). In 1994, upper Rock Creek again had the highest density of trout by volume during early summer, and Trout Creek had the highest density by volume and area during late summer (Table 6).

Visual counts of trout one year and older obtained by snorkeling were biased by the structural complexity of the pool (Table 7). In more complex pools, a smaller proportion of the trout one year and older present were observed than in simple pools. Plotting residuals against water temperature suggested an additional correlation to temperature, though the confidence levels were low ($P > 0.1$). These results suggest a nonlinear correlation to temperature. I used a quadratic temperature term to take the nonlinearity into account. Due to the low confidence associated with this model, it was not used to correct visual observations (see Figure 5). In order to allow for the influence of temperature, I included it as a possible variable during the stepwise regression procedure. If temperature during snorkeling had a significant effect on the number of trout observed, it should be selected.

Table 4. Stream flows taken when pools were characterized and at each sampling period.

Site	Date	Flow (m^3/min)
	1993	
Black Canyon Creek	June 16, 1993	85
	June 29, 1993	60
	July 27, 1993	32
	August 18, 1993	34
upper Rock Creek	June 15, 1993	60
	July 21, 1993	20
	August 8, 1993	7.6
	September 14, 1993	5.6
lower Rock Creek	July 24, 1993	34
	1994	
Black Canyon Creek	June 22, 1994	49
	July 8, 1994	36
	September 7, 1994	37
upper Rock Creek	June 21, 1994	19
	July 14, 1994	9.5
	August 24, 1994	5.4
Trout Creek	June 20, 1994	12
	June 29, 1994	7.8
	August 30, 1994	1.7

Table 5. Mean trout densities (in trout per length, area, and volume) and average water temperature during snorkeling for each sampling period in each site during 1993. N is the number of pools sampled per reach. Variances are reported in parentheses.

Stream	N	Density (trout/m)	Density (trout/m^2)	Density (trout/m^3)	Water temperature (°C)
			June 29 - July 22		
Black Canyon	22	1.05 (0.45)	0.21 (0.02)	0.69 (0.11)	13.7 (2.5)
Upper Rock	15	1.24 (0.44)	0.24 (0.01)	1.10 (0.20)	12.2 (5.2)
Lower Rock	8	0.94 (0.11)	0.21 (0.02)	0.73 (0.14)	11.8 (0.2)
			July 26 - August 10		
Black Canyon	22	1.22 (0.81)	0.27 (0.05)	0.98 (0.29)	14.6 (2.6)
Upper Rock	15	0.95 (0.31)	0.20 (0.02)	1.05 (0.23)	14.1 (6.5)
Lower Rock	8	0.87 (0.03)	0.21 (0.02)	0.82 (0.15)	13.3 (2.8)
			August 16 - September 14		
Black Canyon	22	0.99 (0.45)	0.21 (0.03)	0.78 (0.18)	14.2 (1.9)
Upper Rock	15	0.47 (0.19)	0.09 (0.01)	0.53 (0.10)	10.7 (3.2)
Lower Rock	8	0.47 (0.02)	0.10 (0.01)	0.47 (0.03)	10.7 (0.7)

I used stepwise regression to find the model that best explained trout density by area without using either the pool complexity or the bank complexity variables. Average and range for each variable in each study site are reported in Appendix A. Regression models explained the variability in trout per area better than trout per length or volume (see Appendix B). Pool complexity and bank complexity variables were each added separately to the final model chosen with the stepwise procedure (Table 8). Trout density was strongly correlated to pool complexity during the late summer sampling periods ($P \leq 0.05$) and was not

Table 6. Mean trout densities (in trout per length, area, and volume) and average water temperature during snorkeling for each sampling period in each site during 1994. There were 15 pools sampled at each site. Variances are reported in parentheses.

Stream	Density (trout/m)	Density (trout/m^2)	Density (trout/m^3)	Water temperature (°C)
		June 27 - July 15		
Black Canyon	1.51 (1.14)	0.32 (0.04)	0.97 (0.15)	15.8 (4.3)
Upper Rock	1.09 (1.38)	0.23 (0.04)	1.25 (0.40)	17.5 (10.9)
Trout	1.08 (1.20)	0.29 (0.07)	1.04 (0.46)	17.4 (6.6)
		August 22 - September 10		
Black Canyon	1.57 (0.95)	0.33 (0.03)	1.09 (0.07)	13.7 (2.0)
Upper Rock	0.73 (0.22)	0.16 (0.02)	1.08 (0.11)	14.9 (4.6)
Trout	1.45 (0.94)	0.41 (0.06)	1.90 (0.54)	16.4 (5.0)

Table 7. Results of the multiple linear regression for nineteen snorkel counts calibrated with electrofishing. The dependent variable was the ratio of the snorkel count to the electrofishing estimate.

Independent variable	Coefficient	Standard error	P-value
Constant	0.014	1.352	0.992
Pool complexity	-0.75	0.33	0.042
Water temperature	0.24	0.17	0.176
(Water temperature)^2	-0.0077	0.0058	0.207

correlated to pool complexity during the early summer. The 1993 mid-summer sampling period was intermediate ($P < 0.1$). Appendix B displays the results from stepwise regression with and without the pool structural complexity variable for each sampling period using density as the dependent variable.

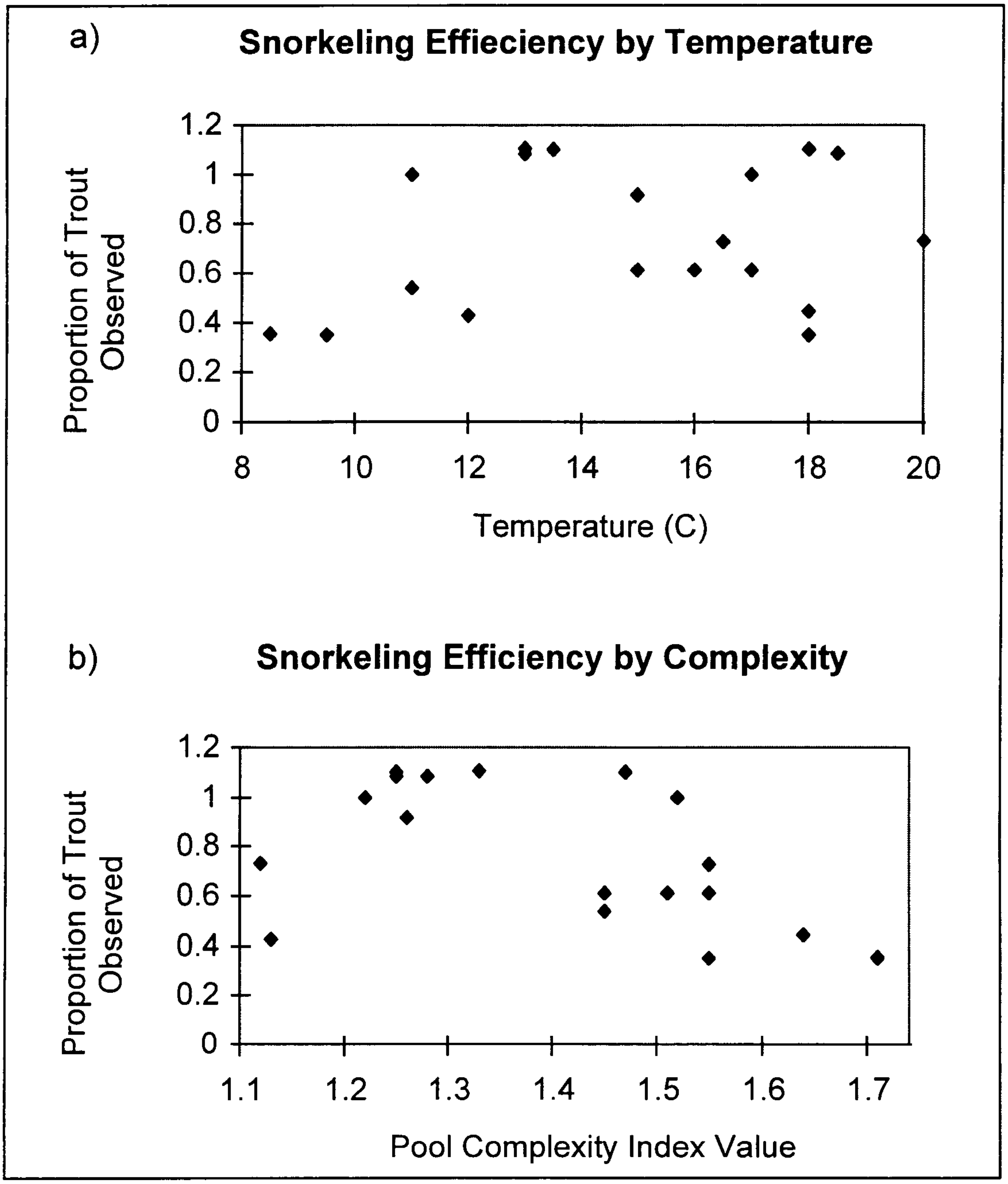

Figure 5. Snorkeling efficiency plotted against a) water temperature and b) pool complexity. The proportion of trout observed represents the number of trout one year and older observed by snorkeling divided by the number of trout one year and older estimated using 3-pass depletion electrofishing.

