AN ABSTRACT OF THE THESIS OF

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Title: Distribution and Juvenile Ecology of Bull Trout (Salvelinus confluentus) in the Cascade Mountains

Abstract approved: Signature redacted for privacy.

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Distribution and juvenile habitat use of bull trout (*Salvelinus confluentus*) were surveyed in selected areas of the Upper Willamette, Deschutes, upper Yakima, and upper Cedar River basins in Oregon and Washington from 1989 to 1991, using day snorkeling, night snorkeling, and electrofishing. These methods were selected after a preliminary diel streamside study of juvenile bull trout showed fry (age 0) counts were significantly higher ($P<0.001$) during the day, while counts of juvenile fish (age 1 and 2) were significantly higher ($P<0.001$) at night. The highest counts of juveniles occurred during a "quiet period" immediately after dusk, during which time fish were inactive, out of cover, and easily counted with underwater flashlights.

In a comparison of four sampling methods on Jack Creek, electrofishing was significantly correlated ($P<0.05$) with day ($r=0.81$) and night ($r=0.89$) snorkeling counts, but not with streambank counts. In a comparison of day and night snorkeling in 10 streams, total density estimates were significantly greater ($P<0.01$) for night snorkeling than day. The diel study and sampling methods comparison suggested surveys of distribution and habitat use of bull trout should include night surveys as well as day.

Distribution surveys found that, except for one stream, juvenile bull trout were found only in, or near, spring-fed areas created by recent lava flows. Presence of bull trout in a stream was related to cold groundwater temperatures, as they were not found in streams with temperatures above 14°C. Distribution of bull trout in Oregon and Washington followed a pattern of decreasing elevation with increasing latitude and longitude(R_a=-0.916). Presence at lower than expected elevations were explained when groundwater temperatures were predicted from mean annual air temperatures. Actual water temperatures for these spring-fed streams were significantly lower ($P<0.001$) than predicted based on elevation, latitude, and longitude.

Comparison of historical distribution of bull trout showed extant bull trout were found in the Willamette and Deschutes River Basins of Oregon, respectively, in only 26.2 and 56.2% of their former ranges. Factors associated with bull trout demise in Oregon Cascade streams were (1) isolation and inundation of spring-fed stream habitat by water control structures, (2) introduction of brook trout and brown trout, and (3) large flood events and habitat degradation.

Juvenile habitat use was analyzed at the macrohabitat (habitat unit) level in five river basins. Diel and seasonal microhabitat use was also documented for one spring-fed stream, Jack Creek. There was a clear difference in habitat use day and night, associated with the low water temperature of the spring-fed streams (mean=8.0°C). All habitat unit types (pool, riffle, glide, side channel) were used day and night, but bull trout only elected to use side channels in both time periods. Bull trout were found at night in (1) a higher percentage of habitat units, (2) in higher densities by unit, and (3) in increasing numbers with increasing habitat unit area. In Jack Creek, bull trout elected to use shallow water depths, low mean velocities, instream woody debris, and small substrates.

Distribution and Juvenile Ecology of Bull Trout (Salvelinus confluentus) in the Cascade Mountains

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Distribution and Juvenile Ecology of Bull Trout (*Salvelinus confluentus*) in the Cascade Mountains

GENERAL INTRODUCTION

Bull trout (*Salvelinus confluentus*) are considered a species of special concern throughout their distribution in the continental United States (Johnson 1987; Williams et al. 1989). Prior to 1940, bull trout were found in most major river systems of the Pacific Northwest and Northern California. Presently, populations from Northern California to Alberta, Canada, have either been extirpated or severely restricted in range (Carl 1985; Rode 1990; Ratliff and Howell 1992; Mongillo 1993).

In Alberta, the bull trout is considered to be an endangered species by some authorities (Roberts 1987). In Northern California, all populations in the Sacramento River Basin were believed to be extirpated by the mid-1980s (Hesseldenz 1985). In Oregon, the Klamath River population (a possible separate subspecies according to Leary et al. 1990) was considered rare by Bond (1974). By 1991, the status of all bull trout populations in Oregon was considered precarious enough that Oregon Trout petitioned the U.S. Fish and Wildlife Service to list it as threatened or endangered. In 1992, public concern for this species in the rest of the Pacific Northwest led the Rocky Mountain Alliance of Montana to petition the U.S. Fish and Wildlife Service for listing of all remaining populations.

As conservation of this species becomes an increasingly important issue for government agencies and the general public, basic information on bull trout ecology will be required. Of prime concern is the need to accurately define their distribution and use of different habitats. As a first step to achieving this goal, sampling methods need to be evaluated and bias determined (Johnson and Nielsen 1983). In Chapter 1, I will compare effectiveness of different sampling techniques in estimating bull trout density as well as determining presence or absence in a variety of habitats.

To date, there have been few studies of juvenile bull trout habitat use (McPhail and Murray 1979; Pratt 1984; Fraley and Shepard 1989) and no studies in Oregon of macrohabitat (habitat unit scale) or microhabitat (focal point) use of juvenile, migratory bull trout. In a recent analysis of the demographic and habitat requirements of bull trout, Rieman and McIntyre (1993) believed they could not clearly define habitat condition thresholds that may control the abundance and distribution of bull trout. They suggested that future studies defining spatial and temporal differences in habitat use may assist in describing these thresholds. In Chapter 2, I will describe juvenile bull trout diel and seasonal habitat use in a variety of habitats. In Chapter 3, I will discuss bull trout distribution in Cascade Mountain streams in relation to major geographic and geomorphic features.

Chapter 1. Sampling Techniques Comparison

INTRODUCTION

Until recently there were few studies comparing the effectiveness of different juvenile fish sampling techniques (Griffith 1981; McClendon and Rabeni 1986; Cunjak et al. 1988; Smith 1989; Van Deventer and Platts 1988; Heggenes et al. 1990; Bozek and Rahel 1991; Heggenes et al. 1991). The sampling of juvenile bull trout in particular has received little attention, although difficulties have been reported in studying their habitat use and in estimating their abundance (Leathe 1980; Pratt 1984; Fraley and Shepard 1989).

Benthic orientation, hiding, and diel or nocturnal behavior make sampling juvenile char difficult (Sparholt 1985; Adams et al. 1988; Stenzel 1987). Night samples in a variety of habitats show higher numbers of Arctic char (S. alpinus) juveniles, a bull trout congener, than day samples (Sandlund et al. 1987; Stenzel 1987). Counts of brook trout (S. fontinalis) fry are also higher after dusk than during daylight hours (Walsh et al. 1988). Like Dolly Varden (S. malma), and Arctic char, juvenile bull trout are benthic oriented, hiding in the substrate or under cover for a large part of the day (Pratt 1984; Elliott 1986; Adams et al. 1988; Sandlund et al. 1988; Fraley and Shepard 1989; Dolloff and Reeves 1990).

In marine reef and temperate freshwater lake fishes, there is a period during dawn and dusk when most fish are inactive. At dusk, this "quiet period" occurs as diurnally active fish become inactive and nocturnally active fish emerge from cover. During this period, both groups of fishes may be found resting on the substrate, out of cover (Helfman 1986).

Adult bull trout in lakes undergo a diel migration from deep water during the day to shallow water areas at night (Thompson and Tufts 1967; Wyman 1975). During initial laboratory experiments for this study, bull trout juveniles displayed a diel pattern of hiding under cover during daylight and emerging from cover after dusk. These observations suggested bull trout juveniles (age 1 and up) and adults may be nocturnally active fish. Investigating this possible nocturnal pattern required comparing the effectiveness of sampling techniques during day and night.

Electrofishing has been a traditional sampling method for small streams. However, this method may be inappropriate for most bull trout streams in Oregon and Washington, as these streams are assumed to have low conductivity (Armantrout and Shula 1975; Hauck et al. 1976; Johnson et al. 1985; Hubbard et al. 1990). Electrofishing in low-conductivity water (5.5-52 umhos/cm) may result in (1) low capture rates or low abundance estimates of bull trout, and/or (2) increased injury and mortality of bull trout from use of higher voltages or multiple passes (Reynolds 1983; Bohlin et al. 1989). Non-lethal sampling methods would be preferable if they provide equally effective sampling.

Snorkeling and SCUBA diving have been used to make visual, non-lethal observations of fish activities and habitat use at night in temperate freshwater lakes and streams (Emery 1973; Hall and Werner 1977; Keast and Harker 1977; Helfman 1981; Kirker 1989). However, few studies have used night snorkeling to count juvenile salmonids (Stenzel 1987). Visual counts from streambanks (streamside counts) is another under-utilized, non-lethal method to estimate fish abundance (Bozek and Rahel 1991). Visual counts avoid injury or mortality of the target species, and typically require less labor and time than electrofishing.

This study, therefore, had two objectives:

1. Compare effectiveness of three visual (hereafter called non-lethal) methods--streamside counts, day snorkeling, and night snorkeling--and a lethal method--electrofishing--in estimating fry and juvenile bull trout abundance in a limited habitat; and

2. Compare effectiveness of two non-lethal methods--day snorkeling and night snorkeling--in estimating fry (age 0) and juvenile (age 1 and 2) bull trout abundance over multiple habitats.

METHODS

Diel Study

Jack Creek. On June 19, 1989, bull trout were counted from streambanks over 24 hours on lower Jack Creek, Metolius River, Oregon, to determine if a "quiet period" exists for use in subsequent enumeration studies.

Three sites were selected on a south-facing side channel and three on the main channel, all within several hundred yards of the Forest Service Road 1420 bridge. The dominant cover for the side channel sites was aquatic vegetation or small woody debris while cover for main channel sites was woody debris and water depth.

Sites were chosen based on a preliminary survey that indicated fish were present, on ease of site access, and on the logistic requirement to be able to visit all sites within one hour. The viewing area at each site was 1 m perpendicular to shore by 2 m in shoreline length. Viewing areas at the side channel sites covered the entire width of the channel, while viewing areas on the main channel were restricted to the near-shore area on the south bank.

Streambank observations began at 1300 h on June 21, 1989, and continued to 1200 h on June 22, 1989. No observations were made from 0100 - 0200 h due to equipment difficulty. Each site was viewed for an average of five minutes per hour.

Fish were differentiated as fry or juveniles and tallied by age class and site. Fish were counted if they were out of cover; fish seen hiding under cover at night were not counted. Flashlights and a lantern were used to illuminate the sites at night. Preliminary observations in the lab with red and green filter paper showed white light was less disruptive than simulated longer wavelengths.

The 24-hour observation period was divided into three smaller periods for analysis: (1) day (0700-1900 h), (2) night (2300-0300 h), and (3) twilight (2000-2200 and 0400-0600). Density estimates (number of fish per m^2) were computed to compare counts by age class and time period.

Differences in density estimates by age class and time period were compared with two-sample t-tests. All data were analyzed with STATGRAPHICS statistical software (STSC, Inc. 1989).

Trapper Creek. On September 29, 1989, a second, more restrictive, count of bull trout was conducted on lower Trapper Creek, Odell Lake, Oregon. The purpose of this count was to describe the beginning of the period of high juvenile abundance ("quiet period") observed at dusk at Jack Creek.

A single pool was selected for observation, at RM 0.4 just upstream of the railroad bridge. The dominant cover in the pool was large and small boulders. This pool was selected because it contained several juveniles when surveyed by night snorkeling in mid-August.

Snorkeling was used to count juveniles because of the pool depth and large substrate. The observation period was 1.5 hours, beginning one hour before and continuing to one-half hour after dusk. At half-hour intervals, a single diver using a small waterproof flashlight thoroughly surveyed the pool, counting juvenile bull trout (observed out of cover) by age class. Surveys averaged 20 minutes. Since this observation was descriptive, statistical analysis was not used.

Comparison of Non-lethal and Lethal Sampling Techniques

Four techniques--streamside counts (above water, visual); day snorkeling; night snorkeling; and day electrofishing (hereafter called electrofishing)--were compared for differences in abundance estimation, sampling effort (labor), and time required. Two comparisons were made: (1) streamside counts and electrofishing, and (2) day snorkeling, night snorkeling, and electrofishing. Each comparison involved one or more non-lethal, direct observation technique vs. electrofishing. Sampling time and personnel required for each method per site were also estimated.

Each technique was used during different times of the day. Electrofishing was conducted in the morning to early afternoon during lower water temperatures of 6-8°C (vs. afternoon temperatures of 8-10°C), to minimize stress on the fish (Reynolds 1983). Day snorkeling and streamside counts were conducted in the late morning and afternoon, when light was optimal for viewing fish. Night snorkeling was begun during the first hour after dusk and completed within three hours of dusk. The time periods for streamside counts, day snorkeling, and night snorkeling were selected to correspond to results of the diel activity study indicating times when different age classes were most likely out of cover: daytime for fry, and early night for juveniles.

First Comparison: Streamside Counts and Electrofishing in a Limited Habitat

On June 28, 1989, streamside counts of bull trout fry were compared to electrofishing estimates on four side channel habitat units on lower Jack Creek (sites 1-4, Table 1).

Table 1. Physical description of sites 1-4 used in the streamside counts and electrofishing comparison on Jack Creek in 1989, sites 5-9 used in the snorkeling and electrofishing and comparison on Jack Creek in 1989, and sites 10-11 on Canyon Creek in 1990.

Site	Date	Habitat Unit Type	Length (m)	Width (m)	Area (m^2)	Dominant Substrate	Temp. Range (°C)	Method[a] SC	E	D	N
One	6/28 1989	Side chan[b] Glide	20.0	2.0	40.0	Sand/Grav[b]	7.0-8.0	X	X		
Two	"	Side chan Glide	30.0	2.0	60.0	Sand/Grav	7.0-8.0	X	X		
Three	"	Side chan Glide	25.0	1.8	45.0	Sand/Grav	7.0-8.0	X	X		
Four	"	Side chan Glide	25.0	2.7	67.5	Sand/Grav	7.0-8.0	X	X		
Five	6/26-7/12 1989	Riffle	18.0	5.5	99.0	Cobble	6.0-7.0		X	X	X
Six	"	Side chan Riffle	17.0	2.0	34.0	Gravel	6.0-7.0		X	X	X
Seven	"	Side chan Pool	24.0	5.0	120.0	Cobble	6.0-7.0		X	X	X
Eight	"	Glide	35.0	6.0	210.0	Cobble	7.0-8.0		X	X	X
Nine	"	Pool	45.0	7.5	337.5	Cob/Grav	7.0-9.0		X	X	X
Ten	7/26-28 1990	Glide	28.0	7.4	207.2	Grav/Cob	N/A		X	X	X
Eleven	"	Pool	19.0	11.0	209.0	Grav/Sand	N/A		X	X	X

a. Sampling methods SC=Streamside Count; E=Electrofishing; D=Day Snorkeling; N=Night Snorkeling.
b. Side chan=Side Channel; Grav=Gravel; Cob=Cobble.

Four side channel glides, two north-facing and two south-facing, were selected. Dominant cover for the four sites was aquatic vegetation or small woody debris with a sand/gravel substrate. Site selection was based on a preliminary survey indicating presence of fry, uniform habitat characteristics, and ease of site access. Site boundaries corresponded to the beginning and end of a glide habitat unit. The viewing area at each site covered the entire width of the channel, averaging 2.1 m in width by 25 m length. Wearing polarized sunglasses, an observer moved slowly upstream once, pausing as necessary to identify and count all fish within the marked boundaries of the unit.

Immediately after the streamside counts, Smith and Root, or Coffelt electrofishers were used in multiple-pass removal of the bull trout (Zippin 1958). Before electrofishing, the upstream and downstream ends of each site were block-netted with small mesh nets. One electrofisher was used at a site. Normally, two individuals with dip nets accompanied the electrofisher as they worked upstream from the lower to upper ends of the unit. Three passes were required per site, until most of the fish within the netted section were captured (2< fish captured on the last pass). Following each pass, captured fish were held in separate buckets and measured for total length (in mm). Age groups were assigned based on size: age 0 fry < 6.5 cm total length; age 1 juvenile = 6.5 - 11 cm; and age 2 juvenile > 11 cm. All fish were returned to the stream.

For the electrofishing population estimate, densities of fish were calculated per m^2 using the removal method, where estimates of N (population size) and P (probability of capture) were made for each age class separately (Zippin 1958). The Zippin (1958) method was developed for two pass removals. Since there are no simple estimation formulas for three or more removal passes, Armour et al. (1983) recommend modifying Zippin's methods using simple polynomial functions. For the streamside counts, fish density estimates (number per m^2) were calculated for each site by dividing the number of fish counted by the total habitat area.

Simple linear regression of streamside counts on electrofishing estimates, with double tailed t-tests, was used to compare density estimates from the techniques. Trippel and Hubert (1990) suggest using the pooled sample variance because calculating confidence intervals separately may produce overly conservative or invalid statistical inferences.

Second Comparison: Day Snorkeling, Night Snorkeling, and Electrofishing in a Limited Habitat

Comparisons of day snorkeling, night snorkeling, and electrofishing abundance estimates were completed on five habitat units (sites 5-9, Table 1) on lower Jack Creek and two (sites 10-11, Table 1) on lower Canyon Creek. Sites 5-9 were each sampled once a week during three consecutive weeks, June 26 through July 12, 1989. Day and night snorkeling of one to three sites were completed in one 24-hour period, with electrofishing of the same sites completed the following day within 12 to 24 h of the snorkeling. Sites 10-11 were sampled during July 26-28, 1990, by day and night snorkeling on consecutive days and followed by electrofishing within 24 h.

The habitat units sampled for the electrofishing and snorkeling comparison were two glides, two pools, one riffle, and two large side channels. The dominant cover-types for these sites were large woody debris, water depth, and undercut banks. Site selection was based on (1) proximity to the streamside counts area, (2) sampling the range of habitat unit types found in Jack and Canyon Creek (Table 1), and (3) ease of site access. Site boundaries correspond to the beginning and end of each habitat unit.

Snorkeling was conducted by two divers, who began at the lower end of each site on opposite sides of the channel and moved slowly upstream looking under available cover while observing the substrate and near-shore areas. Also, at night, hand-held waterproof (Ikelite 2 or Tekna) flashlights were used for illumination. Fish numbers were tallied on

15.2 x 22.9 cm Plexiglas dive slates by species and age class. Total fish length was estimated by associating snout and tail position with adjacent objects and then measuring the distance to the nearest cm.

At a site, one electrofisher was used on each side of the stream. Normally, two to three individuals with dip nets accompanied each electrofisher. Two to four passes were required per site until most of the fish within the netted section were captured. Site 11 was the only habitat unit where block nets were not used at both ends of a site; the upstream end of this site had a physical barrier.

Comparison of Two Non-Lethal Techniques over Multiple Habitats

Two non-lethal techniques, day snorkeling and night snorkeling, were compared in estimating fry and juvenile bull trout abundance over multiple habitats. Nine streams and one reservoir (hereafter referred to as ten waterbodies) in Oregon and Washington were sampled in 1989-1991 to enumerate the number of fry and juvenile bull trout by habitat unit (Tables 2 and 3). One of these streams, Canyon Creek, was sampled in 1989 and 1990 in different reaches. Each year was considered a different sample.

Table 2. Selected habitat parameters, location, and year sampled for streams used in the comparison of day and night snorkeling.