Table 8. P-values from F-tests associated with pool complexity and bank complexity when added to models containing the covariates that best explained density of trout one year and older.

Sampling period	P-value when pool complexity was added	P-value when bank complexity was added	Other significant variables in model
		1993	
June 29 - July 22	0.787	0.433	Average depth Pool volume
July 26 - August 10	0.098	0.869	Average depth Pool volume
August 16 - September 14	**0.017**	0.950	Average depth
		1994	
June 27 - July 15	0.229	0.499	Average depth Pool area Water temperature[a]
August 22 - September 10	**0.046**	0.249	Average depth

[a] Water temperature represents the temperature during each snorkeling survey.

In Black Canyon Creek (Table 9), during late June and early July 1993, fry density was positively correlated ($P < 0.01$) to density of trout one year and older. They may have been responding to similar pool features, but with higher use of shallower pools. During late July and late August, fry were distributed evenly along the length of the pools, but were not correlated to any other measured pool variable ($P > 0.05$). Fry distribution during June 1994, may have been more representative of redd distribution than pool characteristics. During

September 1994, total fry were best correlated to pool volume, perhaps due to the warmer temperatures during 1994, they grew faster and moved away from the edges more than in 1993. Fry density at this time probably increased in larger pools and tapered off (increasing with total trout one year and older and decreasing with pool length). There was also a positive correlation to bank complexity.

Table 9. Black Canyon Creek fry final models selected with stepwise regression on total fry and density of fry (fry/m) for 1993 and 1994. Period 1 = June 29 - July 8, 1993; period 2 = July 26 - 29; period 3 = August 16 - 19, 1993; period 4 = July 6 - 10, 1994; and period 5 = September 6 - 8, 1994.

	fry per pool			fry/m		
period	variable	coeff.[a]	p-value	variable	coeff.	p-value
1	trout density	18.9	0.0045	trout density	1.92	0.0076
	ave depth	-57.9	0.0443	ave depth	-5.93	0.0586
2	length	1.2	0.0010	none chosen	n/a	n/a
3	length	1.15	0.0020	none chosen	n/a	n/a
4	none chosen	n/a	n/a	none chosen	n/a	n/a
5	volume	0.63	0.0006	length	-0.09	0.0001
				total trout	0.09	0.0000
				bank complexity	0.35	0.0466

[a] regression coefficient

Fry in Rock Creek (Table 10) emerged later than fry in Black Canyon Creek and were not present during the early summer sampling periods. During

August 1993, fry were distributed evenly along the length of the pools, but not correlated ($P > 0.05$) to any other measured pool variable. During September 1993, fry distribution was positively correlated to pool structural complexity. During September 1994, fry density was low and distribution was patchy; there was no correlation to any measured pool variable.

Table 10. Rock Creek fry final models selected with stepwise regression on total fry and density of fry (fry/m) for 1993 and 1994. Period 1 = July 12 - 22, 1993; period 2 = August 6 - 9, 1993; period 3 = September 8 - 14, 1993; period 4 = July 12 - 15, 1994; and period 5 = August 22 - 25, 1994.

	fry			fry/m		
period	variable	coeff.[a]	p-value	variable	coeff.	p-value
1	no fry	n/a	n/a	no fry	n/a	n/a
2	length	0.50	0.0495	none chosen	n/a	n/a
3	pool complexity	10.5	0.0307	pool complexity	1.1	0.0014
4	no fry	n/a	n/a	no fry	n/a	n/a
5[b]	none chosen	n/a	n/a	none chosen	n/a	n/a

[a] regression coefficient
[b] very low fry density.

Fry in Trout Creek (Table 11) had not emerged before the first sampling period in 1994. During the late summer sampling period, more fry were observed in simple pools. This may have been a response to lower trout density, as trout density and pool complexity were well correlated.

Table 11. Trout Creek fry final models selected with stepwise regression on total fry and density of fry (fry/m) for 1994. Period 4 = June 27 - 30, 1994, period 5 = August 29 - 31, 1994.

	fry			fry/m		
period	variable	coeff.[a]	p-value	variable	coeff.	p-value
4	no fry	n/a	n/a	no fry	n/a	n/a
5	pool complexity	-16.7	0.0054	pool complexity	-2.12	0.0142

[a] regression coefficient

Microhabitat scale

Microhabitat use and availability data was used to determine electivity. Electivity was tested for the July sampling period only. Both fry and older trout were using habitat nonrandomly. The Chi-square goodness-of-fit values for fry and older trout were 69 and 70, respectively (10 df, $P < 0.0005$). Fry elected for stream margins, moderate depth eddies, and backwater areas and elected against current microhabitats (all depths), deep eddies, turbulent water, and under rock microhabitats (Table 12). Shallow eddies and areas associated with wood debris were used in proportion to their availability. Trout one year and older elected for deep areas and areas associated with wood debris and elected against moderate depth and shallow areas, stream margins, turbulent water, and backwater areas (Table 12). Under rock microhabitats were used in proportion to their availability.

Table 12. Electivity results on microhabitat use and availability data from Black Canyon Creek during July 1993 for fry and older trout. Ninety-five percent confidence intervals were calculated using the proportion of use to estimate the proportion of each microhabitat available.

Microhabitat	Proportion of use	Expected lower limit	Expected upper limit	Proportion available	Electivity +, -, 0
			Fry		
mod.[a] current	0.15	0.09	0.21	0.26	-
shallow current	0.05	0.01	0.08	0.16	-
deep current	0.00	0.00	0.00	0.15	-
deep eddy	0.02	-0.01	0.05	0.10	-
edge	0.38	0.30	0.47	0.08	+
under debris	0.03	0.00	0.07	0.06	0
mod.[a] eddy	0.18	0.11	0.24	0.05	+
turbulence	0.00	0.00	0.00	0.05	-
backwater	0.13	0.07	0.19	0.05	+
shallow eddy	0.06	0.02	0.10	0.03	0
under rocks	0.00	0.00	0.00	0.01	-
			Trout one year and older		
mod.[a] current	0.09	0.04	0.13	0.26	-
shallow current	0.01	-0.01	0.02	0.16	-
deep current	0.36	0.28	0.45	0.15	+
deep eddy	0.36	0.27	0.44	0.10	+
edge	0.02	-0.01	0.04	0.08	-
under debris	0.12	0.06	0.17	0.06	+
mod.[a] eddy	0.02	-0.01	0.04	0.05	-
turbulence	0.01	-0.01	0.02	0.05	-
backwater	0.01	-0.01	0.02	0.05	-
shallow eddy	0.00	0.00	0.00	0.03	-
under rocks	0.03	0.00	0.06	0.01	0

[a] mod. = moderate depth

In Black Canyon Creek, 724 observations of trout older than one year and 675 observations of underyearling trout were recorded in one of eleven possible microhabitats during three sampling periods (Table 13). Although habitat availability data are unavailable for June and August, it is interesting to note shifts in microhabitat use for both fry and older trout. For older trout, use of areas with moderate depths (depth between 0.25 and 0.5 m) decreased and use of deep areas and cover increased throughout the summer as pool volumes declined. Older trout were associated with the following microhabitats in declining order of use (by density): deep eddy > under rocks > deep current > under debris > moderate depth current > moderate depth eddy > edge > backwater > turbulent water > shallow current > shallow eddy (see Table 3 for microhabitat definitions). This order changed little from early to late summer. In contrast, habitat use by trout fry shifted dramatically between sampling periods. During early summer, fry used edge habitat almost exclusively. During mid and late summer fry and larger and beginning to shift to deeper and faster microhabitats. Though fry rarely used the deepest areas, the direct current, or cover, areas commonly used by older trout.

Log weir and natural pool comparisons

Pool size characteristics and trout densities of fifteen pools in Trout Creek were compared: three natural pools, six log weir pools with no structure added, and six log weir pools with a rootwad added (Tables 14 and 15). Tukey's multiple range test was used for all comparisons. Natural pools and log weir pools without a rootwad supported similar densities of trout in late June (Table

Table 13. Microhabitat use in Black Canyon Creek during all sampling periods in 1993. Microhabitat availability was determined during the July sampling period. Use is reported as the number of fish observed using the microhabitat.

Microhabitat	Proportion available	June	July	August
		Fry		
mod.[a] current	0.26	2	39	67
shallow current	0.16	0	12	12
deep current	0.15	0	0	13
deep eddy	0.10	0	6	32
edge	0.08	78	100	98
under debris	0.06	1	9	17
mod.[a] eddy	0.05	7	46	34
turbulence	0.05	0	0	0
backwater	0.05	4	34	36
shallow eddy	0.03	6	15	5
under rocks	0.01	0	0	2
total fry		**98**	**261**	**316**
		Trout one year and older		
mod.[a] current	0.26	30	23	15
shallow current	0.16	1	1	0
deep current	0.15	93	98	89
deep eddy	0.10	76	97	54
edge	0.08	3	4	3
under debris	0.06	23	31	36
mod.[a] eddy	0.05	9	4	7
turbulence	0.05	0	1	0
backwater	0.05	1	2	1
shallow eddy	0.03	0	0	0
under rocks	0.01	2	9	11
total trout		**238**	**270**	**216**

14) and late August (Table 15). Natural pools lacked depth, but had moderate amounts of structural complexity. Log weir pools with rootwads had high densities of trout and high structural complexity. All pool types tended to have

higher numbers and densities of fish in late August than in late June, and weir pools appeared to gain more fish than natural pools. Natural pools lost twice as much volume as weir pools between June and August.

Table 14. Mean trout density, number of trout, pool volume, average depth, maximum depth, and pool complexity index value for natural pools and log weir pools with and without rootwads from June 27 - 30, 1994. Tukey's multiple range comparison was used to determine significant differences between groups.

Pool type	Natural	Log weir	Log weir with rootwad
Trout density (trout/m^3)	0.694	0.687	1.312
Number of trout per pool	4.7	4.8	9.9
Pool volume (m^3)	6.7	7.0	7.6
Average depth (m)	0.21[a]	0.27	0.31
Maximum depth (m)	0.48[b]	0.58	0.67
Pool complexity index value	1.26	1.18[c]	1.35
Number of pools	3	6	6

[a] Natural pools differ from all log weir pools ($P < 0.05$).
[b] Natural pools differ from log weir pools with rootwads ($P < 0.05$).
[c] Log weir pools differ from log weir pools with rootwads ($P < 0.05$).

During August, both pool structural complexity and average pool depth are important to trout. Data shown in Figure 6a display the strong correlation between pool structural complexity and trout density. Although pools numbered

9, 12, and 25 have similar pool complexity index values, there is a great disparity in the densities of trout these pools can support. Plotting the data against average pool depth appears to explain the difference in trout densities between pools numbered 9, 12, and 25 (Figure 6b).

Table 15. Mean trout density, number of trout, pool volume, average depth, maximum depth, and pool complexity index value for natural pools and log weir pools with and without rootwads from August 29 - 31, 1994. Tukey's multiple range comparison was used to determine significant differences between groups (90% confidence).

Pool type	Natural	Log weir	Log weir with rootwad
Trout density (trout/m^3)	1.397	1.392[a]	2.371
Number of trout per pool	5.3	7.9	14.4
Pool volume (m^3)	3.8	5.7	6.0
Average depth (m)	0.12[b]	0.22	0.25
Maximum depth (m)	0.35[b]	0.51	0.54
Pool complexity index value	1.26	1.18[c]	1.35
Number of pools	3	6	6

[a] Log weir pools differ from log weir pools with rootwads ($P < 0.08$).
[b] Natural pools differ from all log weir pools ($P < 0.02$).
[c] Log weir pools differ from log weir pools with rootwads ($P < 0.05$).

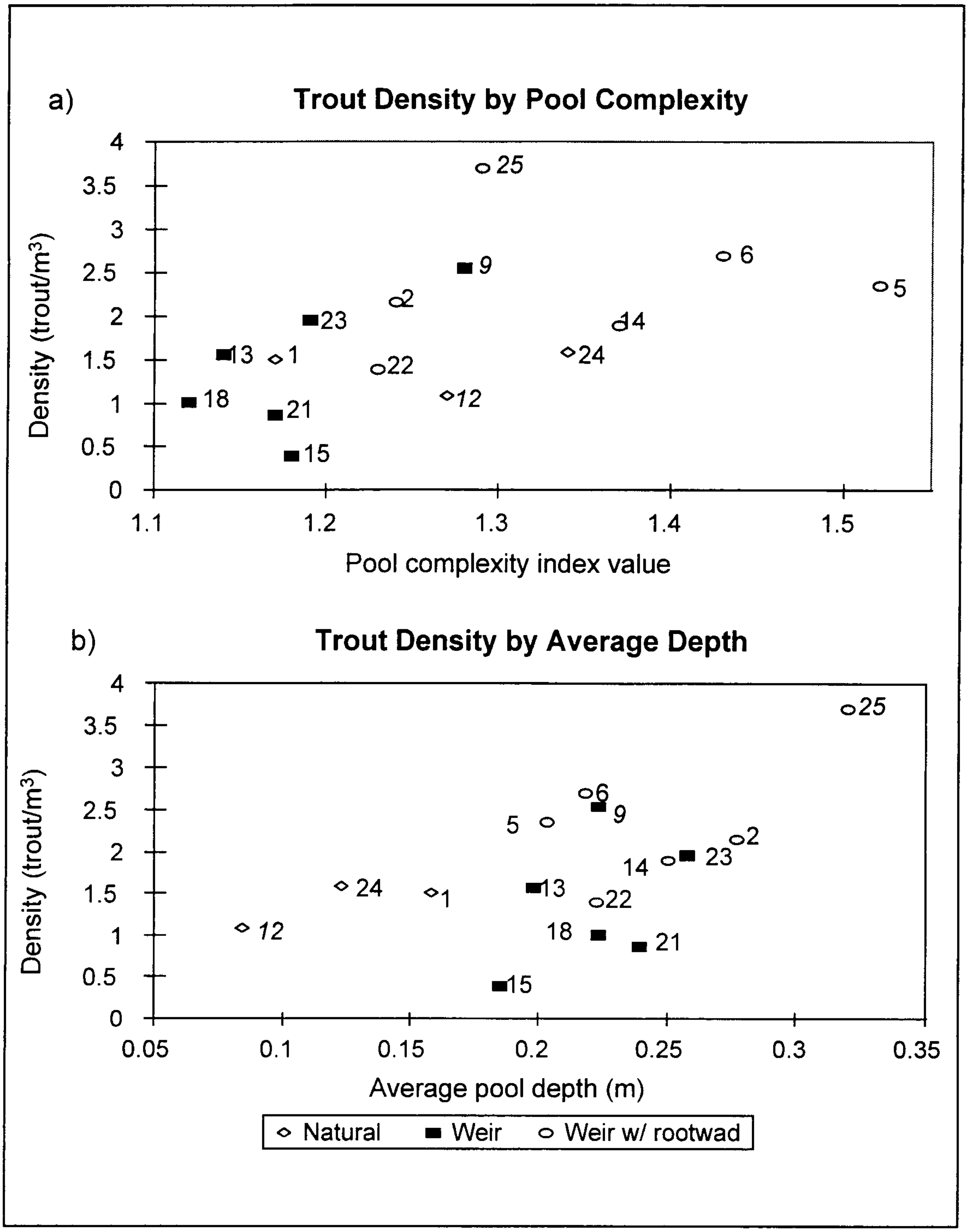

Figure 6. Trout density from natural pools and log weir pools with and without rootwads in Trout Creek plotted against a) pool complexity and b) average pool depth. Pool numbers are provided with pools 9, 12, and 25 italicized to emphasize the importance of both variables.