River or Basin	Year and Stream	County and Legal Description	Stream Order	Elevation (m)	Gradient (%)	Flow[a] (m3/s)	Maximum Temp. (°C)	Width (m)	Dominant Substrate
	1989								
Metolius River	**Jack C[b]**	**Jefferson T12S;R9E;S28,31-33**	**1st**	**878-927**	**1.4**	**1.62**	**10.0**	**5.5**	**Gra/Cob[b]**
	Canyon C	**T12S;R9E;S27-30**	**2nd**	**875-939**	**1.5**	**1.32**	**8.0-13.0[c]**	**8.1[d]**	**Cobble**
	Jefferson C	**T11S;R9E;S33-35**	**3rd**	**846-1097**	**2.5**	**2.80**	**8.0**	**6.7**	**Cobble**
	Candle C	**T11S;R9E;S28-29,33-35 T12S;R9E;S3**	**2nd**	**848-902**	**2.3**	**2.48**	**5.0**	**7.0**	**Cobble**
	Roaring C	**T12S;R9E;S20,29**	**1st**	**915-996**	**2.0**	**0.93**	**7.0**	**8.4[d]**	**Cobble**
Odell Lake	**Trapper C**	**Klamath T23S;R51/2E;S13 T23S;R6E;S18**	**2nd**	**1459-1544**	**4.5**	**1.40**	**9.0**	**7.1**	**SmBo/Co[b]**
McKenzie River	**Anderson C**	**Lane T15S;R6E;S13,14**	**1st**	**632-732**	**6.1**	**0.89**	**6.0**	**6.1**	**Cobble**
	Trailbridge R[b]	**T15S;R6E;S11,12**		**637**	**1.5**	**10.48**	**8.3**	**40.0**	**Boulder**
	1990								
Metolius River	**Canyon C**	**Jefferson T12S;R9E;S29**	**2nd**	**875-939**	**1.5**	**N/A**	**8.0**	**9.0[d]**	**Cobble**
	Roaring C	**T12S;R9E;S19-20**	**1st**	**915-996**	**2.0**	**N/A**	**7.5**	**11.6[d]**	**Cobble**
	1991								
Yakima River	**Gold C**	**Kittatas T22N;R11E;S1,2,11,15**	**2nd**	**782-950**	**1.8**	**0.51**	**11.0**	**5.6**	**Cobble**

a. Flow measurements were taken at the stream mouth during low flow periods from July to September.
b. C=Creek; R=Reservoir; Gra=Gravel; SmBo=Small Boulder; Co=Cobble.
c. There are two distinct sections of stream in Canyon Creek, the upper section is lake fed, reaching a temperature of 13°C, while the lower section is spring-fed, with a maximum temperature of 8°C.
d. The width of stream for the 1989 survey of Canyon and Roaring Creek was averaged from all sampled reaches, the 1990 width was for one reach.

Table 3. Major river basins, sub-basin, and sampling periods for comparison of day and night snorkeling.

State	River Basin	Sub-basin	Sampling Period
Oregon	Deschutes	Metolius	7/3-8/29/89
		Odell Lake	8/14-8/17/89
	Willamette	Upper McKenzie	9/5-9/28/89
Washington	Yakima	Gold Creek	9/3-9/28/91

Day and night snorkeling of four Metolius River streams was completed during July 3-August 29, 1989. A single reach of Canyon Creek, just below its confluence with Roaring Creek, and a single reach of Roaring Creek were sampled during July 26-28, 1990. The lower 2.4 km of Trapper Creek, a tributary of Odell Lake, was sampled during August 14-17, 1989. A limited sample was completed on Anderson Creek, a tributary of the McKenzie River, during September 5-28, 1989. Selected reaches of Gold Creek, the headwaters of Washington's Yakima River, were sampled from September 3-28, 1991. Habitat units snorkeled were selected based on the total number of unit types found in each stream. A systematic sample of n units by habitat type was selected. The initial starting unit of each habitat type was chosen at random with all following units sampled at the "nth" interval.

Five 100 m transects were sampled by day and night snorkeling in Trailbridge Reservoir, an impounded lake 0.8 km upstream of Anderson Creek on the upper McKenzie River, on September 8, 1989. The area sampled in Trailbridge Reservoir was selected based on (1) presence of juvenile char (<u>Salvelinus</u> <u>sp</u>.) observed during a preliminary survey, and (2) the cold surface water temperature (8.3-9.4°C) recorded in the area where char were seen (Fig. 1). This surface water temperature was within the temperature range of sampled streams (Table 2).

The *n* for day-snorkeled units varied according to the total number of habitat units by type (N), and presumed occurrence of bull trout. Habitat units with assumed higher abundance of juveniles, such as pools, were sampled more often. The proportion of units sampled ranged from 0 to 100% for pools, 12.1 to 100% for riffles, 12.2 to 100% for glides, and 5.6 to 35.7% for side channels (Table 4). The sampling ratio for side channels on Jack Creek (5.6%) is low due to inaccessibility to divers because of the small, shallow nature of these units.

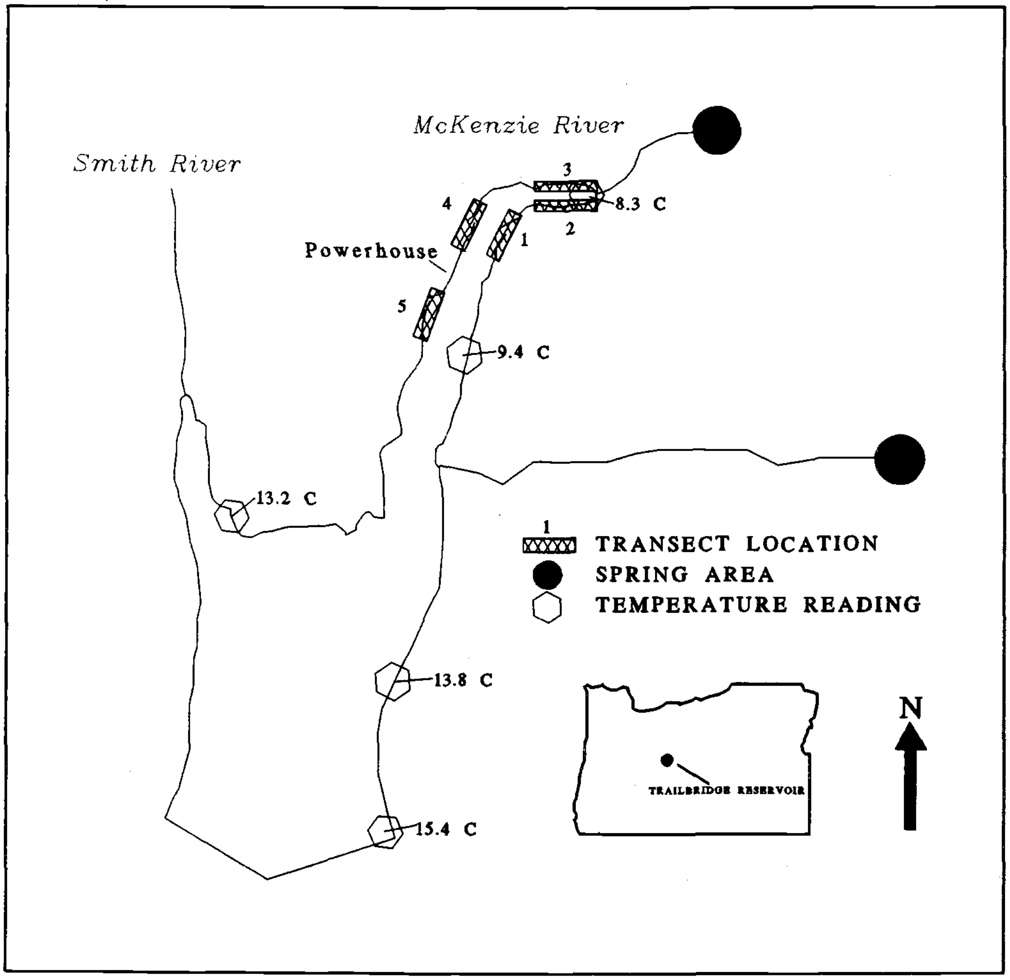


Figure 1. Sampling transects and surface water temperatures for a bull trout survey in Trailbridge Reservoir on September 8, 1989.

Table 4. Total number of habitat units per stream (by type, *N*), number of day snorkel units (*n*), and the number of day and night snorkeled units (*n'*) for the comparison of day and night snorkeling.

River or Basin	Year	Stream or Lake and Year	Unit Type	(*N*)	Day (*n*)	Tl[a] Area (m^2)	Day/Nit[a] (*n'*)
McKenzie	1989	Anderson	Pool	2	0	0	0
			Riffle	18	5	591	2
			Glide	17	10	508	2
			Side Chan[a]	7	1	0	0
		Trailbridge	Lake[b]	5	5	2000	5
Metolius		Candle	Pool	28	7	198	1
			Riffle	108	13	24	1
			Glide	82	10	135	1
			Side Chan	87	23	46	1
			Subunits[a]	19	3	0	0
		Canyon[c]	Pool	100	21	788	5
			Riffle	109	15	234	2
			Glide	62	9	590	2
			Side Chan	61	14	75	2
		Jack	Pool	56	13	546	3
			Riffle	79	12	465	3
			Glide	109	14	321	4
			Side Chan	124	7	154	2
		Jefferson	Pool	13	7	143	1
			Riffle	55	7	72	1
			Glide	44	9	212	2
			Side Chan	24	11	168	1
			Subunits	20	6	0	1
		Roaring[c]	Pool	3	1	21	0
			Riffle	11	4	328	0
			Glide	4	3	408	0
			Side Chan	14	5	431	0
			Subunits	3	3	28	0
Odell Lake		Trapper	Pool	13	13	326	6
			Riffle	26	19	953	5
			Glide	7	7	810	2
			Side Chan	5	1	50	1
Metolius	1990	Canyon[c]	Pool	3	3	427	3
			Riffle	2	2	468	2
			Glide	2	2	284	2
		Roaring[c]	Pool	3	3	191	3
			Riffle	1	1	297	1
			Glide	2	2	527	2
Yakima River	1991	Gold	Pool	23	13	1642	7
			Riffle	84	11	823	4
			Glide	55	13	816	4
			Side Chan	27	6	219	2

a. Tl=Total; Nit=Night; Chan=Channel; Subunits=unit types within a larger unit that are distinct.
b. Five 100 m transects.
c. 1989 survey was for entire stream, 1990 survey

Except for the Jack Creek sites, a minimum of 10% of each habitat unit per section of stream was sampled by day snorkeling (n). Where access and time permitted, a subsample of units (n') snorkeled during the day was snorkeled at night for comparison between day and night snorkeling. All Metolius River streams were sampled day and night in 1989 except Roaring Creek. A night survey of Roaring Creek was not completed that year because one dry suit developed a significant tear, and two divers were required in the highly complex habitat. Usually at least one habitat unit per type (pool, riffle, glide, and side channel) was sampled at night (Table 4). Snorkel surveys followed Smith's (1989) methods using a slow, steady search of all likely cover locations.

RESULTS

Diel Study

Jack Creek. For six sites, there was a significant difference between total density estimates for (1) day (0.087 fish/m^2) and night (0.058) ($t=2.26$, $df=21$, $P<0.05$), and (2) day (0.087) and twilight (0.060) ($t=2.11$, $df=20$, $P<0.05$) (Fig. 2). There was no significant difference between total density estimates for twilight (0.060) and night (0.058) ($t=0.13$, $df=11$, $P<0.90$).

For fry, there was a highly significant difference between density estimates for (1) day (0.078 fry/m^2) and night (0.0003)($t=7.02$, $df=21$, $P<0.001$), and (2) day (0.078) and twilight (0.28) ($t=3.67$, $df=20$, $P<0.01$) for the six sites (Fig. 3). There was no significant difference between fry density estimates for twilight (0.028) and night (0.0003) ($t=1.88$, $df=11$, $P<0.10$).

Fry were not observed in the side channel sites at night (2100-0500 h), except for a single fish seen during twilight (2100-2200 h) (Fig. 4). The highest side channel density estimates (range 0.22-0.28 fry/m^2) were from 1000-1700 h and at 2000 h. The pattern of fry density in the main channel was similar to the side channel pattern. All fry were actively swimming or feeding except for brief periods when they rested on the bottom.

For juveniles, there was a highly significant difference between density estimates for (1) day (0.009 juveniles/m^2) and night (0.054)($t=5.29$, $df=21$, $P<0.001$), and (2) day (0.009) and twilight (0.033) ($t=3.07$, $df=20$, $P<0.01$) for the six sites (Fig. 5). There was

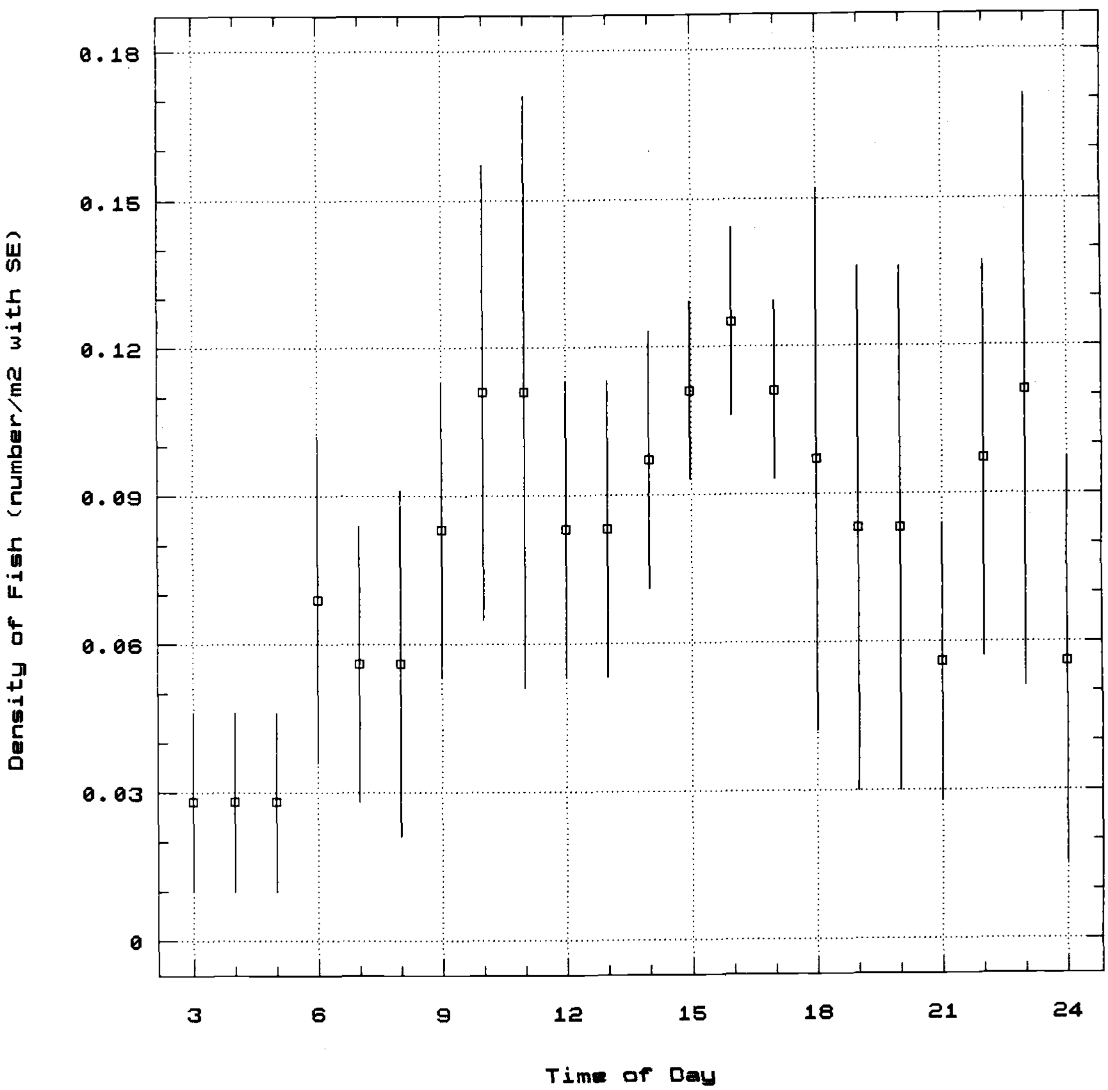


Figure 2. Diel density estimates (with SE) for bull trout fry and juveniles in six sites on Jack Creek.

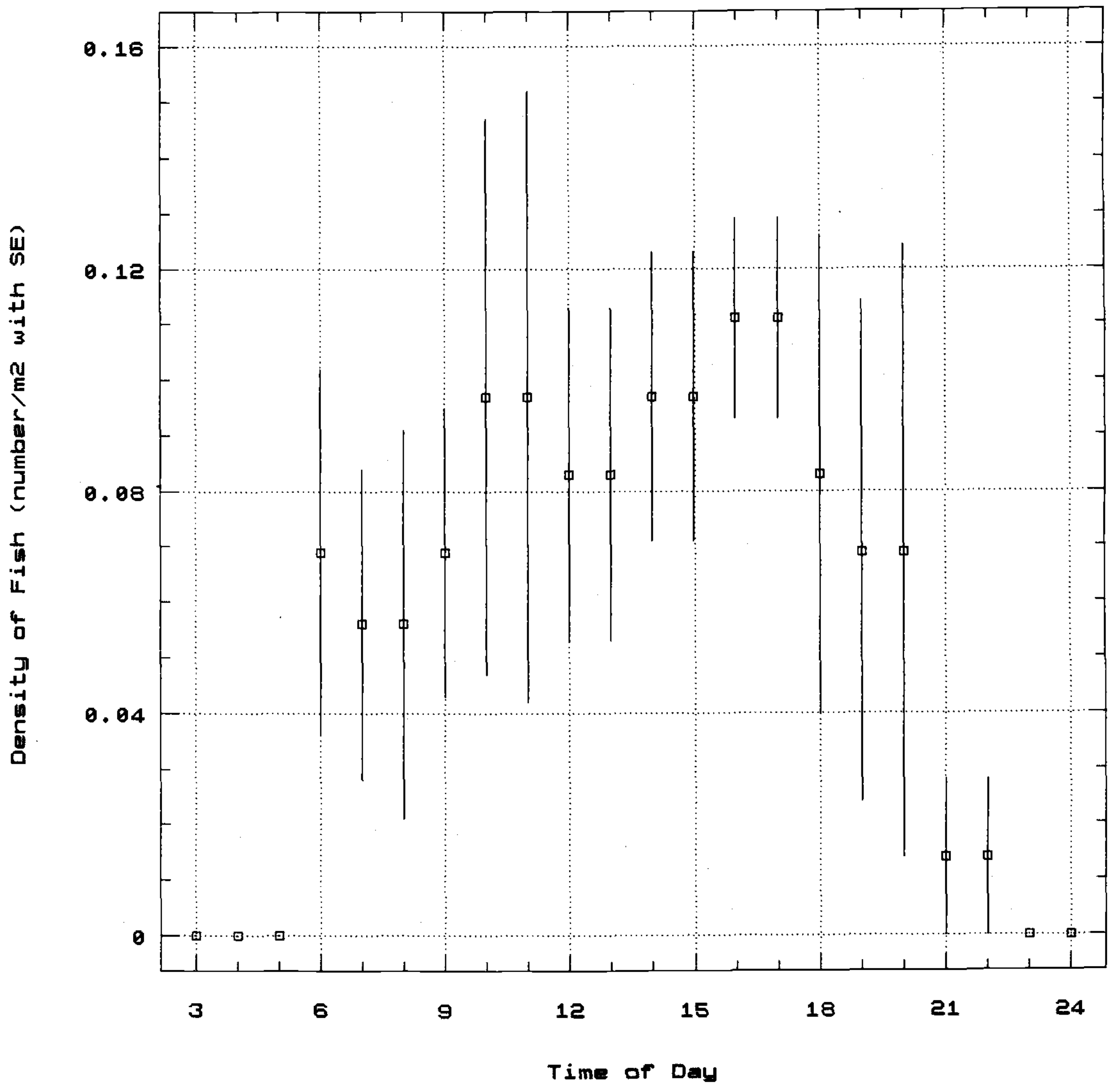


Figure 3. Diel density estimates (with SE) for bull trout fry in six sites on Jack Creek.