Discussion

I defined microhabitat as a subsection of a pool: this definition of microhabitat is more useful to managers than those traditionally used in microhabitat studies. Many microhabitat investigations involve taking numerous measurements at each fish location, describing aspects such as its location, nearest substrate, and focal point water velocity (Bustard and Narver 1975a, Fausch and White 1981, Cunjak and Green 1983, Cunjak and Power 1986, Morantz et al. 1987, Dolloff and Reeves 1990, and Lohr and West 1992). This three-dimensional coordinate system does not capture the essence of a microhabitat or treat it as a whole. I used a broader, more encapsulating technique that defines and describes the microhabitat as a whole. Managers can use this definition to evaluate habitat conditions or re-create key microhabitats in stream rehabilitation projects.

In addition, microhabitat evaluation is typically conducted a maximum of once per year and streams may be compared which were measured at different times, under different conditions. I wanted to limit my habitat evaluation to aspects which tended to change little over time. Velocity, though an important aspect of microhabitat quality, was thus disregarded due to its high variability over time. Though microhabitat use may be more closely related to factors that change over time, I wanted to relate microhabitat use at different times to constant, measurable physical factors.

Microhabitat quality was assessed by trout and fry density and an electivity index. According to the Ideal Free Distribution theory (Fretwell and Lucas 1970), the best habitats should contain the highest density of organisms. Pert and Erman (1994) recommended against using density as a measure of microhabitat quality for salmonids since dominant fish will displace other fish from preferred habitats. I found the highest densities of trout one year and older in the same microhabitats occupied by the largest fish (personal observation). Using the definition of microhabitat that I proposed, trout density seems to be an appropriate measure of relative microhabitat quality and electivity indices would be appropriate. Electivity indices are very useful in determining feeding choices where use verses availability is not obvious. But electivity tests on microhabitat data add only the statistical test of preference verses avoidance; a preference ranking can be easily determined by fish density within each type of microhabitat. In addition, the microhabitat positions of the dominant fish can also indicate high quality habitat.

Microhabitat was partitioned between fry and older trout throughout the summer. The microhabitats used most by trout one year and older in natural pools of a pristine stream were deep areas of direct and indirect flow and cover associated with substrate and wood. They elected against stream margins or other shallow or slack water areas. Fry used shallow, tranquil areas and stream margins. They were not found in deep water or areas with high velocity. Fry rarely used cover, perhaps to increase their foraging efficiency, being able to better see and capture prey in the open. As fry grew throughout the summer, they exhibited a shift in microhabitat use. They moved away from the edges and began using faster, deeper microhabitats. This pattern is consistent with other reports of salmonid fry microhabitat shifts (e.g., Stein et al. 1972).

Use of cover by trout one year and older increased over the summer. This coincided with the increased response to structural complexity at the channel unit scale. The large substrate and wood that provided cover also increased the measured complexity index of the pool. As trout increased their use of cover at the microhabitat scale, they also increased use of pools with more structural complexity. This places a greater premium on pools with more structural complexity.

Trout density was positively correlated with structural complexity of pools during summer base flow. This correlation was similar in three streams of different sizes and management regimes. This correlation occurred during an extreme drought year and a year with average rainfall indicating that base flow conditions may be limiting even in a good water year. Trout density was not correlated to structural complexity in pools during late June and early July, while flows were higher and there was presumably more habitat available outside of pools. There was, however, a strong correlation to structural complexity during summer low flow. As trout moved into pools, pools with more structural complexity contained higher trout densities. Additionally, trout density was positively correlated to pool structural complexity in man-made log weir pools in

Trout Creek during both early and late summer. The simplified nature of Trout Creek may limit habitat options earlier in the summer, causing an earlier response to structural complexity. It is unclear whether this response occurs due to changing trout densities, changing food needs or availabilities, a lowered sense of security with slower, shallower water, or other factors. Structural complexity can provide overhead cover, visual isolation, and velocity refuge. In an experiment designed to isolate these effects, Fausch (1993) determined that steelhead parr only selected for overhead cover.

The streams appear to approach the carrying capacity of the system later in the summer. As habitat volume decreases and trout density increases, competition for space increases. Increased correlation with structural complexity may also have been caused by changing use of cover, as suggested by my microhabitat analysis. Trout may either need cover more, or the types of cover they were using early in the summer (e.g., deeper water, or faster water which would have more surface distortion or bubbles) may be less available and they are therefore switching to use of structural cover.

Although the focus of the study was on trout one year and older, fry response to structural complexity was also examined. Correlation of fry density with variables at the channel unit scale was inconsistent among streams and years. I expected fry density to be correlated to bank complexity, especially earlier in the summer when fry were still closely associated with stream margins. Moore (1987) and Moore and Gregory (1988) found higher densities of cutthroat trout fry in more complex stream margins. However, fry density in the current study was correlated to bank complexity only in Black Canyon Creek during late summer in 1994. This general lack of correlation may have resulted from the small sample sizes, since each stream and sampling period was analyzed separately, or from inefficient sampling of fry. It is also possible that the measurement of bank complexity I used was not sensitive to elements important to fry or that bank complexity is unimportant to fry in pools in these systems.

Snorkeling has the potential to influence trout behavior, though the effect would be difficult to determine. Increased trout use of cover could have been an avoidance response to a diver during late summer. However, trout observed using cover appeared undisturbed. Trout displaying flight response to a diver were rarely observed again, and if so were not included in the analysis. In addition, I feel the trout locations observed were more likely representative of undisturbed microhabitat use since changes in use of cover corresponded to increased trout densities in pools with higher structural complexity, and presumably more cover. I assume that overall trout density within a pool was independent of the presence of the diver, although microhabitat use has the potential to reflect diver influence.

Creation of log weir pools is a common stream restoration practice. The intent is to create pools in areas where the natural pool forming elements (e.g., large wood, beaver, etc...) have been removed or altered. Trout Creek is a good example of a stream in which the natural pool forming elements have been removed. Historical stream-side logging occurred along some reaches of Trout Creek and beaver are no longer present. Trout Creek has also been constrained by a valley-bottom road and is downcut, isolating it from its floodplain. As a result, in these reaches Trout Creek has very few natural pools and these pools are shallow. Restoration in Trout Creek was intended to remedy some of these impacts. Deciduous vegetation is returning following cattle exclusion and beaver activity is evident (though there are no ponds). Log weirs were placed in a highly degraded reach to increase the number of deep pools. Some of the log weir pools had a rootwad added to increase pool quality.

Log weir pools with rootwads had higher trout densities than log weir pools without rootwads and natural pools in Trout Creek. Addition of a rootwad increased the structural complexity of the pool. Log weir pools provide deep areas which are important microhabitats and rootwads provide cover, another microhabitat important to trout. Natural pools, which lacked depth, and log weir pools without rootwads, which lacked structural complexity, supported similar trout densities. Undercut banks and large substrates in natural pools contributed to their increased complexity. Log weir pools have smooth, sandy substrates that reduce the structural complexity of these pools. The greater structural complexity in natural pools apparently compensated for lack of depth. Log weir pools were deeper and lost less volume than natural pools occurring in the reach. Addition of a rootwad to log weir pools in this system appears to have the potential to almost double trout density. Shirvell (1990) also found that rootwads increased use of previously infrequently-used areas.

Pools created by log weirs are plunge pools that are excavated upon construction, with depth maintained by scour at high flow. The natural pools were all shallow, side scour pools. Log weir plunge pools do not imitate natural side scour pools. While trout may respond positively to these pools, log weir pools may be affecting hydraulic patterns and physically anchoring the stream, limiting the ability of the channel to meander, which may be detrimental to trout habitat in the long term.