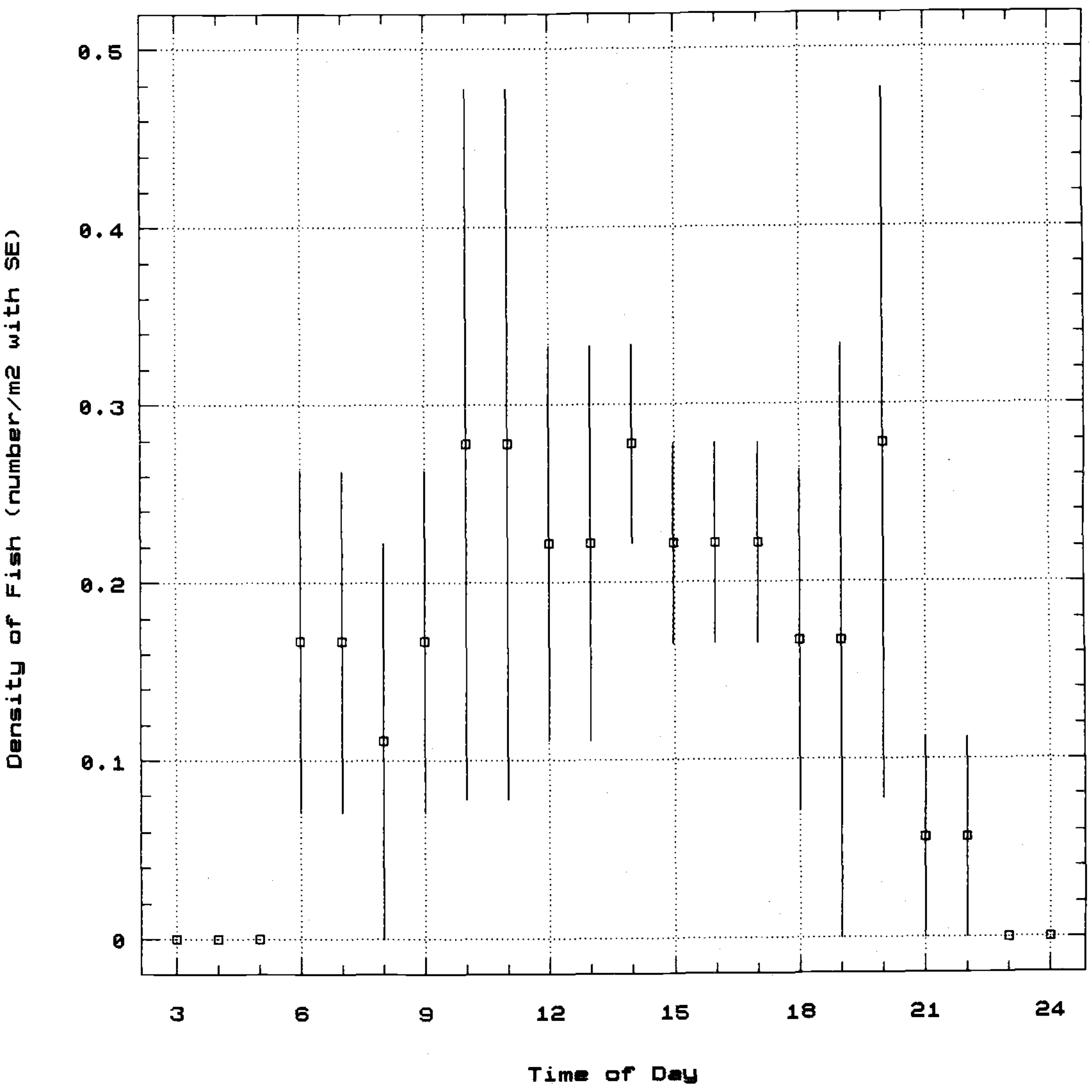


Figure 4. Diel density estimates (with SE) for bull trout fry in three side channel sites on Jack Creek.

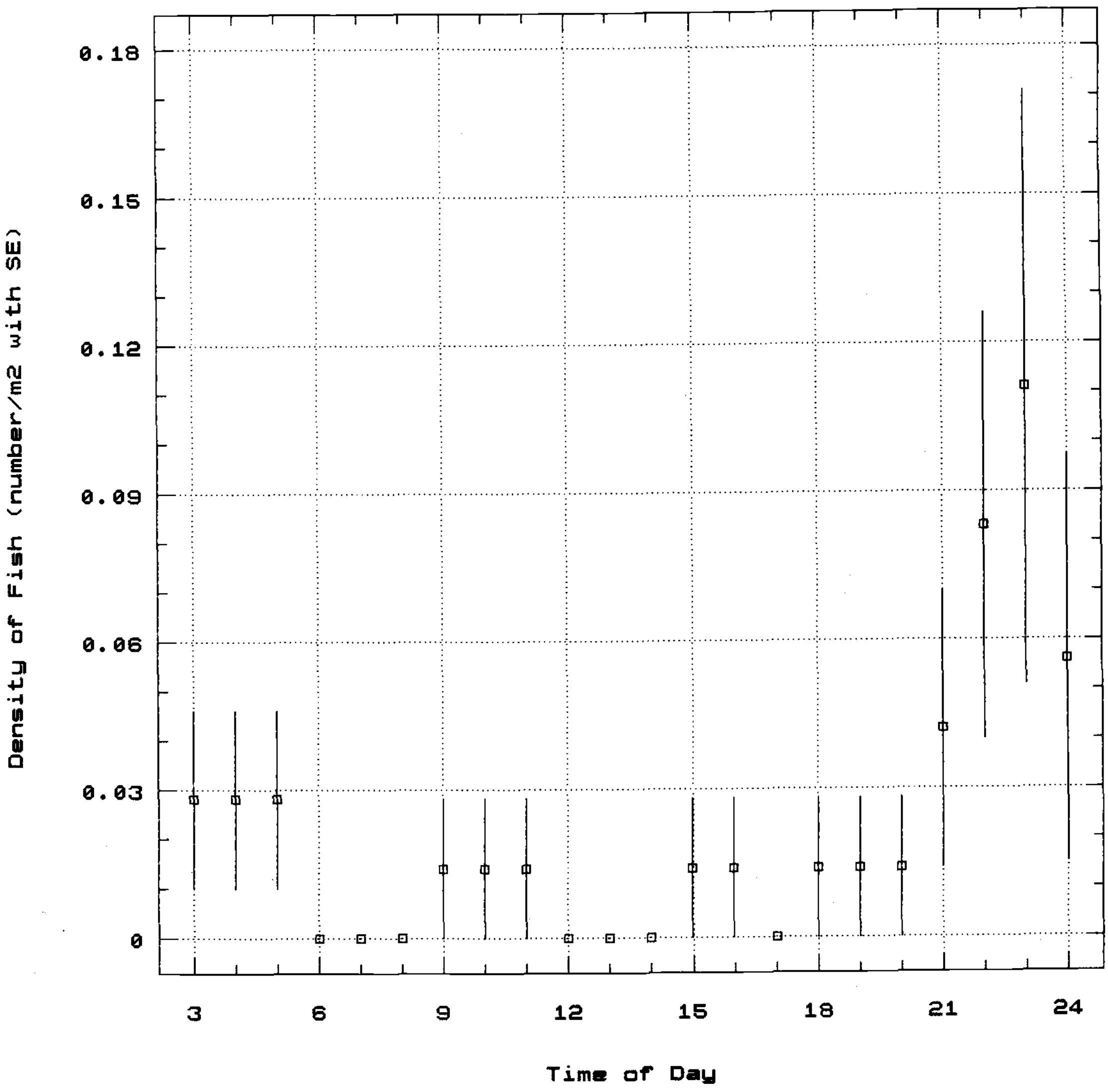


Figure 5. Diel density estimates (with SE) for bull trout juveniles in six sites on Jack Creek.

no significant difference between juvenile density estimates for twilight (0.033) and night (0.054) ($t=1.24$, $df=11$, $P<0.24$).

From 0600 to 1500 h, from 1700-2200 h, and at 2400 h, no juveniles were observed in the side channel. No juveniles were seen in the main channel from 0600-0800 h, from 1200-1400 h, and at 1600-1700 h. Peak density estimate for juveniles (0.32-0.39 juveniles/m^2) was from 2100-2200 h, which coincided generally with dusk (Fig. 6). Unlike fry daytime activity, the juveniles rested on the bottom at dusk, completely out of cover. During daylight hours, juveniles were near cover most of the time.

Trapper Creek. No fish were observed 55 and 25 minutes before dusk whereas three age 2 juveniles were observed 5 minutes after dusk. The juveniles observed were lying in crevices of small or large boulders and were not easily seen.

Comparison of Non-Lethal and Lethal Sampling Techniques

First Comparison: Streamside Counts and Electrofishing in a Limited Habitat

There was no significant correlation between the two sampling methods for estimating mean densities ($r=0.86$) ($t=2.34$, $df=3$, $P<0.15$). The electrofishing mean estimate was significantly higher than the streamside count mean estimate ($t=3.00$, $df=6$, $P<0.05$). Streamside count mean estimate and mean fry estimate were the same at 0.13 fry/m^2 (range=0.07-0.27) whereas the electrofishing mean estimates were 0.62 fish/m^2 (range=0.24-1.01) and 0.48 fry/m^2 (range=0.19-0.87).

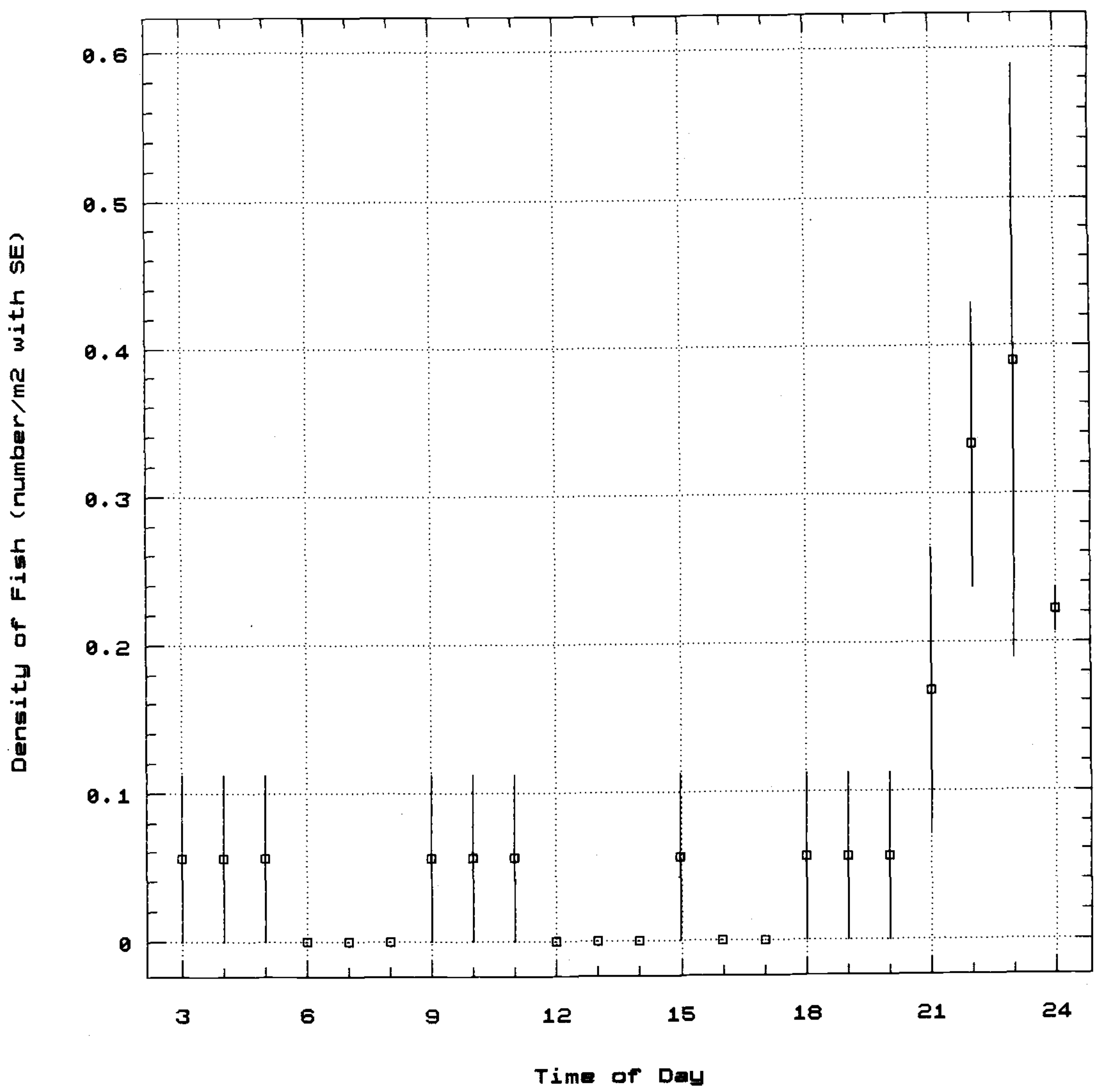


Figure 6. Diel density estimates (with SE) for bull trout juveniles in three main channel sites on Jack Creek.

There was no significant correlation between the two methods for estimating fry density (r=0.94) (t=3.35, df=3, P<0.10). The slope of the regression line for streamside counts on electrofishing fry densities was significantly less than one (b=0.41, SE=0.002), indicating this technique underestimated electrofishing.

Electrofishing the side channel sites collected 91 fry (75.8% of total), 28 age 1 juveniles (23.3%), and 1 age 2 (0.8%). Electrofishing capture probabilities were fairly good, ranging from 0.49-0.71 (Table 5) (Armour et al. 1983). The average labor and approximate time required to survey a site by streamside counting and electrofishing was, respectively, (1) 1 person and 20 minutes, and (2) 3 persons and 1.5 hours.

Table 5. Number of removal passes (U_n), estimated probability of capture for the total population (P_1), total catch by age class (T), and population size ($N \pm$ 95%) of bull trout surveyed by electrofishing at four side channel sites (sites 1-4).

Stream	Site	Age Class	Number of Passes (U_n)	Mean Total Length (cm ±SE)	P_1	T	Total N (±95% CI)
Jack	One	0	3	46.57 ± 2.20	0.58	7	9.7 + 1.39
		1		98.0 ± 4.12		2	
	Two	0	3	46.03 ± 2.06	0.49	23	40.5 + 5.1
		1		91.72 ± 2.49		11	
	Three	0	3	46.01 ± 2.34	0.62	37	45.5 + 2.46
		1		87.67 ± 2.49		6	
	Four	0	3	49.96 ± 2.83	0.71	24	38.4 + 1.4
		1		91.44 ± 2.17		9	
		2		123		1	

Second Comparison: Day Snorkeling, Night Snorkeling, and Electrofishing in a Limited Habitat

Day Snorkeling vs. Electrofishing. There was a significant correlation between day snorkeling and electrofishing (r=0.81) (t=3.01, df=6, P<0.05). The slope of the regression line for day snorkeling on electrofishing was significantly less than one (b=0.34, SE=0.11), indicating this technique underestimated electrofishing estimates (Fig. 7). There was a highly significant difference between mean density estimates for day snorkeling (2.3 fish/100 m^2, SD=2.22) and electrofishing (9.0, SD=5.48) (t=3.33, df=12, P<0.01)(Table 6).

Table 6. Comparison of site densities for fry, age 1, and age 2 juvenile bull trout as estimated by electrofishing (removal method), day snorkeling, and night snorkeling.

			Density Estimate (no./100 m^2)			
Stream	Site	Age Class	Electrofish. (*N*)	Electrofish. (*T*)	Day Snork.	Night Snork.
Jack	Five	0	8.9	8.1	2.0	0.0
		1	1.0	1.0	0.0	4.0
		2	2.3	2.0	2.0	2.0
	Six	0	8.8	8.8	0.0	0.0
		1	5.9	5.9	5.9	11.8
		2	0.0	0.0	0.0	2.9
	Seven	0	0.8	0.8	0.0	0.0
		1	0.8	0.8	0.0	0.8
		2	0.0	0.0	0.0	0.8
	Eight	0	10.4	9.5	2.4	1.4
		1	3.0	2.9	1.4	10.5
		2	2.0	2.0	0.0	4.3
	Nine	0	3.6	3.6	0.0	2.4
		1	6.5	6.5	0.6	3.3
		2	1.5	1.5	0.0	1.5
Canyon	Ten	0	4.0	3.4	0.0	0.0
		1	0.0	0.0	1.0	1.0
		2	0.5	0.5	0.0	1.4
	Eleven	0	6.0	3.8	0.0	0.5
		1	1.0	1.0	1.0	1.0
		2	0.0	0.0	0.0	1.0

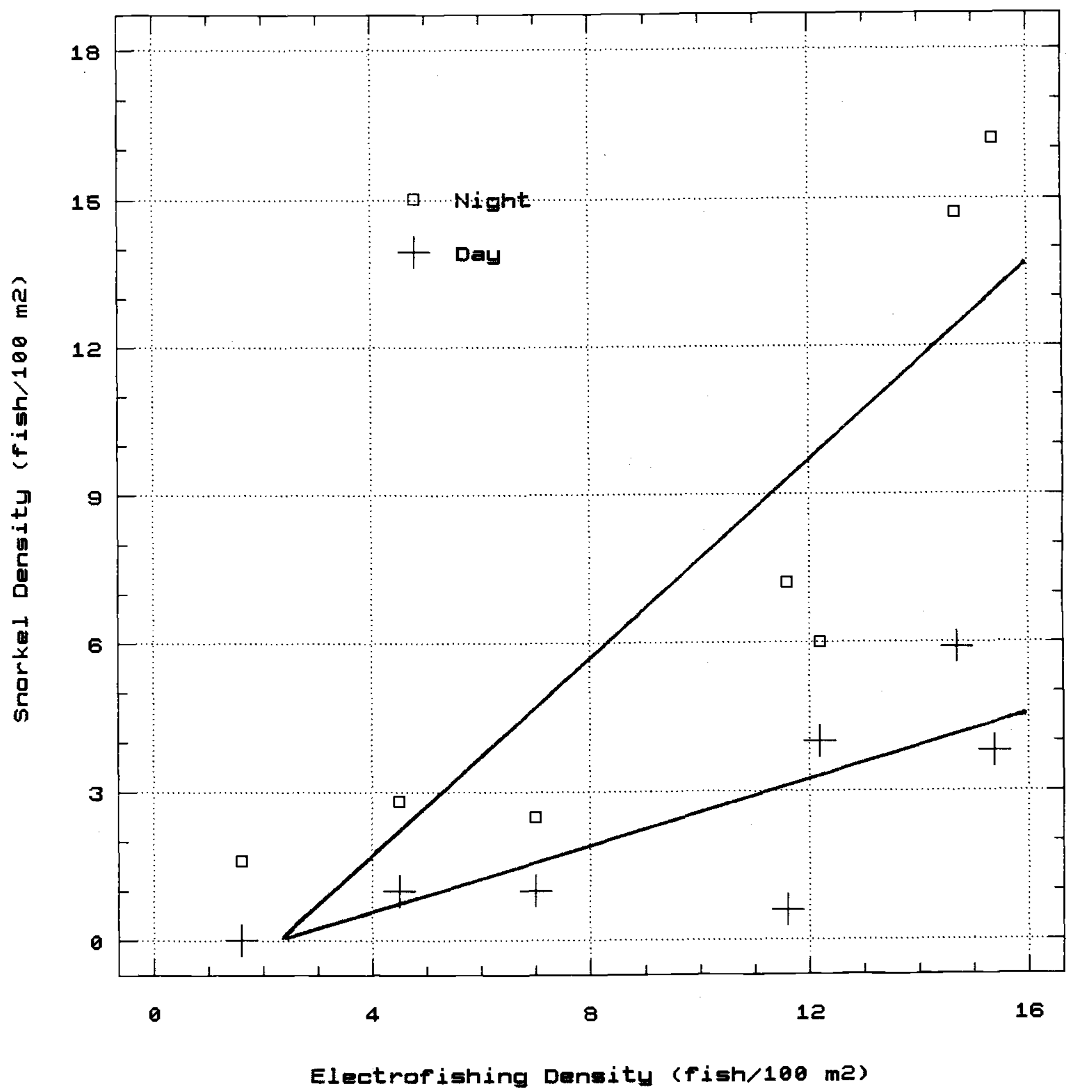


Figure 7. Relation of total density estimates (fish/100 m^2) for day snorkeling and night snorkeling to electrofishing for seven sites on Jack Creek and Canyon Creek. Regression equation for day snorkeling on electrofishing is $y=-0.91 + 0.34x$ ($r^2=0.64$). Regression equation for night snorkeling on electrofishing is $y=-2.26 + 1.00x$ ($r^2=0.79$).

For fry, there was a highly significant difference between mean density estimates for day snorkeling (0.62 fry/100 m^2, SD=1.08) and electrofishing (5.4, SD=3.33) (t=3.63, df=12, P<0.01). For juveniles, there was no significant correlation between density estimates for day snorkeling and electrofishing (r=0.38, P<0.40).

There was no significant difference between juvenile mean density estimates for day snorkeling (1.7 juveniles/100 m^2, SD=1.95) and electrofishing (3.5, SD=2.91) (t=1.36, df=12, P<0.20). For age 1 juveniles, there was no significant difference between mean density estimates for day snorkeling (1.4 age 1 juveniles/100 m^2, SD=2.05) and electrofishing (2.6, SD=2.65) (t=0.94, df=12, P<0.37)(Table 6).

Night Snorkeling vs. Electrofishing. There was a significant correlation between density estimates for night snorkeling and electrofishing (r=0.89) (t=4.30, df=6, P<0.01). For night snorkeling and electrofishing, the slope of the regression line was one (b=1.00, SE=0.23), indicating this technique approaches electrofishing estimates (Fig. 7). There was no significant difference between mean density estimates for night snorkeling (7.3, SD=5.96) and electrofishing (9.0) (t=1.26, df=12, P<0.23)(Table 6).

For fry, there was a highly significant difference between mean density estimates for night snorkeling (0.61, SD=0.94) and electrofishing (5.4) (t=3.68, df=12, P<0.01). For juveniles, there was no significant correlation between night snorkeling and electrofishing (r=0.61, P<0.15). One site was considered an outlier for night snorkeling and electrofishing. Site 9 was the only site where the electrofishing density estimate (8.0 juveniles/100 m^2) was much greater (1.67 X) than night snorkeling (4.8). With removal of this site, there was a highly significant correlation ($r=0.99$) between the night snorkeling and electrofishing estimates ($t=4.71$, $df=5$, $P<0.01$).

There was no significant difference between juvenile mean density estimates for night snorkeling (6.6, SD=5.75) and electrofishing (3.5) ($t=1.26$, $df=12$, $P<0.22$). Although not significantly different, juvenile density estimates for electrofishing were lower than night snorkeling in 6 of 7 sites, averaging 53% (range=21-167%) of the night snorkeling estimate (Fig. 8).

For age 1 juveniles, there was no significant difference between mean density estimates for night snorkeling (4.6, SD=4.64) and electrofishing (2.6) ($t=1.00$, $df=12$, $P<0.34$). Although not significantly greater, in six of seven sites age 1 density estimates for night snorkeling were equal to or greater then electrofishing estimates. For age 2 juveniles, there was a significant difference between mean density estimates for night snorkeling (2.0 age 2 juveniles/100 m^2, SD=1.23) and electrofishing (0.91, SD=1.03) ($t=1.79$, $df=12$, $P<0.05$).

Day Snorkeling vs. Night Snorkeling. There was a significant correlation between day snorkeling and night snorkeling ($r=0.80$) ($t=2.96$, $df=6$, $P<0.05$). Per site, day snorkeling averaged 26% (range=0-40%) and night snorkeling 81% (range=36-105%) of the electrofishing total density estimate (Fig. 9). In comparison to night snorkeling, day snorkeling density estimates per site averaged 32% (range=0.0-67%) of the night estimate.

Per site, fry were counted in only two of seven sites by day snorkeling (sites 5 and 9) and in only three of seven by night snorkeling (sites 8, 9, and 11). Sites 5 and 9 are faster water unit-

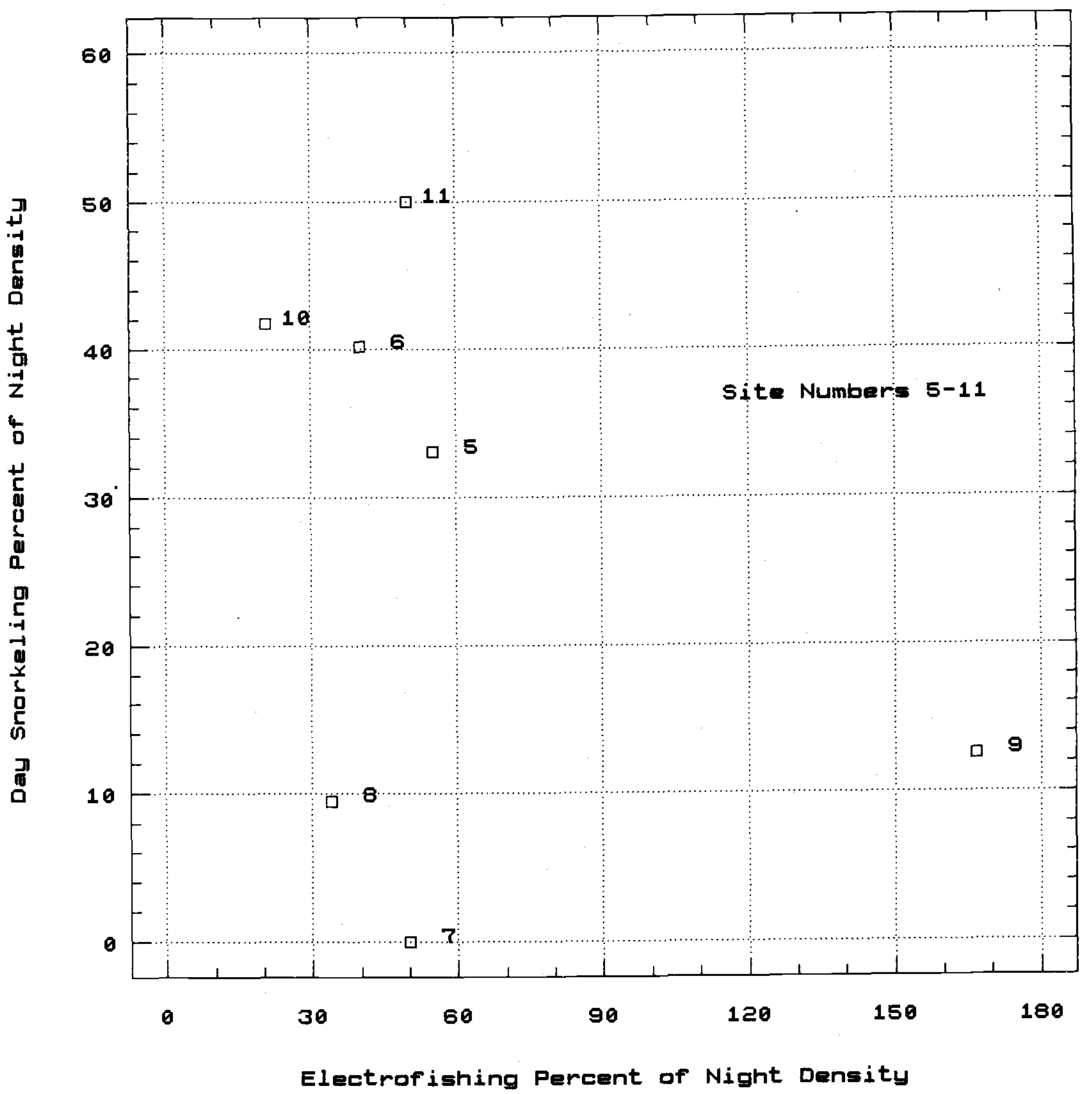


Figure 8. Electrofishing and day snorkeling juvenile density estimates as a percentage of night snorkeling juvenile densities for seven sites on Jack Creek.

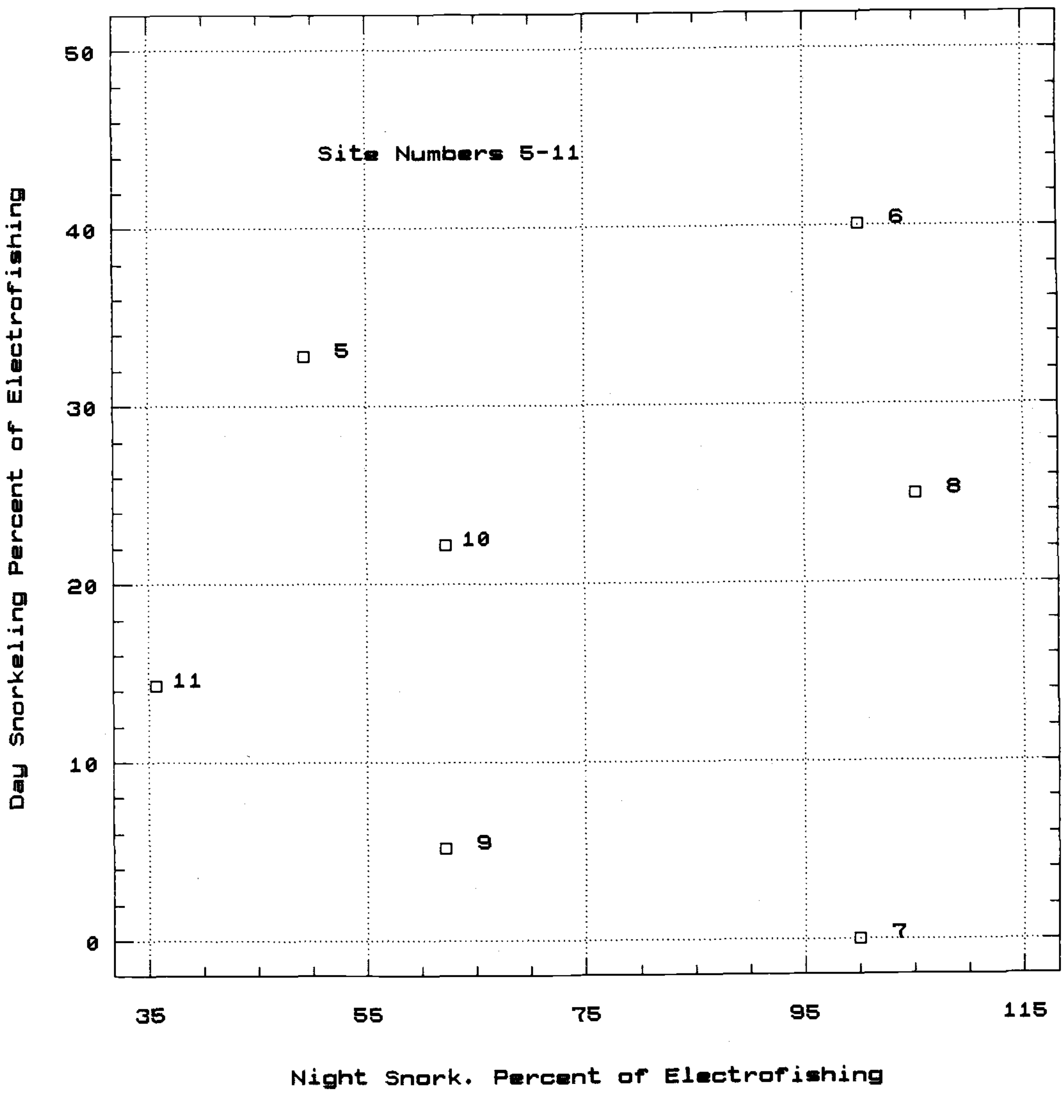


Figure 9. Night snorkeling and day snorkeling total density estimates as a percentage of electrofishing total densities for seven sites on Jack Creek. Snork. = snorkeling.

types, while sites 8, 9, and 11 had the greatest depth, most abundant cover, and the greatest area of low velocity water of all sites.

For juveniles, there was no significant correlation between density estimates for day snorkeling and night snorkeling (r=0.71, P<0.08). There was a significant difference between the juvenile mean density estimates for day snorkeling (1.7) and night snorkeling (6.6) (t=2.15, df=12, P<0.05). By site, day snorkeling density estimates averaged 26% (range=0-50%) of the night snorkeling estimate (Fig. 8).

For age 1 juveniles, there was no significant difference between mean density estimates for day (1.4) and night snorkeling (4.6) (t=1.68, df=12, P<0.12). For age 2 juveniles, there was a highly significant difference in mean density estimates between day snorkeling (0.3, SD=0.76) and night snorkeling (2.0) (t=3.14, df=12, P<0.01).

The estimated probability of capture for the entire population at a site (P_1) was always greater than 0.57 (P_1>0.57-1.0). The estimated probability of capture (*P*) for each age class was >.50 in 17 of 18 classes, and the population proportion removed after three to four electrofishing passes was usually >.90 (Table 7).

Because of the high summer flows of these spring-fed streams (Table 2), the equipment, labor, and time required for electrofishing sites 5-9 and 10-11 were considerably higher than for snorkeling. Deeper pools and faster units could not be electrofished effectively because they were too deep or the high flow pushed the barrier nets down. Labor was also much more intensive, partly due to the extremely complex habitat formed by large accumulations of woody debris. It took five to seven crew members four hours to survey main channel sites thoroughly by electrofishing while two divers required 50 minutes to snorkel the same sites.

Table 7. Number of removal passes (U_n), estimated probability of capture by age class (P), estimated probability of capture for all age groups (P_1), total catch (*T*), and population size (*N* ± 95%) of bull trout surveyed by electrofishing at seven sites (5-11).

Stream	Site	Age Class	Number of Passes (U_n)	Mean Total Length (cm ± SE)	*P*	P_1	*T*	*N* (±95% CI)
Jack	Five	0	3	4.28 ± 0.06	0.54	0.59	8	8.84 ± 3.46
		1		1.11	0.99		1	1.0
		2		14.30 ± 0.05	0.52		2	2.24 ± 0.74
	Six	0	2	5.10 ± 0.29	0.50	0.75	3	3.0 ± 2.30
		1		9.75 ± 0.35	1.0		2	2.0
	Seven	0	2	4.0	1.0	1.0	1	1.0
		1		10.4	1.0		1	1.0
	Eight	0	3	5.24 ± 0.19	0.56	0.58	20	21.91 ± 2.24
		1		10.10 ± 0.20	0.62		6	6.36 ± 6.31
		2		11.38 ± 0.18	0.62		4	4.24 ± 2.23
	Nine	0	4	4.51 ± 0.13	0.78	0.74	12	12.0 ± 0.16
		1		9.75 ± 0.14	0.52		22	23.2 ± 0.17
		2		2.07 ± 0.38	0.65		5	5.10 ± 0.40
Canyon	Ten	0	2	4.91 ± 0.26	0.60	0.57	7	8.33 ± 2.08
		2		13.6	1.0		1	1.0
	Eleven	0	2	4.95 ± 0.37	0.40	0.67	8	12.50 ± 9.80
		1		9.95 ± 0.55	1.0		2	2.0

Comparison of Two Non-Lethal Techniques over Multiple Habitats

Day snorkeling and night snorkeling were significantly correlated (r=0.81, P<0.01) for the ten waterbodies (Fig. 10). The Candle Creek day density estimate (2.45 fish/100 m^2) was lower than expected from the regression (4.16).

There was a highly significant difference between the mean total density estimates for night snorkeling (5.72 fish/100 m^2, SD=8.27) and day snorkeling (1.57, SD=3.12) (t=4.26, df=82, P<0.001). Sample density

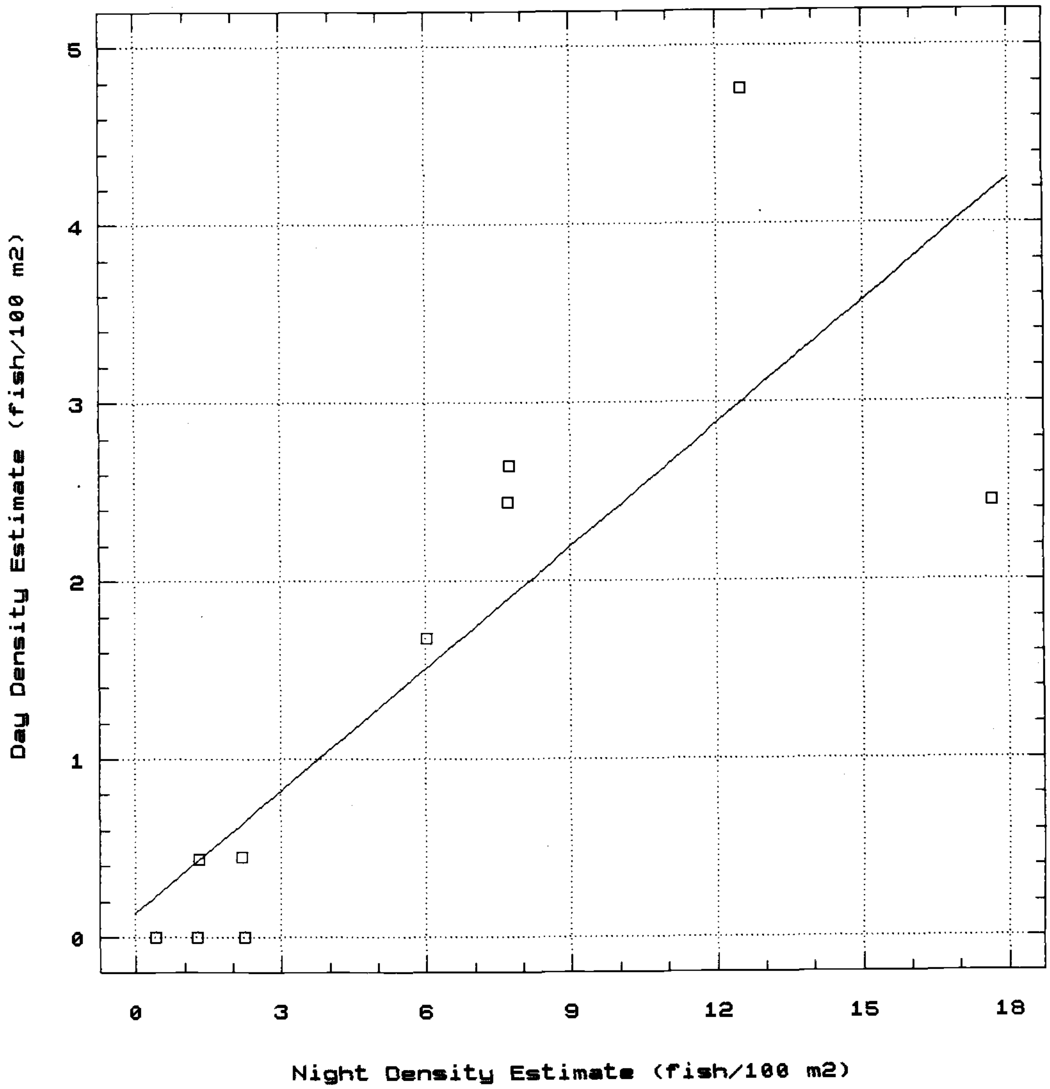


Figure 10. Relation of day snorkeling and night snorkeling total density estimates (fish/100 m^2) for 10 waterbodies. Regression equation is $y=0.14 + 0.23x$ ($r^2=0.66$).

estimates for day snorkeling averaged 27% (range=0-38%) of night snorkeling (Fig. 11). For Anderson Creek and Trailbridge Reservoir, waterbodies of the upper McKenzie River, no fish were observed during day snorkeling, and night snorkeling sample density estimates were the lowest observed.

There was a highly significant difference between night snorkeling and day snorkeling mean density estimates for (1) fry and juveniles combined, (2) juveniles, and (3) age 2 juveniles ($P<0.001$). There was a significant difference between age 1 mean density estimates ($P<0.01$) (Table 8).

Table 8. Age class mean density estimates for 10 waterbodies for day and night snorkeling, standard deviation (SD), two tailed t statistic (t stat), and significance level (Sig. level).

Age Class	Day Mean Density	SD	Night Mean Density	SD	t stat	Sig. level (<)
1	0.92	2.20	2.87	5.56	2.94	.01
2	0.37	1.11	2.18	2.48	6.02	.001
1 & 2	1.30	2.93	5.05	7.54	4.20	.001
All	1.57	2.93	5.72	8.27	4.20	.001

For 10 waterbodies, bull trout occurred in 89% of night samples and 50% of day samples (total units snorkled day and night n'=86, Table 4). Within a stream, bull trout occurrence by habitat unit ranged from 71-100% in night samples and 0-92% for day samples (Fig. 12). Four of six Metolius River streams had bull trout present in every unit sampled at night. Canyon Creek (1990) had the lowest percent occurrence at night (71%). The highest occurrence rates for day snorkeling were in Jack and Roaring Creeks (92% and 83%).