Trout density increased in pools in Trout Creek through the summer as available riffle habitat declined. Natural pools gained fewer fish through the summer than log weir pools with or without rootwads. Density doubled in natural pools, although the increase in trout density in natural pools could be attributed more to a loss in pool volume than to a net gain in trout. Natural pools maintained trout densities similar to that of log weir pools without rootwads, implying that the quality of habitat was similar between these two categories. Due to their more stable volumes, log weir pools with and without rootwads were able to accommodate increases in numbers of trout as overall trout densities were increasing.

This study of trout habitat use in Trout Creek is a rare example of effectiveness monitoring that can provide much needed information for improvement of techniques. There are few examples of effectiveness monitoring of log weir projects throughout the Columbia River Basin, although millions of dollars were spent on this activity during the late 1980's. The Ochoco National Forest Land and Resource Management Plan (1989) placed an emphasis on riparian area management. Riparian area degradation is common on the Forest as a result of past resource management activities. Trout Creek is a good example of a highly modified stream that has been the focus of recovery efforts during the last decade. This study shows that temporary improvements are possible in modified systems to provide habitat while the system recovers and that more complex structures are more effective.

The adoption of the PACFISH Forest Plan Amendment (USDA Forest Service and USDI Bureau of Land Management 1995) has increased emphasis on riparian area protection and restoration. Even with improved protection of riparian areas, it may take hundreds of years for complete natural recovery of streams. In-channel fish habitat restoration may be an appropriate activity in highly degraded systems with slow recovery rates. While I would caution against the creation of additional log weir pools, there is little doubt that log weir pools were effective summer base flow refuges for one year and older trout with the addition of hiding cover. Late summer carrying capacity of simple log weir pools can be doubled during base flow conditions with the addition of a rootwad for hiding cover.

Stream restoration comprises much more than creation of pools. Restoration must reach beyond the channel and requires the restoration of the whole ecosystem for proper stream functioning, including the upslopes, streamside vegetation, and channel morphology. In addition, reach specific limitations must be identified and the cause of the degradation needs to be addressed and, if possible, reversed. Only after these factors have been addressed, temporary measures, such as instream structures, may be appropriate if they mimic natural processes. If artificial structures are to be used effectively, specific channel unit and microhabitat needs must be understood for all life stages for animals of concern.

Conclusion

* Summer low flow appears to be a critical period in streams of the Ochoco National Forest.
* Structural complexity appears to be a major factor influencing base flow carrying capacity for trout in pristine streams of the Ochoco Mountains..
* The structural complexity of each pool can be quantified using an index integrating structural variation and depth.
* Structural complexity appears to be more important late in the summer, as pools approach their carrying capacity.
* Redband trout displayed a seasonal shift in habitat use from early to late summer on two scales, microhabitat and channel unit.
* The late summer association of trout density with complex pools was coupled with an increased use of microhabitats associated with physical cover.
* Use of cover by trout one year and older doubled from June to August.
* Microhabitat partitioning was apparent between fry and older trout: fry used stream margins and other slow water microhabitats extensively and older trout used cover and deep water microhabitats.
* Defining a microhabitat as a subsection of a pool (or other channel unit) is a definition that is useful to managers and a technique which remains consistent over time.

* In Trout Creek, log weirs simplified the habitat, creating a square smooth-bottomed pool.
* Addition of a rootwad to a log weir pool increased the structural complexity of the pool and these pools supported a higher density of trout.
* Observing trout pool and microhabitat use in relatively undisturbed streams gave insights to management by providing a way to evaluate impacted systems and habitat improvement structures.

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APPENDICES

Appendix A. Variables used in regression analyses. Average values, ranges, and standard errors for variables used.

Table A.1. Average values and ranges for each study site during 1993 for variables used in regression analysis. Standard errors are reported in parentheses. Period 1 = June 29 to July 22, Period 2 = July 26 to August 10, Period 3 = August 16 to September 14.

Variable	Black Canyon Creek (N = 22)	Upper Rock Creek (N = 15)	Lower Rock Creek (N = 8)
Pool Length (m)	10.5 (0.7) 5.1 - 18.3	13.6 (1.2) 6.1 - 24.4	16.2 (1.4) 10.8 - 20.4
Pool Area (m^2)	58.5 (5.3) 31.0 - 130.6	74.5 (8.6) 34.3 - 160.1	83.7 (10.1) 44.6 - 125.1
Pool Volume (m^3) Period 1	17.3 (1.9) 10.5 - 50.9	16.4 (1.6) 7.8 - 31.7	25.2 (3.2) 13.6 - 36.8
Period 2	14.2 (1.7) 7.6 - 45.6	13.1 (1.3) 5.7 - 23.2	21.4 (3.2) 10.5 - 34.0
Period 3	14.4 (1.6) 8.5 - 43.0	11.3 (1.1) 5.4 - 19.2	19.1 (2.9) 9.9 - 29.7
Maximum depth (m) Period 1	0.75 (0.05) 0.43 - 1.46	0.54 (0.03) 0.37 - 0.70	0.72 (0.04) 0.55 - 0.94
Period 2	0.70 (0.05) 0.40 - 1.43	0.48 (0.03) 0.30 - 0.67	0.67 (0.04) 0.49 - 0.91
Period 3	0.71 (0.05) 0.40 - 1.43	0.45 (0.03) 0.30 - 0.64	0.64 (0.04) 0.46 - 0.85
Average depth (m) Period 1	0.30 (0.01) 0.21 - 0.49	0.23 (0.01) 0.16 - 0.32	0.30 (0.02) 0.24 - 0.38
Period 2	0.26 (0.02) 0.18 - 0.49	0.19 (0.01) 0.12 - 0.29	0.26 (0.02) 0.19 - 0.33
Period 3	0.26 (0.02) 0.16 - 0.49	0.17 (0.01) 0.11 - 0.26	0.24 (0.02) 0.16 - 0.30
Temperature (°C) Period 1	13.7 (0.3) 10.6 - 16.1	12.2 (0.6) 7.8 - 15.6	11.8 (0.2) 10.8 - 12.2
Period 2	14.6 (0.3) 12.2 - 18.3	14.1 (0.7) 10.6 - 18.3	13.3 (0.6) 11.1 - 15.6
Period 3	14.2 (0.3) 11.7 - 17.2	10.7 (0.5) 7.2 - 13.3	10.7 (0.3) 9.7 - 11.9
Pool complexity	1.31 (0.02) 1.13 - 1.54	1.41 (0.04) 1.19 - 1.71	1.28 (0.03) 1.21 - 1.45
Bank complexity	1.62 (0.06) 1.21 - 2.15	1.54 (0.04) 1.32 - 1.91	2.08 (0.19) 1.58 - 3.34

Table A.2. Average values and ranges for each study site during 1994 for variables used in regression analysis. Standard errors are reported in parentheses. Period 4 = June 27 to July 15, Period 5 = August 22 to September 10. N = 15 for each site.

Variable	Black Canyon Creek	Upper Rock Creek	Trout Creek
Pool Length (m)	10.0 (0.8)	11.4 (1.0)	6.9 (0.5)
	5.0 - 15.3	3.7 - 17.6	4.1 - 11.3
Pool Area (m^2)	50.1 (4.8)	52.9 (4.7)	26.1 (1.9)
	23.9 - 97.5	25.0 - 90.0	18.4 - 46.1
Pool Volume (m^3)	16.1 (1.5)	9.5 (1.0)	7.2 (0.6)
Period 4	8.5 - 28.3	5.4 - 19.2	3.8 - 11.3
Period 5	14.8 (1.3)	7.5 (0.8)	5.5 (0.5)
	8.5 - 25.5	2.8 - 11.9	1.8 - 9.2
Maximum depth (m)	0.72 (0.05)	0.48 (0.04)	0.60 (0.03)
Period 4	0.52 - 1.21	0.30 - 0.75	0.37 - 0.82
Period 5	0.70 (0.05)	0.43 (0.04)	0.49 (0.03)
	0.49 - 1.14	0.24 - 0.67	0.23 - 0.64
Average depth (m)	0.33 (0.02)	0.18 (0.01)	0.28 (0.01)
Period 4	0.24 - 0.58	0.09 - 0.28	0.18 - 0.37
Period 5	0.31 (0.02)	0.15 (0.01)	0.21 (0.02)
	0.22 - 0.53	0.05 - 0.26	0.08 - 0.32
Temperature (°C)	15.6 (0.5)	17.1 (0.8)	17.8 (0.7)
Period 4	12.8 - 18.9	10.8 - 21.1	12.2 - 20.3
Period 5	13.4 (0.3)	14.5 (0.7)	16.6 (0.6)
	11.9 - 15.6	9.2 - 17.8	12.8 - 18.6
Pool complexity	1.30 (0.02)	1.41 (0.04)	1.26 (0.03)
	1.14 - 1.47	1.19 - 1.71	1.12 - 1.52
Bank complexity	1.59 (0.08)	1.54 (0.04)	1.33 (0.04)
	1.21 - 2.15	1.32 - 1.91	1.13 - 1.66

Appendix B. Stepwise regression results. Results of stepwise regression for each sampling period not including and including the structural complexity variable. Analysis was done on the dependent variable density, calculated as trout older than one year per m, m^2, and m^3. Other variables included for selection by the stepwise procedure were: pool length, pool area, pool volume, average pool depth, maximum pool depth, and water temperature during sampling. Data was statistically blocked by study site. Coefficients and p-values from the final model selected are presented.