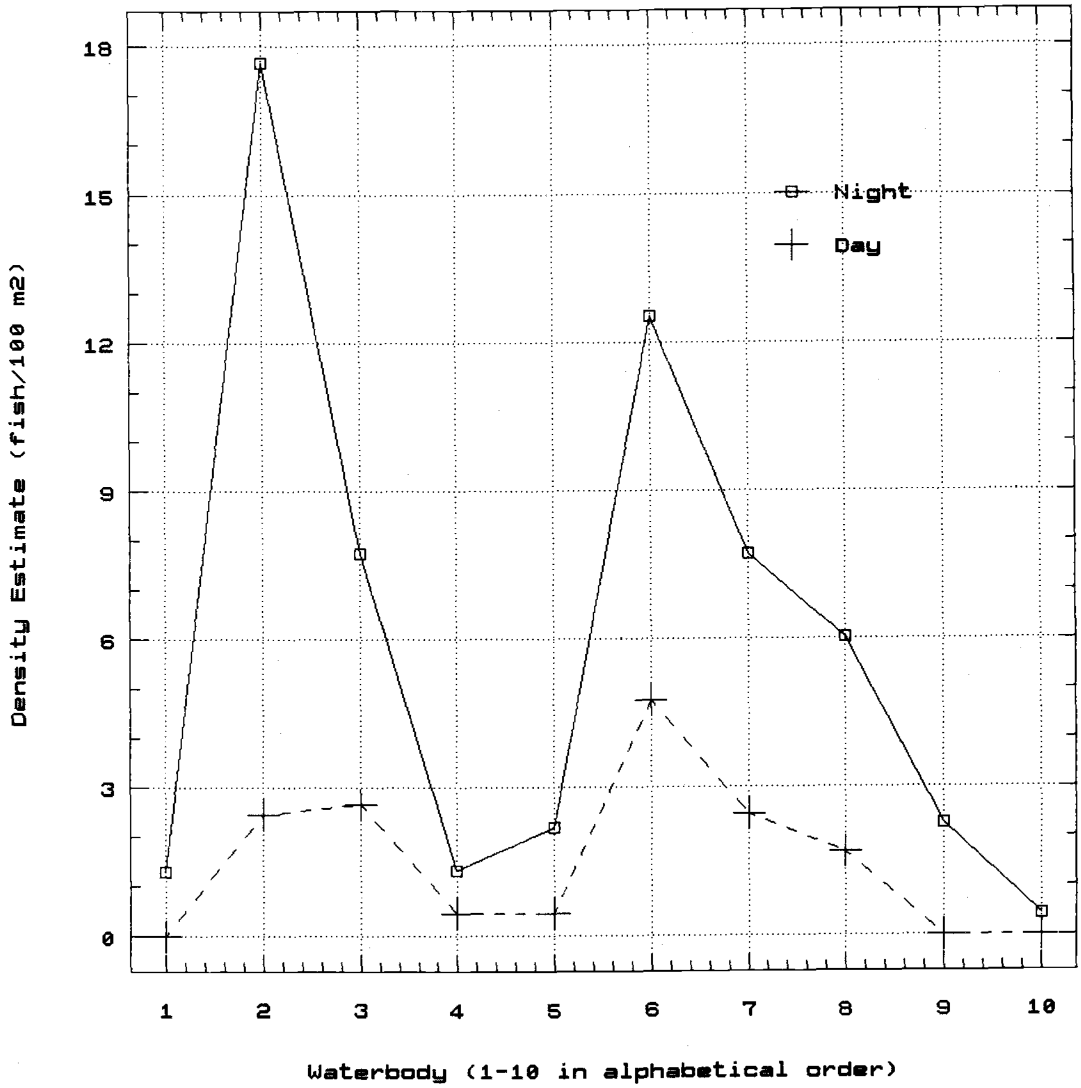


Figure 11. Day snorkeling and night snorkeling total density estimates (fish/100 m^2) for 10 waterbodies (waterbodies are arranged in alphabetical order (1) Anderson, (2) Candle, (3) Canyon 1989, (4) Canyon 1990, (5) Gold, (6) Jack, (7) Jefferson, (8) Roaring, (9) Trailbridge, and (10) Trapper).

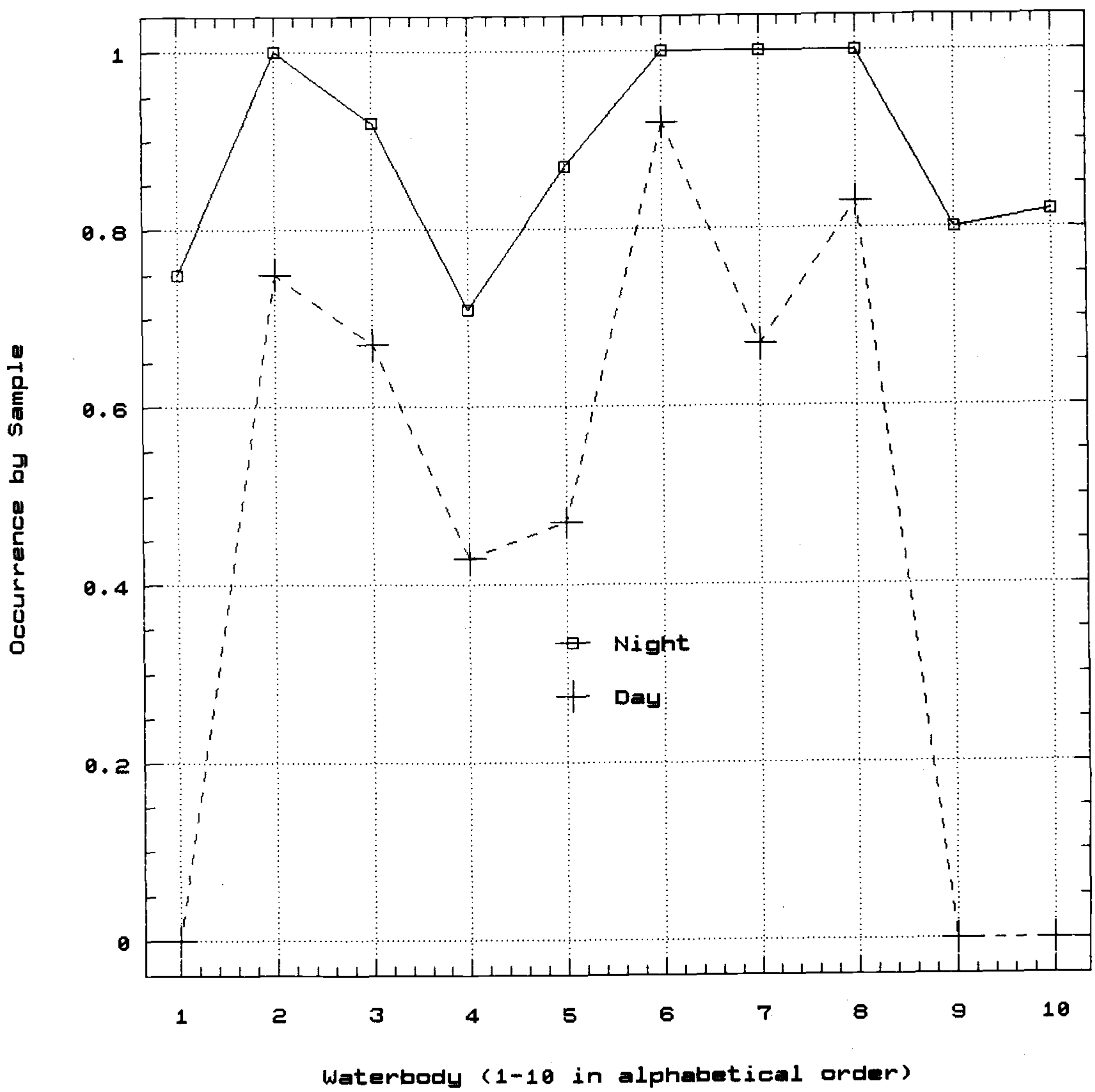


Figure 12. Bull trout occurrence by sample (percent of habitat units with bull trout by stream) for day snorkeling and night snorkeling of 10 waterbodies (waterbodies are arranged in alphabetical order (1) Anderson, (2) Candle, (3) Canyon 1989, (4) Canyon 1990, (5) Gold, (6) Jack, (7) Jefferson, (8) Roaring, (9) Trailbridge, and (10) Trapper).

Bull trout were not seen in Trailbridge Reservoir during the day, but at night seven juvenile bull trout were found in four of five transects (Fig. 1). Bull trout were not found in transect 4, which is located under a large bank of street lights. No bull trout were found during a night survey of the remainder of the McKenzie arm 24 h later.

DISCUSSION

Diel Study

Fry density estimates differed by time of day (Fig. 2) and between main channel and side channel. Fry in the side channel were out of cover throughout the day, with peak numbers from late morning to early evening (Fig. 3). In the main channel, peak fry densities occurred at 1600-1700 h with all individuals under cover approximately two hours before dusk (Fig. 4). Brown trout (S. trutta) and brook trout fry also display diurnal activity (McNichol et al. 1985; Heggenes 1988; Walsh et al. 1988).

Juvenile bull trout were intermittently out of cover throughout the 24 h period (Fig. 5). However, there was a highly significant difference ($P<0.001$) between night and day density estimates, and twilight and day estimates, with an apparent peak in density during a "quiet period" immediately after dusk (Fig. 6). Just before and during this "quiet period," juveniles moved from cover to open areas where they were observed resting on the bottom in shallow nearshore areas, often near conspecifics. Near midnight, two to three hours after dusk, all juveniles in main channel sites underwent a reverse movement to deeper water or sought cover (Fig. 6).

Vertical migration of adults and juveniles to shallow nearshore areas at dusk was also noted in Trailbridge Reservoir, in several river mainstems, and in a small lake near Gold Creek (Chapter 3). Other studies have reported crepuscular and nocturnal behavior of juvenile and adult bull trout along with diel vertical migrations from deep water during the day to shallow water at twilight (Thompson and Tufts 1967;

Andrusak and Northcote 1971; Schutz and Northcote 1972; Horner 1978).

Lab and field studies have documented a greater tendency of diurnalism for salmonids other than Salvelinus (Sagar and Glova 1988; Angradi and Griffith 1990; Glova and Sagar 1991). Juvenile and adult Salvelinus are adapted to low light intensities, while members of Oncorhynchus are less well adapted to these light conditions. This lack of adaptation may preclude most crepuscular and nocturnal activity (Schutz and Northcote 1972; Ali and Wagner 1980; Henderson and Northcote 1985; Dervo et al. 1991; Perrault et al. 1990).

Ontogenetic changes in vision have been related to the alteration of fishes' diel activities (Magnan and Fitzgerald 1984). The change from diurnal behavior for younger fishes to crepuscular or nocturnal for older individuals could result from younger fishes' smaller eyes, which collect less light and therefore preclude activity at lower light intensities (McFarland and Munz 1975). Hobson (1972) considers these ontogenetic changes are due to the increased predation on small, young fish.

Developmental differences in behavior at twilight are not unusual. In freshwater temperate streams and lakes, diurnal juvenile fish became adult nocturnal foragers, or, as older juveniles, became active later during evening (Helfman 1978; Magnan and Fitzgerald 1984; Huru 1986). Similar diel activity changes from diurnal fry to nocturnal juvenile and adult have been documented for Arctic char (Sandlund et al. 1987; Sandlund et al. 1988).

The diurnalism of fry and diurnalism/nocturnalism of older fish found in this study indicates a time partitioning of the available habitat. Fry were most abundant in side channel sites and the shallowest areas of the main channel sites during the day; juveniles occupied this space intermittently during the day and dominated during twilight periods (Fig. 13).

Clark and Levy (1988) suggest there are two daily periods of "antipredation": during twilight when the ability of predators to locate prey is diminished, and during the day when these predators retreat to low light areas to maximize metabolic efficiency. In this study, fry sought cover when potential predators (frogs, juvenile fish, and people) were present at a site. Furthermore, the fewest fry counted in a side channel site were in the site with the least amount of overhanging cover. These fry were the most sensitive to the observer's presence, seeking cover at the slightest movement. Piscivory by larger juvenile and adult bull trout was observed in Gold Creek and Gold Creek Pond (Chapter 3), while cannibalism occurred during electrofishing of Roaring and Jack Creeks when juveniles and fry were held in the same bucket.

In summary, in this study bull trout fry density estimates were highest during daylight hours while juvenile density estimates peaked after dusk. A "quiet period" for juveniles occurred from dusk and up to three hours after dusk. During this period, juveniles exhibited a diel movement from deeper water areas or from under cover to open, nearshore, and shallow areas. Ontogenetic differences in the vision of fry and juveniles at different light intensities, and avoidance of predators by fry are assumed to be the operating factors for the differences in day and night density estimates by age-class.

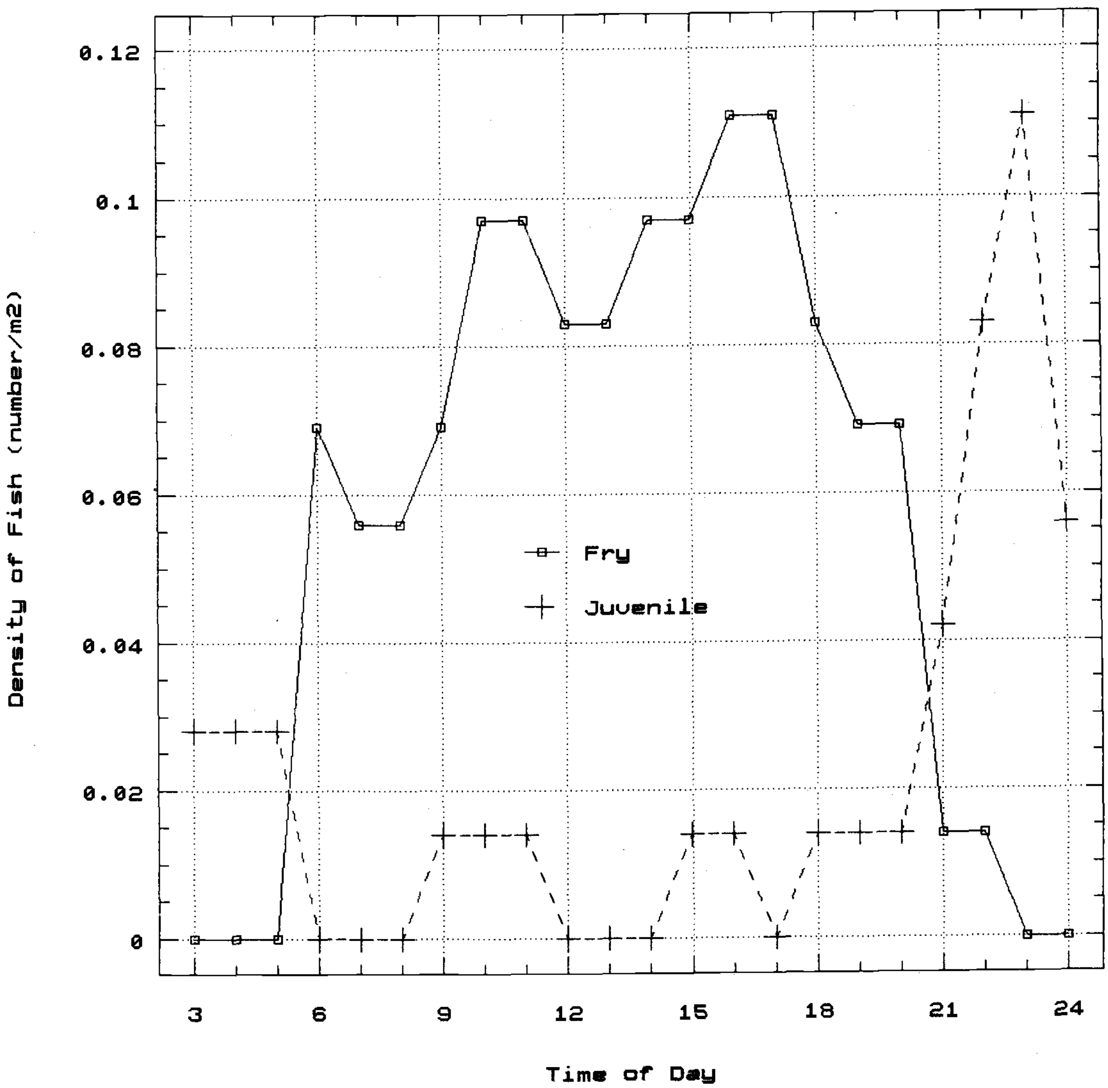


Figure 13. Diel density estimates of fry and juveniles at three main channel sites.

This is the first study to count bull trout fry and juveniles over 24 hours. These study results suggest that the preferred time to sample for fry is during periods of high light. For juveniles it is during twilight, after dusk during their "quiet period."

Comparison of Sampling Techniques

Streamside Counting. The author hoped streamside counting would be an effective non-lethal method for estimating fry abundance in side channels. However, streamside counting of both fry and age 1 juveniles was very difficult in side channels. Behavior of the fry and the type of habitat sampled strongly influenced counts. Most fry (70% or 64 of 91 electrofished) were either under cover or could not be seen by the observer. Because of the slow nature of these side channels, they collect a large amount of fine brown or black material that blends in with the dark dorsal surface of the fry and age 1 juveniles. Streamside counts significantly ($P<0.05$) underestimated fry abundance (20%) in comparison to electrofishing estimates (Table 5).

While streamside counts were not significantly correlated with electrofishing estimates in this study, a similar technique was used successfully by Bozek and Rahel (1991) to count cutthroat trout fry. These authors suggest that standardized techniques, proper observer training, and tools to minimize fry disturbance may increase fry estimates and consistency of estimates.

Electrofishing. Although the higher juvenile (age 1 and 2) density estimates from night snorkeling vs. electrofishing were not statistically significant in this study, night snorkeling may have practical advantages. Fraley and Shepard (1989) reported that electrofishing probably underestimates juvenile bull trout populations in Montana streams, because of their benthic orientation and cover-seeking behavior. However, electrofishing did produce higher total density estimates (fry and juveniles) (Fig. 7) and significantly higher ($P<0.01$) estimates for fry (Table 7).

Because electrofishing can be injurious or lethal, and many bull trout populations are rare or declining (Mongillo 1993; Ratliff and Howell 1992), the preferred application of electrofishing as a sampling method may be in estimating fry abundance. As body voltage increases with fish length, larger fish receive a greater electroshock, and in low conductivity water (100 ummhos/cm<) fish may not be affected by the electrical field until they are touched by the electrode, often resulting in death (Reynolds 1983). In Jack and Anderson Creeks, numerous juveniles and a few adults had "brand" marks on their flanks from direct contact with the electrofisher probe while others died almost immediately after capture.

Electrofishing may also be well-suited to higher conductivity water, side channels, and shallow nearshore stream and river habitats. Electrofishing density estimates for side channel sites 1-4, for all age groups at a site, were the highest of all habitat units sampled in this study (Tables 5, 6).

Day Snorkeling. Day snorkeling significantly ($P<0.01$) underestimated total density and fry density in comparison to electrofishing (Fig. 7, Table 7). In comparison to night snorkeling, day snorkeling significantly underestimated (1) total density ($P<0.001$),

(2) total juvenile density (P<0.001), and (3) juvenile density of both age 1 (P<0.01) and age 2 fish (P<0.001) (Table 8).

Other studies have noted the size-related bias of day snorkeling and electrofishing (Bozek and Rahel 1991). In a comparative sampling study of Atlantic salmon, fry were usually found in nearshore shallows and were underestimated by day snorkeling (Cunjak et al. 1988). These areas are very difficult to sample by snorkeling, particularly where fish can hide in abundant cover if disturbed. In contrast to the results for fry, day-snorkeling estimates of juvenile Atlantic salmon in the above study were similar to electrofishing estimates.

Shardlow et al. (1987) state that day snorkeling, despite its failings, is a useful method and may be superior to electrofishing under certain conditions. This method is appropriate for sampling juvenile bull trout in areas that are relatively remote or inaccessible, have a known population, or are treacherous for night diving.

Night Snorkeling. Although this method produced higher juvenile density estimates than electrofishing (Fig. 8), the difference was not statistically significant, possibly because of the small sample size.

There were several practical advantages with night snorkeling, however: (1) it is a non-injurious visual technique, (2) it produced significantly higher density estimates than day snorkeling (P<0.001) (Table 8), (3) site surveys are faster (35 minutes vs. 4 hours) and require less labor (2 divers vs. 5-7 personnel) than electrofishing, and (4) it can be used in larger waterbodies such as rivers and lakes. Also, night snorkeling documented the presence of juvenile bull trout in several streams and river systems where they had not been recorded in decades or were previously unrecorded (Chapter 3).

One factor explaining the higher night density estimates is the increased gregarious behavior of juveniles during their "quiet period." Juveniles were often together during the diel study and the night snorkel surveys. In one extreme example in Candle Creek, a "cloud" of 15 fish was observed in the outflow of a small spring. Their gregarious behavior could relate to the cold temperatures of the spring-fed streams where bull trout are found (Chapter 2). Brook trout and brown trout also show a tendency toward more gregarious behavior at low temperatures, hiding under cover during the day and emerging at night (Cunjak and Power 1986). Most snorkel surveys were in the 6-11°C temperature range. Candle Creek had the coldest temperature (5°C) and the largest difference between day (2.45 fish per 100m^2) and night (17.67) density estimates.

Implications of Study Findings

Fish density estimates in this study varied with different sampling methods and times. It is possible, therefore, that low occurrence rates and abundance estimates of bull trout in previous studies may be due to their method and time of sampling. In a survey of fishes of the Clearwater River in Idaho, Maughan (1976) took 75 stream collections and found bull trout in only one stream (a 0.9% site occurrence). In collecting community fish samples from 71 sites in Washington, Beecher et al. (1988) found bull trout in only three sites. These surveys may have missed the presence of bull trout, however. Both studies used only daylight sampling and employed seines for a significant part of the sampling, although hook and line, snorkeling and electrofishing were used in some collections. Concluding that bull trout are absent based on these techniques may be incorrect. Verification of presence or absence may require night snorkeling. Stenzel (1987) attempted to collect juvenile Arctic char with dip nets and seines but was largely unsuccessful. Night snorkeling was his preferred method for abundance estimates.

The only published density estimates for juvenile bull trout come from streams in Idaho and Montana. For bull trout populations in the Flathead River, Fraley and Shepard (1989) reported average snorkel density estimates of 1.5 fish per 100 m^2. Because of the benthic orientation and cover-seeking behavior of juvenile bull trout, the authors considered these underestimates. Electrofishing population estimates ranged up to 15.5 fish per 100 m^2 for certain streams. Pratt (1984) had a range of 0-37.5 fish per 100 m^2 in units sampled in Idaho streams. These values may be overestimates since her sampling criteria required beginning counts after surveying upstream until juvenile fish were observed, rather than beginning from a random starting point. Results from this study fall within the values reported by these authors (Table 7 and 8), although night snorkeling estimates for some individual habitat units did range up to 46 fish per 100 m^2.

Density estimates for this study may be better indicators of abundance throughout the stream than previous work done on "representative stream reaches" (Hankin and Reeves 1988). Abundance estimates inferred for areas outside representative reaches can produce biased results. In this study, day snorkeling involved systematic sampling of "nth" units, while night snorkeling involved an "nth" subsample of the day sample. These two methods were significantly correlated (r=0.81), with night estimates consistently resulting in higher densities (5.72 fish per 100 m^2) than day estimates (1.57) in all streams and habitat types.

Potentially higher juvenile abundance estimates are not the only data available from night snorkeling. Information on distribution, activity, and habitat use can also be collected from sampling at night (Chapter 2 and 3).

Recent uses of night snorkeling in other bull trout studies have produced contradictory results. In Idaho mountain streams, Schill (1992) found no significant difference between night snorkeling, day snorkeling, and electrofishing density estimates. However, night snorkeling was used successfully in two later studies in different habitats of the Oregon and Washington Cascades. In a study of juvenile bull trout habitat, Sexauer and James (in press) surveyed 700 m of eastern Washington stream habitat. They found no bull trout juveniles using day snorkeling, but counted 22 juveniles using night snorkeling. During spring and early summer, Jim Capurso (U.S. Forest Service, McKenzie Bridge Ranger District, McKenzie Bridge, Oregon, pers. comm. 1993), used night SCUBA surveys of Trailbridge Reservoir and found older juvenile and adult bull trout present throughout the reservoir.

Chapter 2. Diel and Seasonal Habitat Use

INTRODUCTION

Bull trout have specific habitat requirements for rearing of juveniles (Chapter 3). In the Cascade Mountains of Oregon, juvenile bull trout are found in selected headwater streams in association with large coldwater springs. Geomorphology, low water temperature, and sufficient late-summer flow are important large-scale factors explaining bull trout presence in this area, although little is known of bull trout habitat use at smaller scales. To date, there have been no studies in Oregon of fry and juvenile macrohabitat (habitat unit scale) or microhabitat (focal point) of migratory bull trout. The only available literature for Oregon has related to qualitative stream habitat (Buckman et al. 1992; Ratliff 1992) or involved study of resident populations (Dambacher et al. 1992; Ziller 1992).

Most juvenile chars (Salvelinus) are bottom dwellers (Noakes 1980; Pratt 1984; Stenzel 1987). They are substrate-oriented with their territory limited to two-dimensional or horizontal segregation of the available habitat. For large bull trout streams in Idaho, Pratt (1984) believed this horizontal segregation resulted in increased juvenile bull trout numbers with increasing habitat unit area. Where horizontal segregation is not possible, interactions among juvenile char may cause specialization or emigration. This specialization may result in temporal partitioning of the available habitat with differences in use by day or night (Stenzel 1987) and by season (Cunjak and Power 1986).

At water temperatures below 8°C in nonspring-fed streams in winter, salmonids display distinct differences in diel behavior (Hillman et al. 1987; Riehle and Griffith, in press). During the day they hide under "concealment cover" (Griffith and Smith 1993) and then emerge at night, congregating in loose groups (Campbell and Neuner 1985; Cunjak and Power 1986; Contor 1989). This behavior may minimize their metabolic expenditures at these low water temperatures (Griffith and Smith 1993). In the Cascade Mountains of Oregon, fry and juvenile bull trout are only found in cold, spring-fed streams with average water temperatures below 8°C even during summer (Table 2). At these low water temperatures, bull trout young may show diel differences in habitat use similar to winter hiding behavior of other salmonids.

In the Diel Study (Chapter 1), bull trout young showed differences in summer habitat use in physical and temporal space in a limited area. Fry were diurnal and used side channel or nearshore main channel habitat. Juveniles were out of cover intermittently throughout the day and night, using shallow water habitat exclusively at dusk and deeper water habitat at other times. Because of these spatial and temporal differences in habitat use, a quantitative study of juvenile bull trout habitat should investigate diel and seasonal use in a variety of habitats.

Therefore, objectives of this chapter are as follows:

1. Describe and evaluate bull trout summer habitat use at the habitat unit scale; and

2. For one spring-fed stream, describe and evaluate microhabitat used and available for summer and identify differences in habitat use daily and seasonally.

METHODS

I studied summer habitat use of fry (age-0) and juvenile (age-1 and 2) bull trout from 1989 to 1991 in three Oregon basins -- tributaries of the Metolius River (Candle, Canyon, Jack, Jefferson, and Roaring Creeks), Trapper Creek in the Odell Lake basin, and Anderson Creek and upper South Fork McKenzie in the McKenzie River basin -- and one Washington basin, Gold Creek in the upper Yakima River. Locations and sampling periods are presented in Chapters 1 and 3.

Habitat use was quantified at the macrohabitat level for all streams and at the microhabitat level for one spring-fed stream, Jack Creek. Macrohabitat represents general stream characteristics at the habitat unit scale. Microhabitat represents habitat characteristics such as water column depth and water column velocity, estimated or measured at fish positions (focal point) in the stream.

Microhabitat analysis of Jack Creek included (1) analysis of diel summer habitat use compared with habitat available (1989), and (2) comparisons of diel seasonal habitat use during summer, late fall, and spring (summer 1989 to spring 1990).

Summer Macrohabitat

Using methods described in Chapter 1, occurrence (presence) and density estimates of bull trout (number of fish per m^2, fry, and juveniles) during summer were compiled for day and night snorkeling by habitat type (pool, riffle and glide) in Cascade Mountain streams of Oregon and Washington. Habitat units used in this analysis were limited to the last upstream unit in which bull trout were observed. An analysis of general stream characteristics is presented in Chapter 3.

Habitat unit area was estimated visually. Habitat units for Metolius River streams were mapped by U. S. Forest Service crews in 1988 (Mike Riehle, U.S. Forest Service, Sisters Ranger District, Sisters, Oregon, unpublished data) using methods outlined in Hankin and Reeves (1988). Using the same methodology, I surveyed Trapper Creek habitat during August 1989, McKenzie River habitat in September 1989 and 1990, and Gold Creek in the upper Yakima River basin in September 1991. Pooled values for all habitat units surveyed are presented in Table 9.

Table 9. Total number of habitat units and area surveyed by day and night snorkeling from 1989 to 1991 for juvenile bull trout habitat use for (1) all streams, (2) by basin, and (3) for Jack Creek and the microhabitat study.

Basin or Stream	Units (n)	Area (m^2)	Glide (n)	Area (m^2)	Pool (n)	Area (m^2)	Riffle (n)	Area (m^2)	Side Channel (n)	Area (m^2)
All Streams	85	13157	24	4508	29	4229	19	3295	13	1125
Metolius R[a]	48	6359	15	2440	17	2156	9	1108	7	655
Odell L	11	1959	2	810	4	326	4	773	1	50
U Yakima R	17	3500	4	816	7	1642	4	823	2	219
McKenzie R	9	1339	3	442	1	105	2	591	3	201
Jack Creek[b]	11	1032	3	358	3	257	2	261	2	156

a. Basin numbers are subsets of the All Streams total; R=River; L=Lake; U=Upper.
b. Jack Creek is a subset of the Metolius River total.

Two-sample analysis was used to test whether fish density estimates differed between day and night within the units (for example, day density of glides vs. night density of glides). Correlation analysis was used to compare bull trout number to (1) total habitat unit area and (2) habitat unit area by type. Vanderploeg and Scavia's electivity index (E_i*) was computed to assess electivity for habitat unit use vs. habitat available (Vanderploeg and Scavia 1979; Lechowicz 1982; Gipson and Hubert 1993). The electivity index is defined as:

(1)

$$E_i* = [W_i - (1/n)] / [W_i - (1/n)]$$

where Wi is calculated by:

(2)

$$W_i = r_i/p_i / \sum_i r_i/p_i$$

where E_i* is the value of electivity, n is the number of kinds of habitat types, W_i is the selectivity coefficient, r is the proportion of fish in a habitat type i, and p is the proportion of that habitat area. The index has a range of +1 to -1 and is nonlinear and asymmetrical. The index has the advantage of being unaffected by the relative abundance of habitat types (Lechowicz 1982). Positive values indicate electivity, negative values indicate avoidance, and values equal to 0 indicate random electivity.

Jack Creek Microhabitat

Diel and Seasonal Microhabitat. Microhabitat use for individual fish was measured under diel and seasonal (summer, late fall, and spring) conditions. Five sites were selected along the entire length of Jack Creek. These sites contained 11 habitat units which represented the full range of habitat unit types used by bull trout (glide, pool, riffle, and side channel). For summer microhabitat, all five sites were also mapped for available habitat and compared with diel habitat used by individual fish. Differences in seasonal microhabitat use were compared for summer, late fall, and spring. The sampling periods were mid-July to the end of August 1989, early-December 1989, and the end of April 1989, respectively.

At each site, microhabitat use was defined for individual fish. Each fish seen during the day and at night was observed for approximately one to three minutes to determine its focal point. The night observation period was between 0 and 3 hours after dusk. The location of each individual was marked with a wire flag and noted later within the point map of the site. Information estimated or measured for each fish included focal point measurement of total water column depth (hereafter referred to as total depth), focal elevation (height of fish above substrate), mean velocity (average water column velocity at 0.6 depth), substrate type (Table 10), substrate embeddedness (percent), cover type (Table 11), distance to nearest cover (DTNC), and activity. The measurement of mean velocity is a standard used in other microhabitat studies (Moyle et al. 1985; Heggenes et al. 1991; Bozel and Rahel 1992).

Table 10. Microhabitat substrate classification identifying substrate by size range (modified from Rodnick (1983)).

Substrate Classification	Size Range (cm)
Sand	< 0.2
Fine Gravel	0.2 - 3.2
Large Gravel	3.2 - 6.4
Cobble	6.4 - 30.0

Table 11. Microhabitat cover classification identifying cover types.

Classification	Types or Size Range
Substrate	Cobble and Rubble
Fine Woody Debris	<10 cm diameter
Coarse Woody Debris	11 - 50 cm diameter
Large Woody Debris	> 51 cm diameter
Undercut Bank	Stable Bank, Undercut
Vegetation	Overhanging, Emergent, Aquatic
Depth	Water Column Depth
Turbulence	Water Turbulence

During the summer sampling period, each site was also mapped for available habitat within 24 hours of the microhabitat use survey using a point-sampling system outlined in Rodnick (1983). Habitat use was characterized, but available habitat was not measured during winter and spring. Jack Creek was assumed to have a year-round constant flow like other High Cascade spring-fed streams, and habitat available should show little variation (Fig. 43). A grid was set up for each site, and points selected at 1 to 2 m intervals along the length and width of the site. As a result, characteristics of available microhabitat were measured at 32-114 points within each site. For each point, I recorded the same information as for microhabitat use (listed above) except for focal elevation and DTNC.

Vanderploeg and Scavia's electivity index (E_i*, formula 1) was computed to assess electivity of habitat use vs. habitat available (Vanderploeg and Scavia 1979; Gipson and Hubert 1993).

Differences in diel and seasonal habitat use were compared by use of the K-S test for continuous variables (depth, focal elevation, average velocity, embeddness, DTNC) and by the power divergence (P-D) test for discrete data (substrate particle size, cover type). Read and Cressie (1988) consider the power divergence statistic as a robust test for small sample sizes. Comparisons were made for both day and night for (1) between-season differences (summer vs. winter and summer vs. spring) and (2) within-season differences (summer day vs. summer night). Summer habitat was used as the basis for between-season comparison because available habitat was measured for this season.

Diel Activity. As part of the Jack Creek microhabitat study, general activity type was observed (summer) or recorded (winter and spring) for individual fish during the day and at night for three seasons.

Activity type was defined as (1) resting, (2) holding, (3) feeding, and (4) swimming. Fish that were sitting on the substrate were counted as resting. Fish maintaining position just above the substrate were holding. Fish foraging from the drift or benthos were feeding. Fish actively moving were counted as swimming.

RESULTS

Macrohabitat Use

Occurrence by Habitat Unit. For all streams, bull trout were found during the day in 31.6% of riffles (n=19) and up to 58.6% of pools (n=29) (total habitat units n=85). Night use (occurrence) was almost two times greater than day, ranging from a low of 52.6% in riffles to a high of 100% in side channels (n=13) (Fig. 14). Bull trout use of units snorkeled during the day was much lower for every age group, although fry or juveniles could have been under cover in a unit and not seen by the diver (Fig. 15). Bull trout found at night were typically in backwater areas (alcoves) or pocket pools.

In the Metolius River tributaries, occurrence during the day varied from 44.4% in riffles (n=9) to 100 % in side channels (n=7) (total n=48). Night use was higher than day use, ranging from 66.7% in riffles to 100% in glides (n=15) and side channels (Fig. 16). Bull trout were not found in any habitat units during the day in Trapper Creek (n=11). Night use ranged from 25% in riffles (n=4); 100% of pools (n=4), glides (n=2), and side channels (n=1).

In Gold Creek, bull trout were not found in side channels (n=2) or riffles (n=4) during the day. Juvenile bull trout were found in 42.5% of pools (n=7) and 50% of glides (n=4) during the day. At night, bull trout used habitat units in the same proportions as in Trapper Creek -- 25% of riffles, 100% in pools, glides, and side channels.

In the McKenzie River basin, bull trout were not found in any habitat unit during the day. Night use ranged from 66.7% for glides (n=3) to 100% for riffles (n=2), side channels (n=3), and pools (n=1).

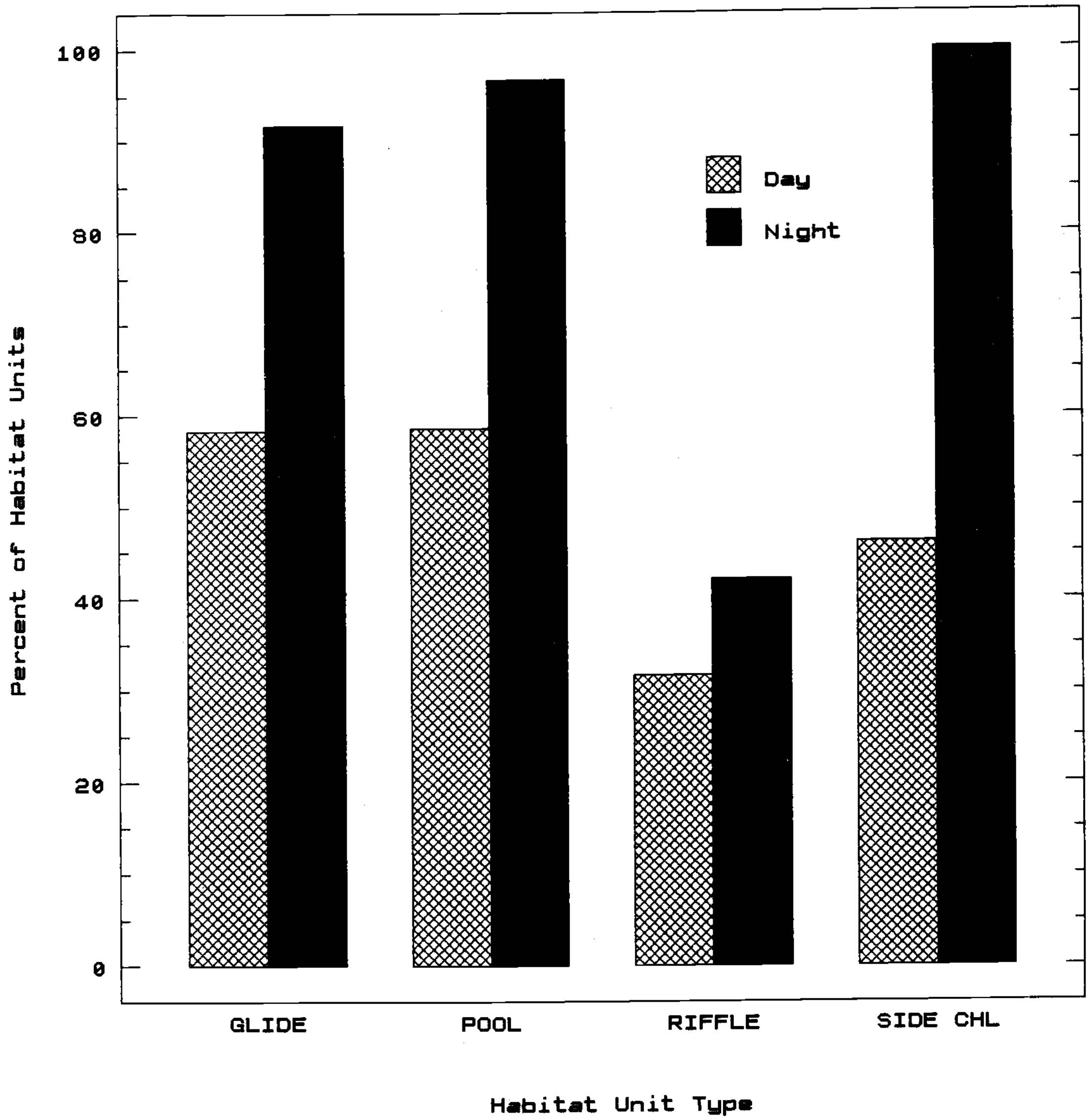
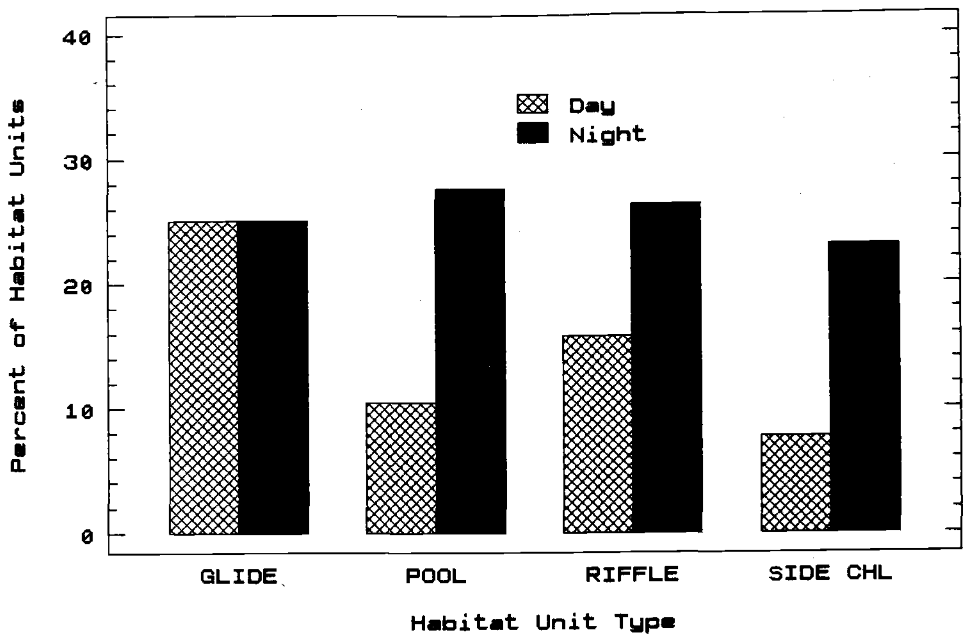


Figure 14. Percentage of habitat units of each type (Side Chl=Side Channel) in which bull trout were found in day and night surveys of all streams from 1989-1991.