Table B.1. Stepwise regression results for June 29 - July 22, 1993. Results were identical with and without the structural complexity variable being included in the stepwise process.

variable	coefficient	p-value	partial r^2	model r^2
		log (trout/m)		
1. average depth	6.74	0.0001	0.429	0.461
		log (trout/m^2)		
1. average depth	8.73	0.0001	0.528	0.558
2. pool volume	-0.0195	0.0263	0.052	0.610
		log (trout/m^3)		
1. average depth	5.24	0.0001	0.222	0.423
2. pool volume	-0.0191	0.0302	0.065	0.488

Table B.2. Stepwise regression results for July 26 - August 10, 1993, excluding the structural complexity variable.

variable	coefficient	p-value	partial r^2	model r^2
		trout/m		
1. maximum depth	3.11	0.0001	0.577	0.622
2. pool length	-0.0518	0.0025	0.078	0.700
		trout/m^2		
1. average depth	1.96	0.0001	0.636	0.674
2. pool volume	-0.0105	0.0001	0.100	0.774
3. maximum depth	0.364	0.0114	0.035	0.808
		trout/m^3		
1. average depth	5.69	0.0001	0.322	0.347
2. pool volume	-0.0311	0.0010	0.157	0.505

Table B.3. Stepwise regression results for July 26 - August 10, 1993, including the structural complexity variable.

variable	coefficient	p-value	partial r^2	model r^2
		trout/m		
1. maximum depth	2.81	0.0001	0.577	0.622
2. pool length	-0.0532	0.0012	0.078	0.700
3. complexity	1.24	0.0262	0.036	0.736
		trout/m^2		
1. average depth	1.61	0.0005	0.636	0.674
2. pool volume	-0.0106	0.0001	0.100	0.774
3. maximum depth	0.398	0.0044	0.035	0.808
4. complexity	0.270	0.0340	0.022	0.830
		trout/m^3		
1. average depth	n/a	n/a	0.322	0.347
2. pool volume	-0.0349	0.0001	0.157	0.505
3. complexity	1.47	0.0021	0.059	0.564
4. maximum depth	1.56	0.0001	0.052	0.615
5. average depth	removed	n/a	0.009	0.606

Table B.4. Stepwise regression results for August 16 - September 14, 1993, excluding the structural complexity variable.

variable	coefficient	p-value	partial r^2	model r^2
		log (trout/m)		
1. maximum depth	n/a	n/a	0.200	0.466
2. pool length	-0.0992	0.0001	0.051	0.517
3. pool area	0.0335	0.0001	0.100	0.617
4. average depth	11.0	0.0001	0.042	0.659
5. maximum depth	removed	n/a	0.005	0.654
6. pool volume	-0.0893	0.0085	0.058	0.713
		log (trout/m^2)		
1. average depth	7.45	0.0001	0.330	0.589
		log (trout/m^3)		
1. average depth	3.27	0.0158	0.116	0.250

Table B.5. Stepwise regression results for August 16 - September 14, 1993, including the structural complexity variable.

variable	coefficient	p-value	partial r^2	model r^2
		log (trout/m)		
1. maximum depth	1.47	0.0015	0.200	0.466
2. pool length	-0.107	0.0001	0.051	0.517
3. pool area	0.0126	0.0003	0.100	0.617
4. complexity	2.03	0.0030	0.080	0.697
		log (trout/m^2)		
1. average depth	5.67	0.0002	0.330	0.589
2. complexity	1.81	0.0109	0.062	0.651
		log (trout/m^3)		
1. complexity	2.00	0.0021	0.180	0.314

Table B.6. Stepwise regression results for June 27 - July 15, 1994, excluding the structural complexity variable.

variable	coefficient	p-value	partial r^2	model r^2
		log (trout/m)		
1. average depth	5.63	0.0001	0.435	0.546
2. pool length	-0.167	0.0002	0.064	0.610
3. temperature	0.0746	0.0020	0.043	0.653
4. pool area	0.0238	0.0051	0.066	0.719
		log (trout/m^2)		
1. average depth	5.51	0.0001	0.424	0.499
2. temperature	0.0694	0.0014	0.087	0.586
3. pool length	-0.0572	0.0051	0.076	0.662
		log (trout/m^3)		
1. pool length	-0.0562	0.0049	0.172	0.233
2. temperature	0.0772	0.0004	0.190	0.423
3. average depth	1.92	0.0506	0.055	0.477

Table B.7. Stepwise regression results for June 27 - July 15, 1994, including the structural complexity variable.

variable	coefficient	p-value	partial r^2	model r^2
		log (trout/m)		
1. average depth	5.63	0.0001	0.435	0.546
2. pool length	-0.167	0.0002	0.064	0.610
3. complexity	n/a	n/a	0.044	0.654
4. temperature	0.0746	0.0020	0.034	0.689
5. pool area	0.0238	0.0051	0.049	0.737
6. complexity	removed	n/a	0.018	0.719
		log (trout/m^2)		
1. average depth	5.51	0.0001	0.424	0.499
2. temperature	0.0694	0.0014	0.087	0.586
3. pool length	-0.0572	0.0051	0.076	0.662
		log (trout/m^3)		
1. pool length	-0.0562	0.0049	0.172	0.233
2. temperature	0.0772	0.0004	0.190	0.423
3. average depth	1.92	0.0506	0.055	0.477

Table B.8. Stepwise regression results for August 22 - September 10, 1994, excluding the structural complexity variable.

variable	coefficient	p-value	partial r^2	model r^2
		log (trout/m)		
1. average depth	7.57	0.0001	0.441	0.730
		log (trout/m^2)		
1. average depth	6.92	0.0001	0.380	0.739
		log (trout/m^3)		
1. average depth	2.09	0.0118	0.095	0.441

Table B.9. Stepwise regression results for August 22 - September 10, 1994, including the structural complexity variable.

variable	coefficient	p-value	partial r^2	model r^2
		log (trout/m)		
1. average depth	6.91	0.0001	0.441	0.730
2. complexity	1.19	0.0203	0.034	0.764
		log (trout/m^2)		
1. average depth	6.44	0.0001	0.380	0.739
2. complexity	0.853	0.0899	0.018	0.757
		log (trout/m^3)		
1. average depth	1.64	0.0491	0.095	0.441
2. complexity	0.807	0.0689	0.045	0.486

Appendix C. Water temperature during sampling periods. Continuously monitored water temperature for Rock Creek, Black Canyon Creek, and Trout Creek.