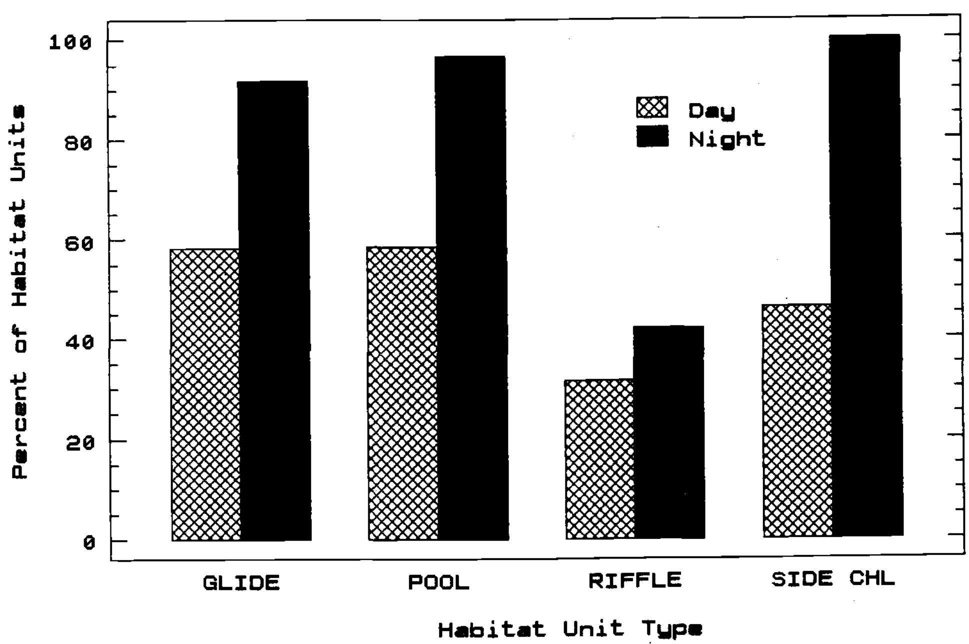


Figure 15. Percentage of habitat units of each type (Side Chl=Side Channel) in which fry (Fr=Fry, top figure) and juvenile (Jv=Juvenile, bottom figure) bull trout were found in day and night surveys of all streams from 1989-1991.

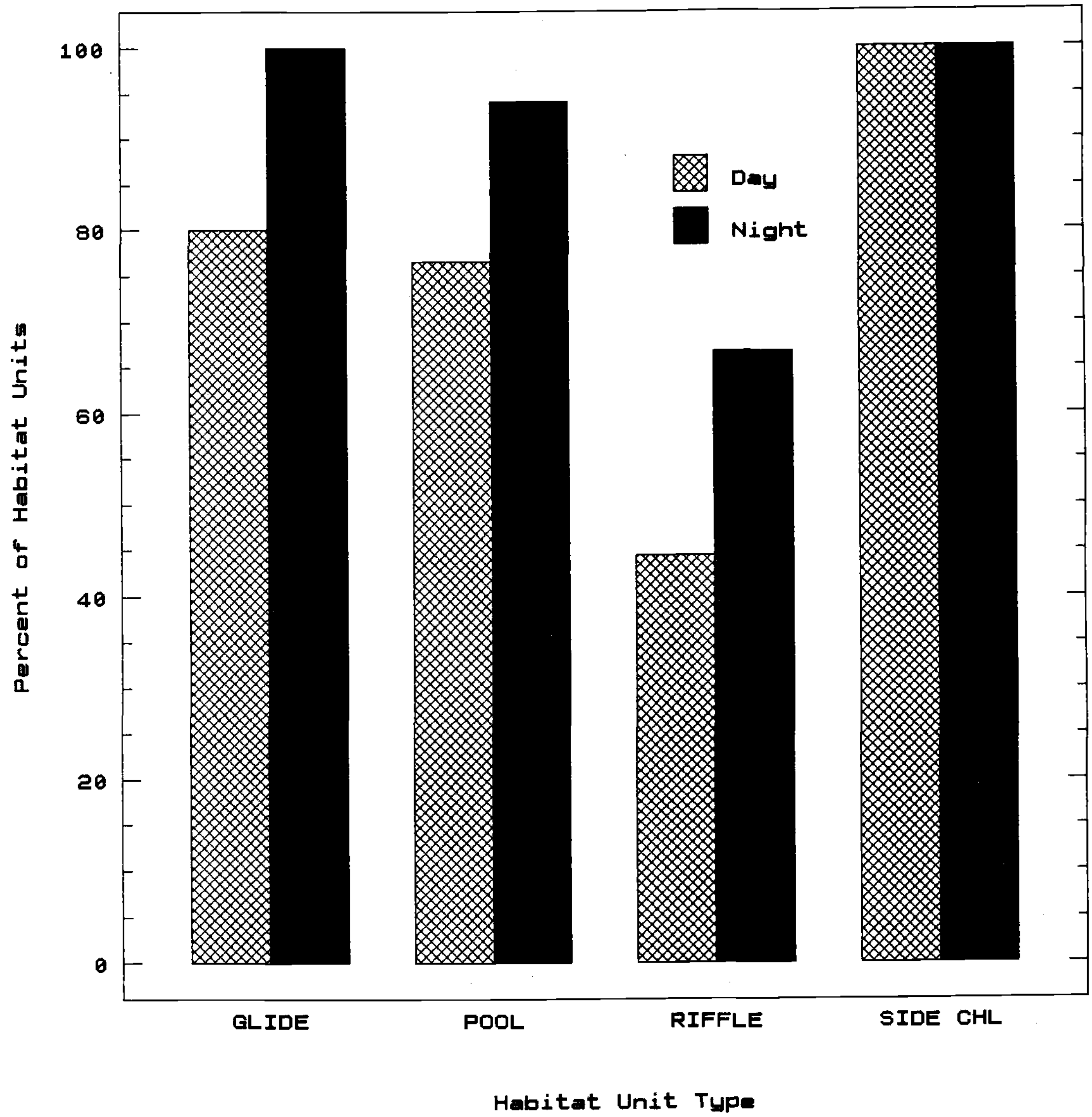


Figure 16. Percentage of habitat units of each type (Side Chl=Side Channel) in which bull trout were found in day and night surveys of Metolius River streams from 1989-1990.

In Jack Creek, occurrence during the day varied seasonally, with bull trout using 36.4% of all units (n=11) in winter, 54.5% in spring, and 100% in summer. Night occurrence did not vary by season, with bull trout using 90.9% of all units (Fig. 17). Except for summer day, bull trout occurrence in riffles was lower than in any other unit, day or night.

Habitat Unit Density Estimates. The bull trout night density estimates for glides, pools, and side channels were significantly greater than the day estimates for all basins (Fig. 18). There was no significant difference for riffles for any basin between day and night density estimates.

Regression of Bull Trout Number on Habitat Unit Area. There was a significant correlation between bull trout numbers and habitat unit area at night for (1) Metolius River streams (r=0.50) (t=3.90, df=47, P<0.001) (Fig. 19) and (2) Gold Creek (r=0.60) (t=2.67, df=14, P<0.05). There was no significant correlation between bull trout numbers during the day and area of habitat unit for any basin or stream.

In Jack Creek, there was a significant correlation during the winter between habitat unit area and bull trout numbers at night (r=0.67, t=2.71, df=10, P<0.05) (Fig. 20). There was no significant correlation between numbers and area during the summer and spring. Water temperatures ranged from (1) 3°c during winter, (2) 4-5°C during spring, and (3) 7-10°C during summer.

By habitat unit, there was a significant correlation of bull trout numbers at night and area of glide habitat unit in Metolius River tributaries (r=0.59, t=2.66, df=14, P<0.05). There was no significant

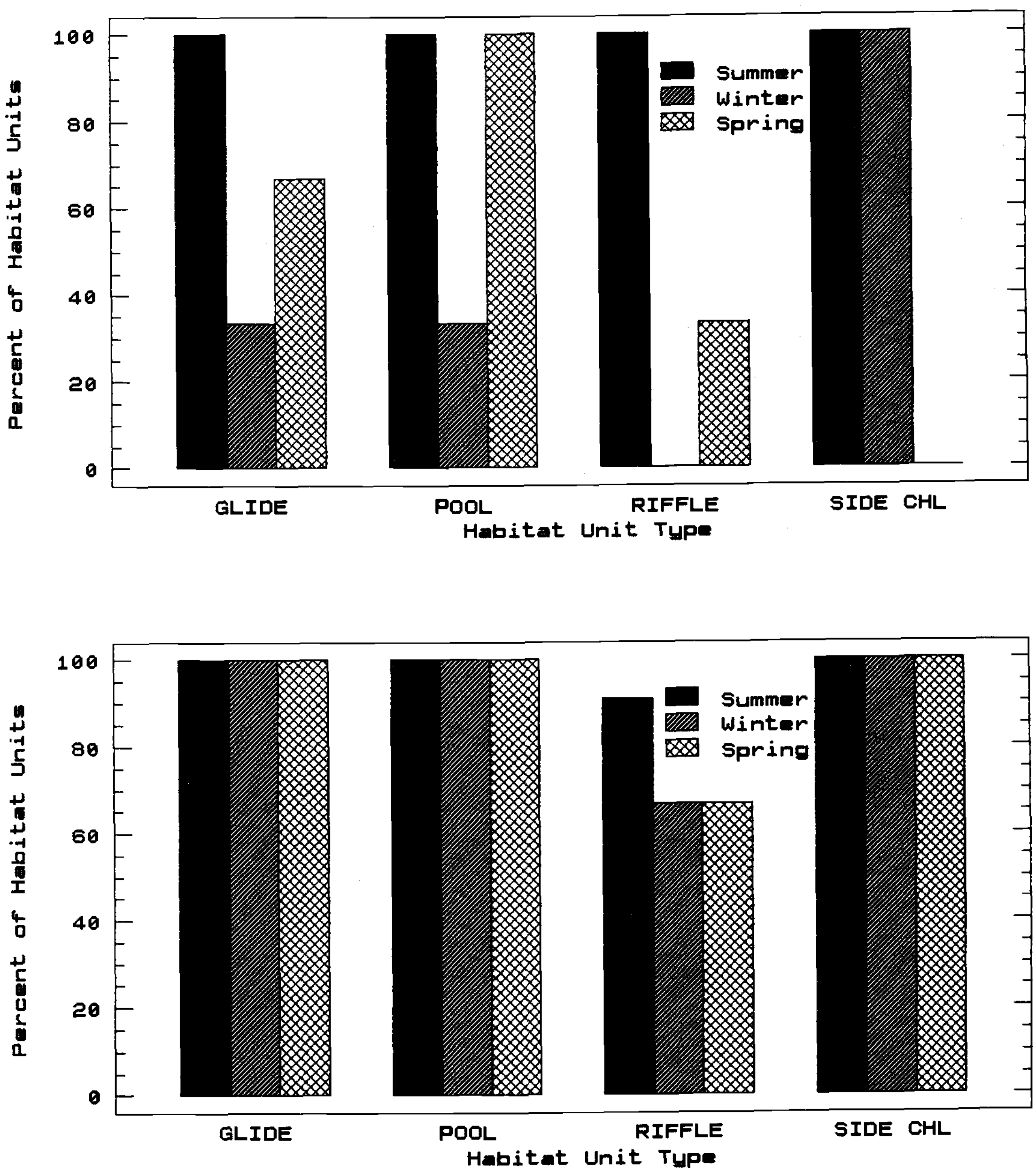
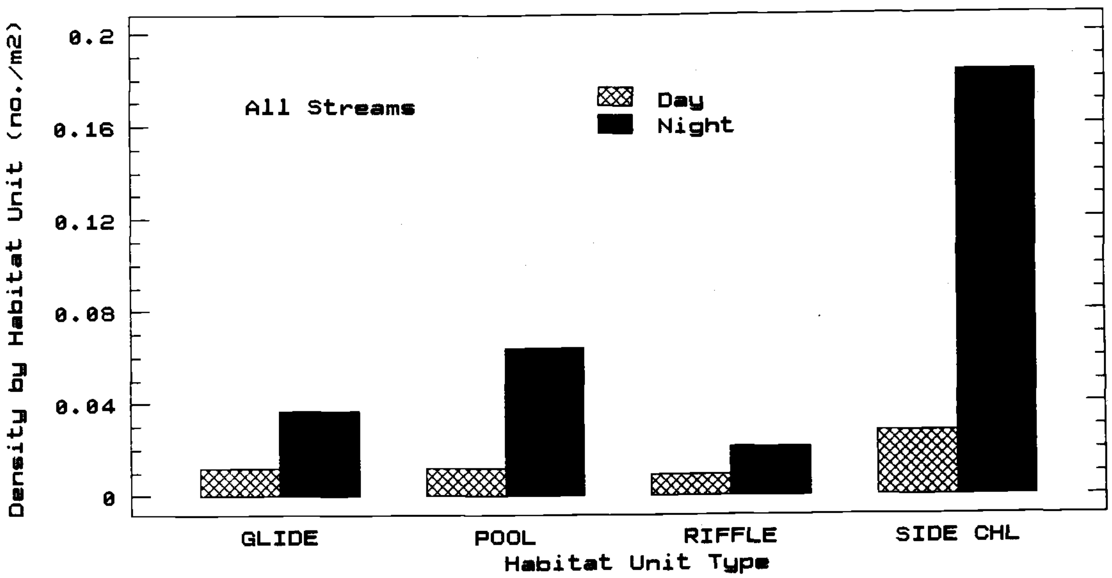


Figure 17. Percentage of habitat units of each type (Side Chl=Side Channel) in which bull trout were found in day (top figure) and night (bottom figure) surveys in Jack Creek for summer, late fall, and spring from 1989-1990.



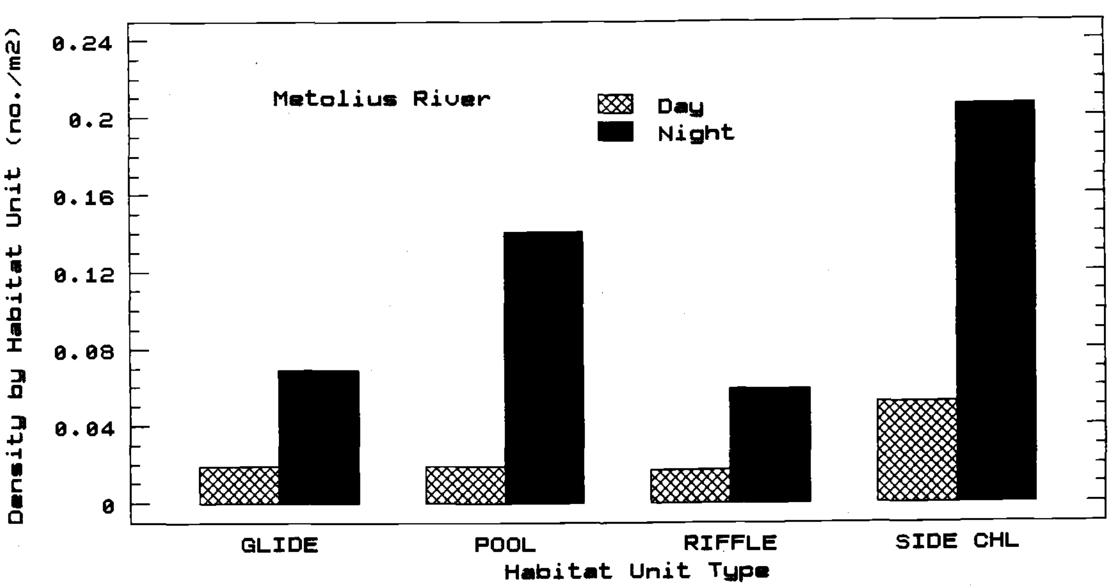


Figure 18. Density of bull trout (number/m^2) day and night for (1) all bull trout streams surveyed, 1989 to 1991 (top figure) and (2) Metolius River tributaries, 1989 and 1990 (bottom figure). Density is pooled by habitat unit for all Metolius streams.

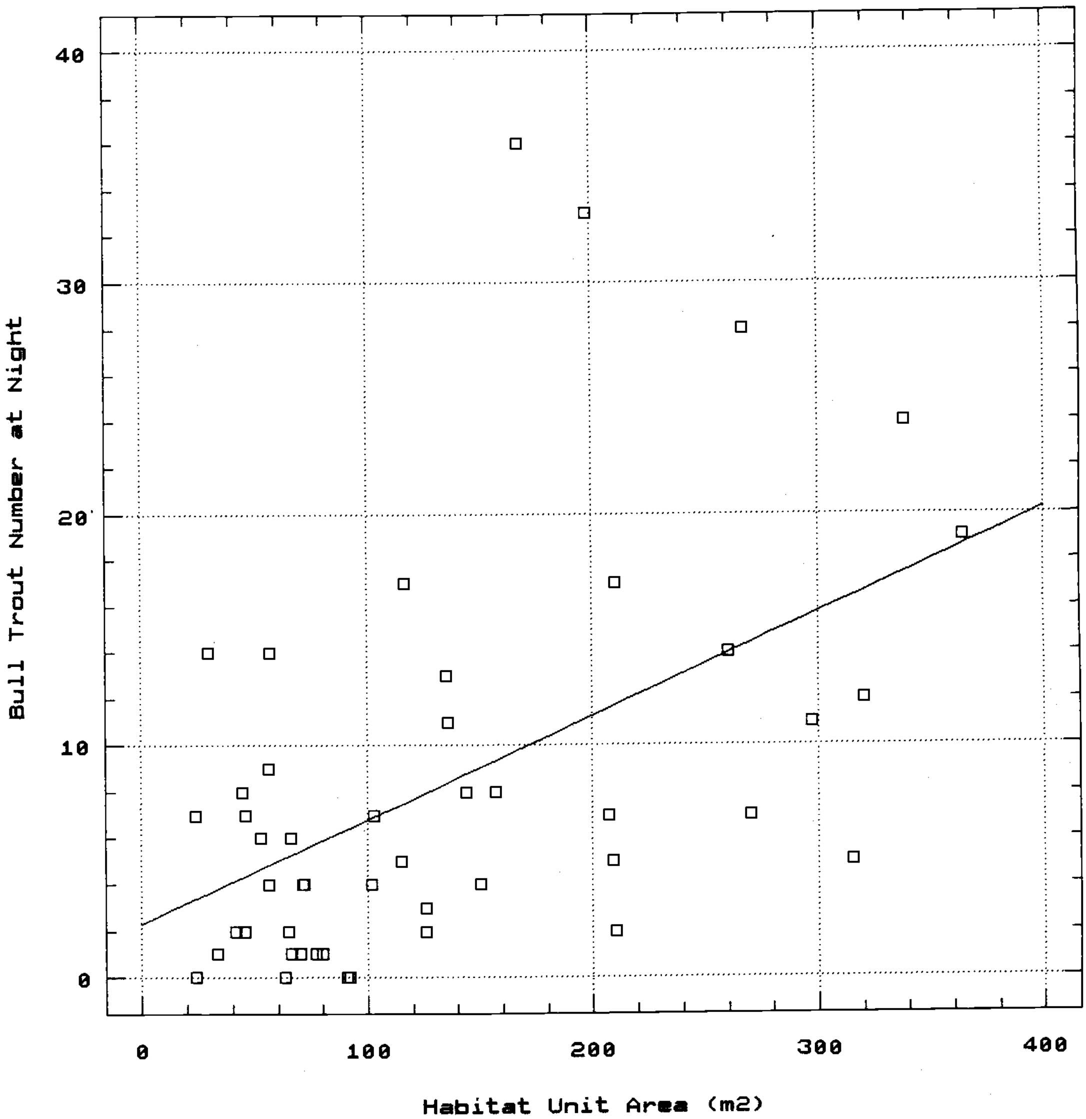


Figure 19. Relation of bull trout numbers at night and habitat unit area (n=48) for Metolius River tributaries surveyed in 1989 and 1990. Regression equation is $y=2.31 + 0.05x$ ($r^2=0.25$).