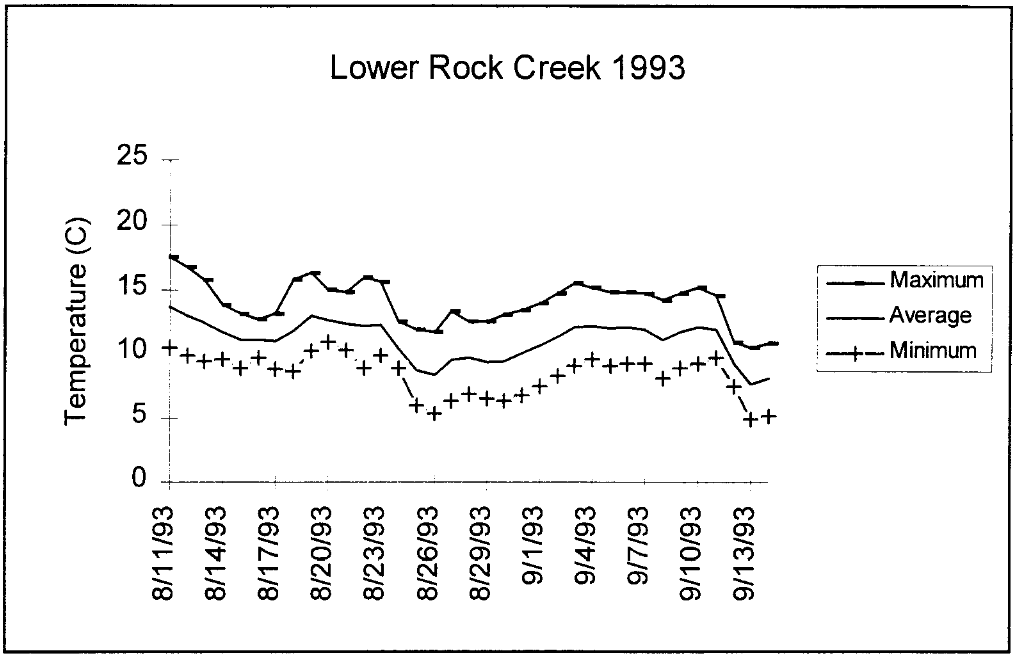
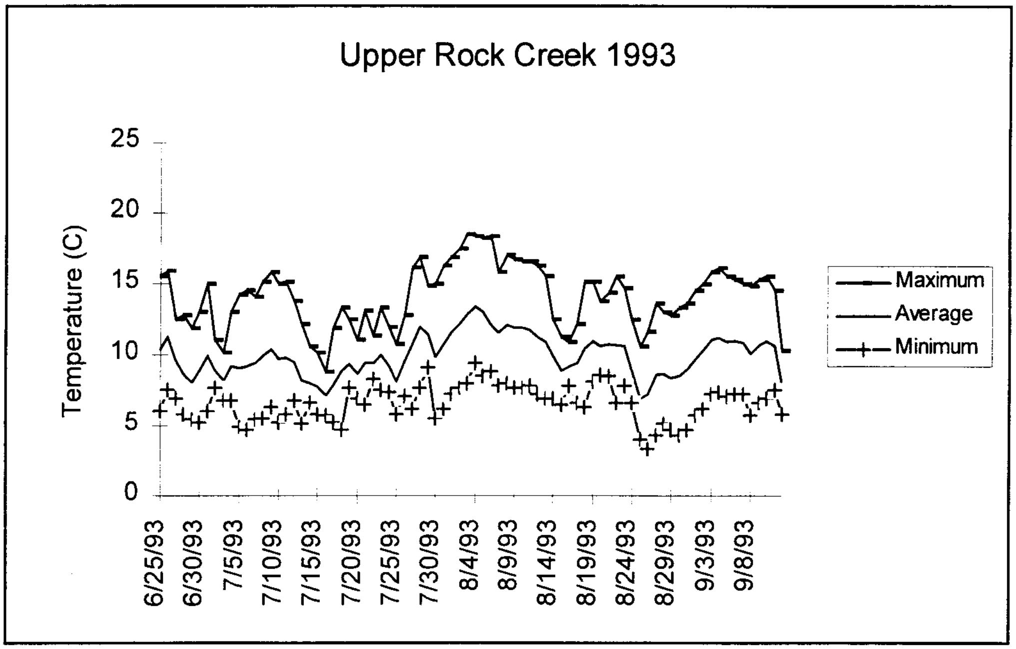


Figure C.1. Daily maximum, average, and minimum water temperatures in lower Rock Creek during late summer in 1993.



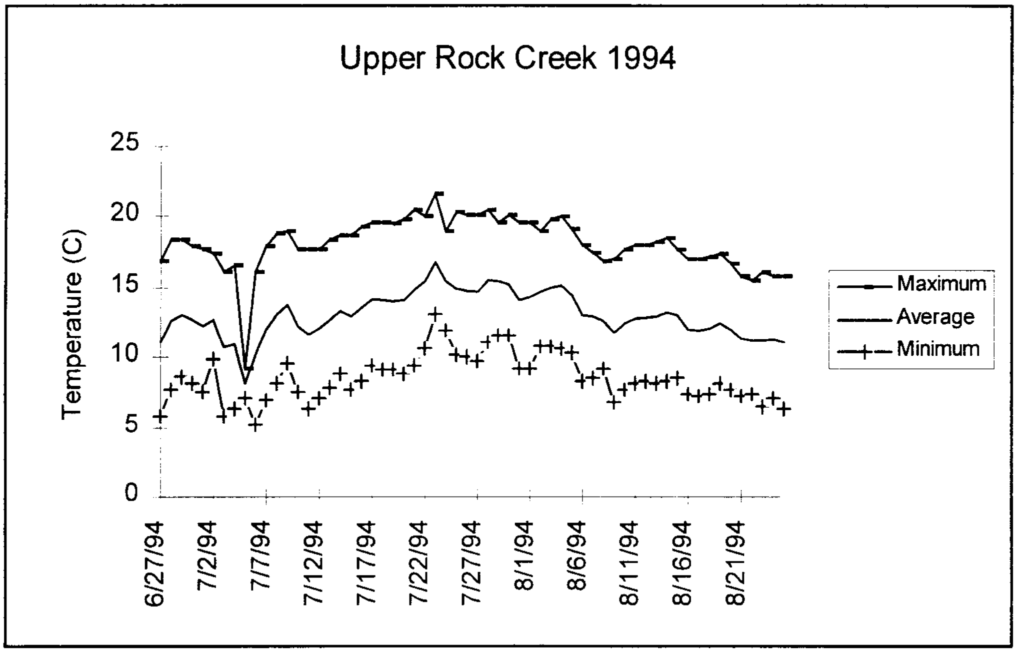
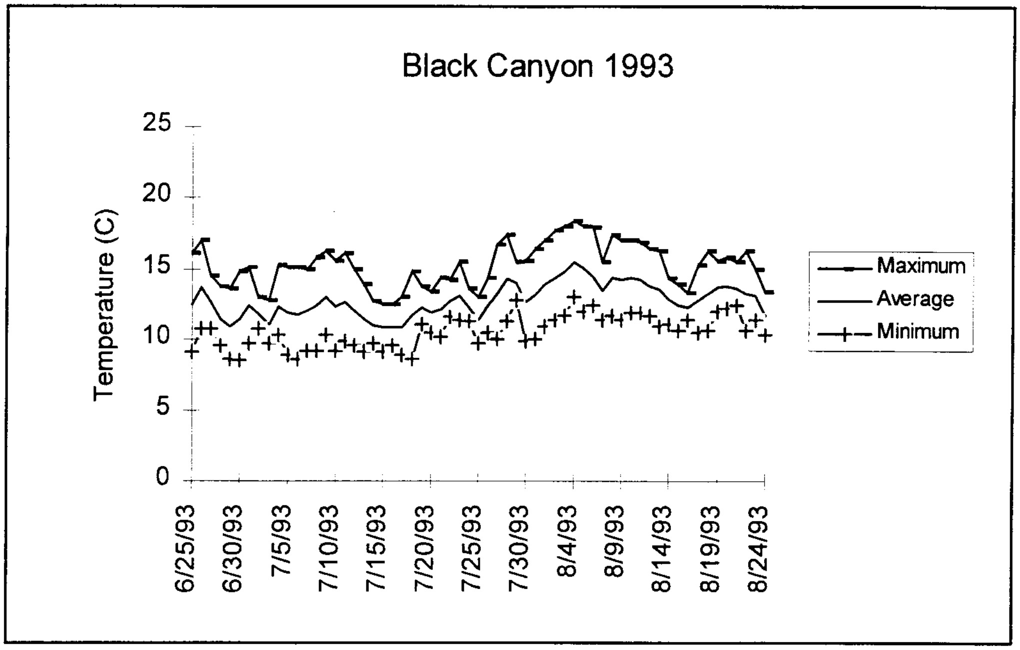


Figure C.2. Daily maximum, average, and minimum water temperatures in upper Rock Creek during 1993 and 1994 sampling periods.



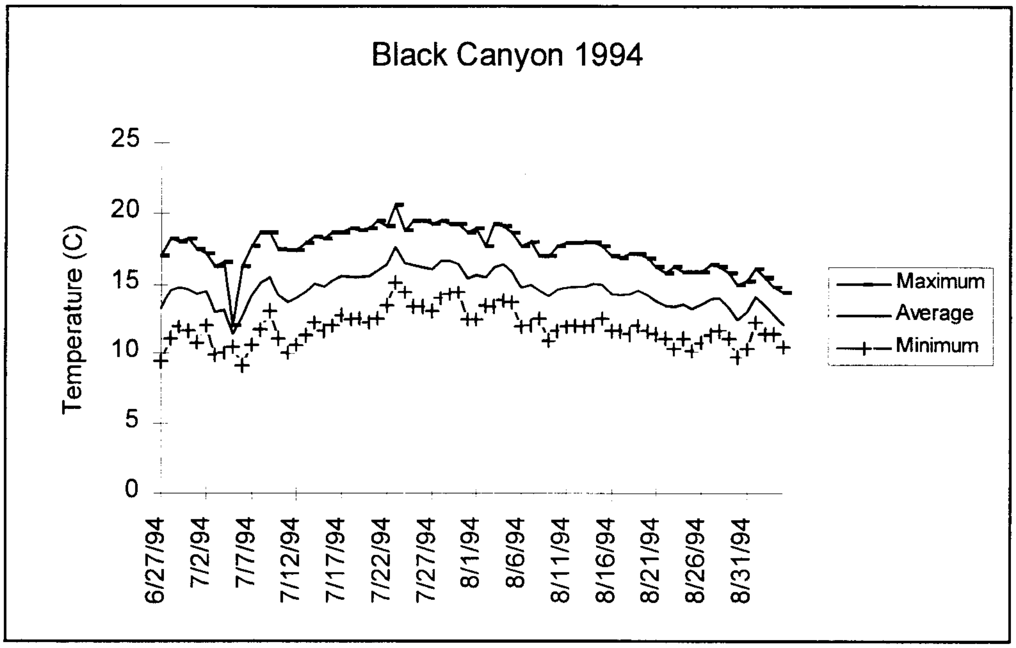


Figure C.3. Daily maximum, average, and minimum water temperatures in Black Canyon Creek during 1993 and 1994 sampling periods.

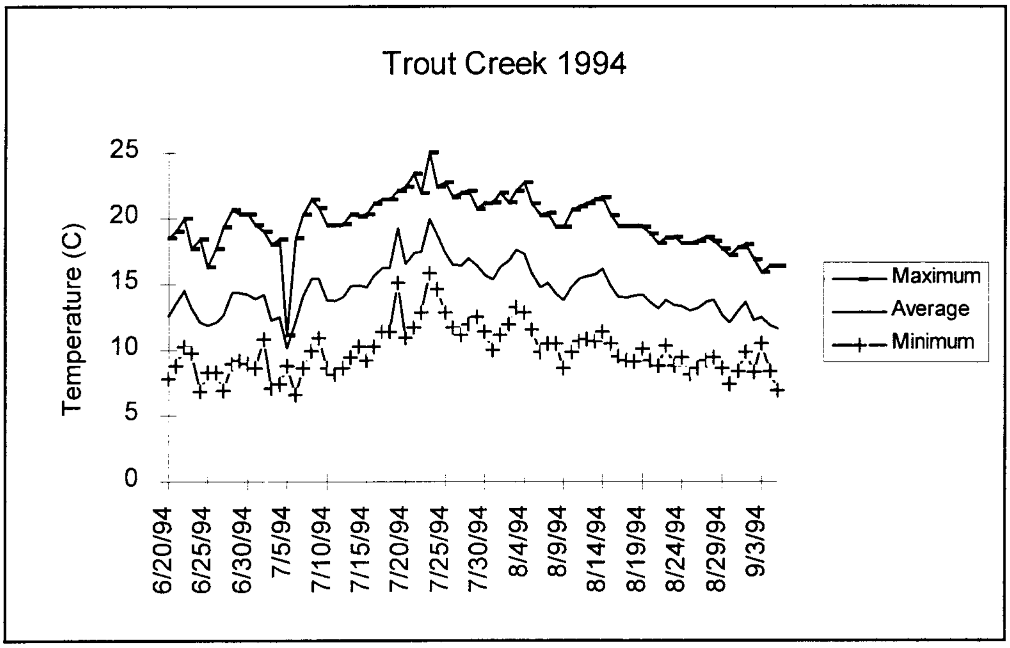


Figure C.4. Daily maximum, average, and minimum water temperatures in Trout Creek during the 1994 sampling period.

Appendix D. Radio-tracking narrative. A description of radio-tracking attempts and results, conducted in Trout Creek during 1994.

Radio-tracking

To compliment my study on the correlation between pool structural complexity and trout density, I attempted a preliminary investigation of trout movement in complex and simple pools. I felt that since structural complexity appears to create higher quality habitat, it may also affect the amount of movement occurring into and out of pools. Specifically, I wanted to determine if trout in complex pools moved less that trout in simple pools.

Trout were captured by electrofishing or fly fishing and anesthetized with MS-222 for tag implantation. Tags were inserted down the throat into the stomach using a plastic pipette, running the antenna through the pipette and using it to hold the tag securely at the end. Trout were recovered in ventilated dark green 5 gallon buckets set in the stream, then released to the pool in which they were captured. I used 1.1 g stomach-implanted ATS radio transmitters in trout ranging from 123 mm to 202 mm fork length (average 156 mm). In total, 30 trout were tagged. The spitting rate was almost 100 percent. Half of the trout spit the tag while being recovered or at the moment they were released. Any trout which spit its tag was not retagged. Seventy-seven percent of trout greater than 140 mm fork length spit tags immediately. All trout under 140 mm fork length retained tags and were released. With three exceptions, all tags were eventually spit within about one week. The exceptions included two tags for which we lost the signal and one trout still tagged captured 20 days after tagging.

The tagged trout appeared to be in very poor condition and I easily captured it by hand while snorkeling. All other spit tags were recovered by snorkeling.

Although others have used this method successfully on salmonids of similar size, it appears to be a poor technique on wild rainbow trout during the summer. Very similar 1.3 g ATS stomach-implanted radio transmitters have been successfully used by in two other studies run by the Oregon Cooperative Fisheries Research Unit. In one study, using subyearling hatchery chinook salmon smolts, fish were tagged in three locations, spitting rates averaged 10.2, 28.5, and 12 percent for the three locations (Larry Davis, Oregon Cooperative Research Unit, personal communication). Fork length averaged 145 mm and ranged from 123 mm to 170 mm. Results were similar in another two-year study using hatchery chinook salmon smolts in which both yearlings and underyearlings were tagged (John Snelling, Oregon Cooperative Fisheries Research Unit, personal communication). For underyearlings, in 1994, 8.4 percent spit and 20.5 percent died, and in 1995, 5.1 percent spit and 2.5 percent died. Average fork length was 125 mm in 1994 and 118 mm in 1995. For yearlings, in 1994, 15.5 percent spit and 14.3 percent died, and in 1995, 14.6 percent spit and 5.2 percent died. Average fork length was 160 mm in 1994 and 155 mm in 1995. A study on wild cutthroat trout in the Umpqua River had 5 of 25 trout spit tags (Waters 1993). Trout ranged in length from 154 mm to 234 mm, radio-transmitters used were 1.7 g tags. This study was conducted in the winter. Each of these studies had conditions different from those I encountered.

The first two studies were using a different species (chinook salmon) at a different life stage (smolt) and were using hatchery fish. The third study was using a different species (cutthroat) and a different time of year (winter) and using larger tags and somewhat larger fish. My results suggest that one should not use stomach-implanted radio transmitters on wild rainbow trout during the summer.

Literature Cited

Waters, E. 1993. Winter habitat utilization of radio-tagged coastal cutthroat trout. Master's thesis, North Carolina State University, Raleigh, NC. 43 p.