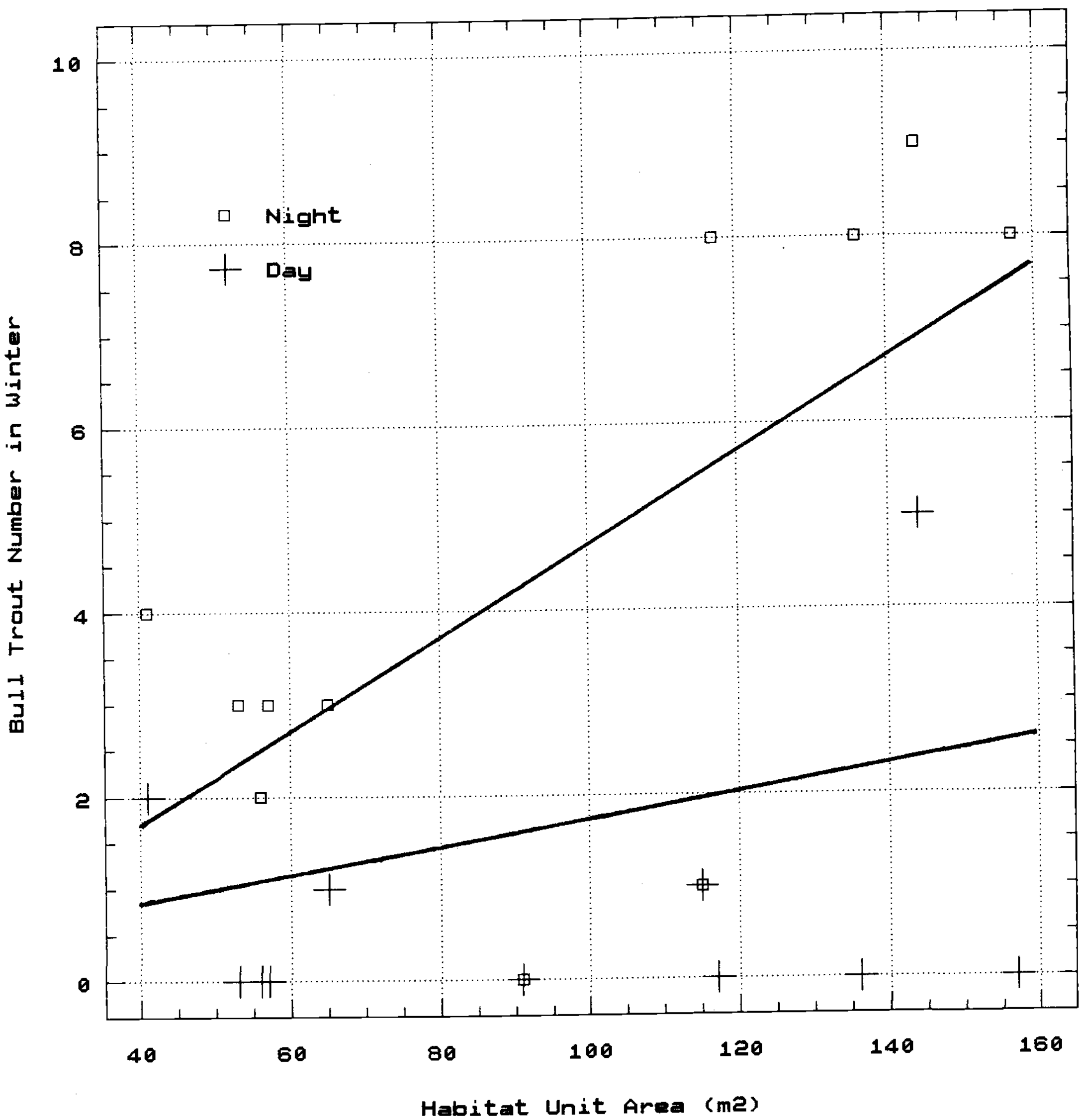


Figure 20. Relation of bull trout number counted during the day and night on habitat unit area (n=11) for Jack Creek during late fall 1989 (water temperature=3.0 C). Regression equation for number at night and habitat area is $y=-0.38 + 0.05x$ ($r^2=0.45$). Regression equation for number during the day and habitat area is $y=0.07 + 0.01x$ ($r^2=0.05$).

correlation regressing bull trout numbers during the day on area of glide habitat unit for any basin.

There was a significant correlation between bull trout numbers at night and area of pool habitat unit in (1) all streams ($r=0.51$, $t=3.11$, $df=28$, $P<0.01$) and (2) Metolius River tributaries ($r=0.61$, $t=3.00$, $df=16$, $P<0.01$). Removal of the three smallest units in the Metolius River regression increased the correlation from $r=0.61$ to $r=0.88$ ($t=6.41$, $df=13$, $P<0.001$). The two units with the highest density estimates are complex units: one pool unit on Canyon Creek was a series of dammed pools (from large woody debris), and the second pool unit on Jack Creek was a series of subunits (riffle, pool, dammed pool).

There was a significant correlation between bull trout numbers at night and area of side channel unit in (1) all streams ($r=0.62$, $t=2.61$, $df=12$, $P<0.05$) and (2) Metolius River tributaries ($r=0.83$, $t=3.34$, $df=6$, $P<0.05$).

In summary, there was a general increase in bull trout numbers at night, with increasing habitat unit area for all streams and Metolius River tributaries. There was no trend of bull trout numbers increasing or decreasing during the day with increasing habitat unit area. By habitat unit type, the same pattern of increasing bull trout numbers at night with increasing habitat area occurred in glides, pools, and side channels for all streams and Metolius River tributaries. No pattern was found in riffles day or night.

Habitat Unit Electivity. Bull trout used all habitat types, but elected to use only side channels in (1) all streams ($E_i*=0.26$ for day, $E_i*=0.37$ for night) and (2) all Metolius River tributaries ($E_i*=0.24$ for day, $E_i*=0.35$ for night). In Gold Creek, bull trout elected to use glides and pools during the day and pools and side channels at night (Fig. 21). In Trapper Creek, pools (*Ei**=0.32) and side channels (*Ei**=0.26) were elected at night. Except for Jack Creek, bull trout avoided riffles during the day and night in all basins, and avoided glides at night in all basins.

There were seasonal differences in habitat types elected by bull trout in Jack Creek. All habitat types were used in every season either day or night, but only pools were elected in every season. Glides were elected during the day in winter and at night in winter and spring. Riffles were avoided or used randomly in every season. Side channels were elected only in late fall during the day (Fig. 22). The side channel units were about 150 m downstream of a road culvert. There was little riparian cover or woody debris next to or within these two units.

Summer Microhabitat Electivity

Total Depth. Bull trout used most available total depths up to 125 cm with a peak in use at 25-50 cm depth both day and night (Fig. 23). Within the range used, most total depths were elected except the 50-75 cm depth (Fig. 24). There was a much higher electivity of the 75-100 cm depth during the day (*Ei**=0.39) than at night (*Ei**=0.031). The 50-75 cm depth was avoided during the day (*Ei**=-0.31) and at night (*Ei**=-0.20), and no bull trout were observed in depths greater than 125 cm.

Juvenile bull trout electivity of shallow water (0-25 cm) differed day and night. The shallow water depth (0-25 cm) was elected by all bull trout both day and night, but only during the night by juveniles

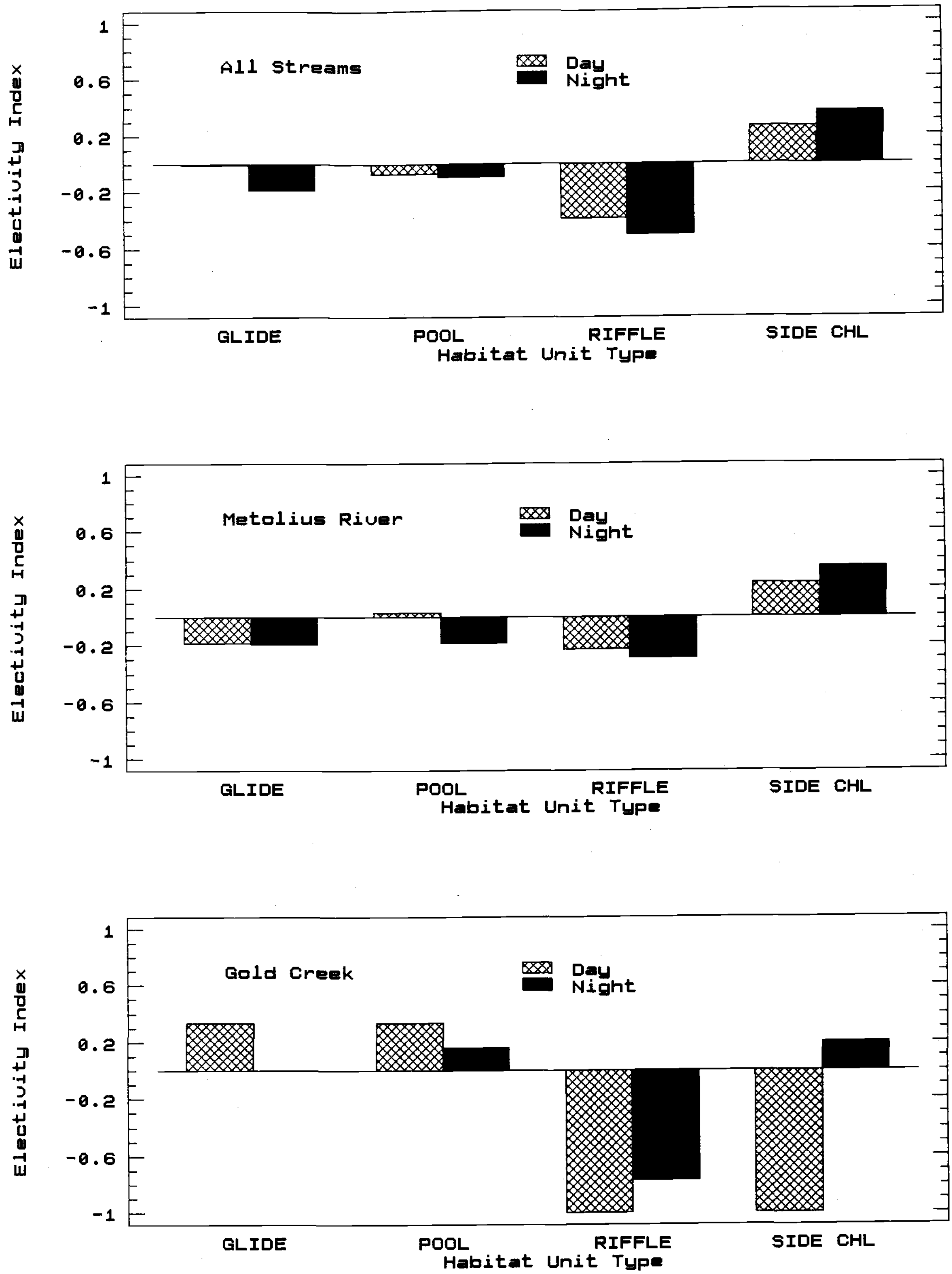


Figure 21. Electivity index (Vanderploeg and Scavia 1979) for habitat unit type (Side Chl=Side Channel) selected by bull trout in (1) all streams (n=85) (top figure), (2) Metolius River tributaries (n=48) (middle figure), and (3) Gold Creek (n=17) (bottom figure) during day and night. Positive values indicate selection of a habitat type; negative values indicate avoidance.

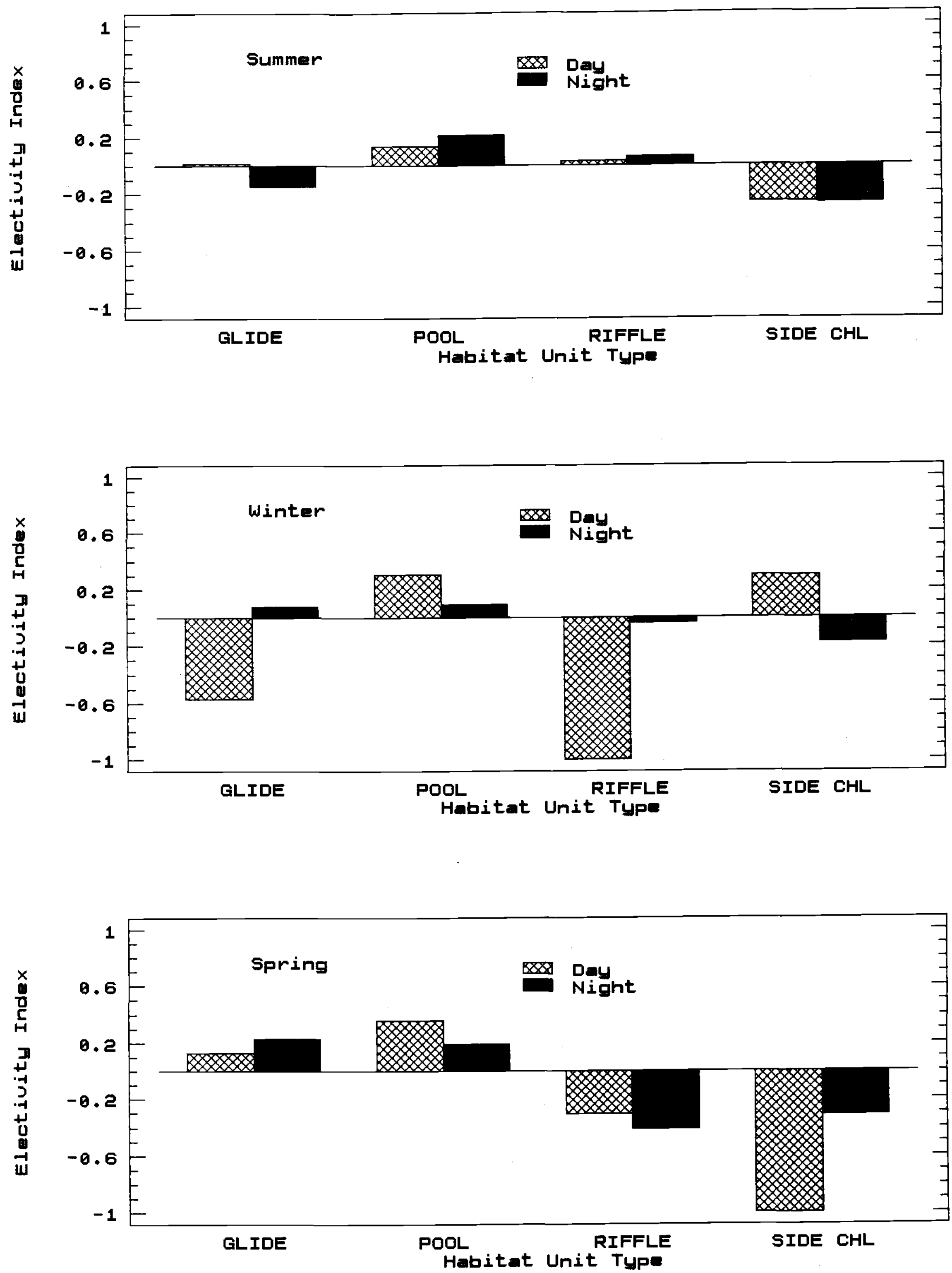
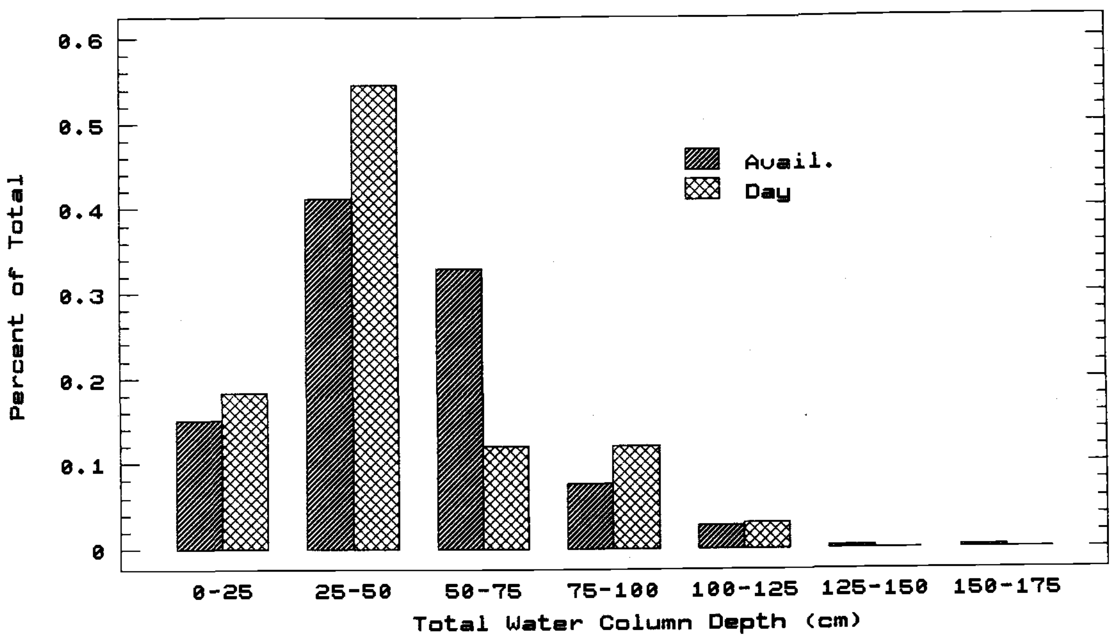


Figure 22. Electivity index (Vanderploeg and Scavia 1979) for habitat unit type (Side Chl=Side Channel) (n=11) selected by bull trout in Jack Creek in (1) summer (top figure), (2) late fall (middle figure), and (3) spring (bottom figure) during day and night. Positive values indicate selection for a habitat type, negative values indicate avoidance.



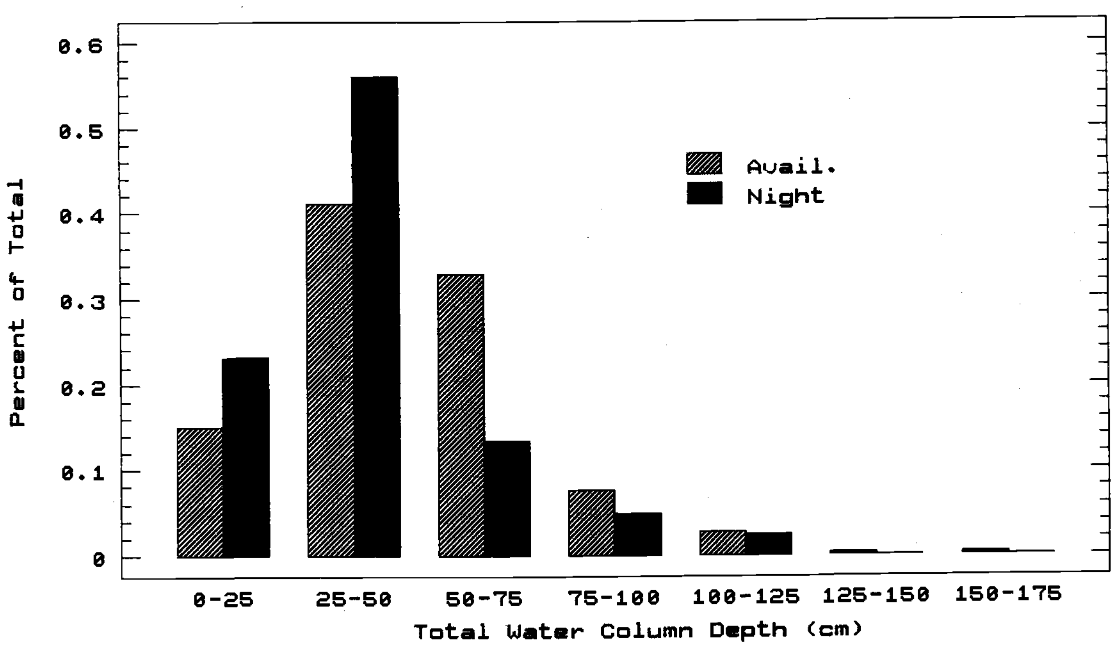


Figure 23. Total water column depths (in cm) used by bull trout (top figure=day, n=35; and bottom figure=night, n=82) and depths available (Avail.=Available, n=331) in the five microhabitat sites in Jack Creek during summer 1989.

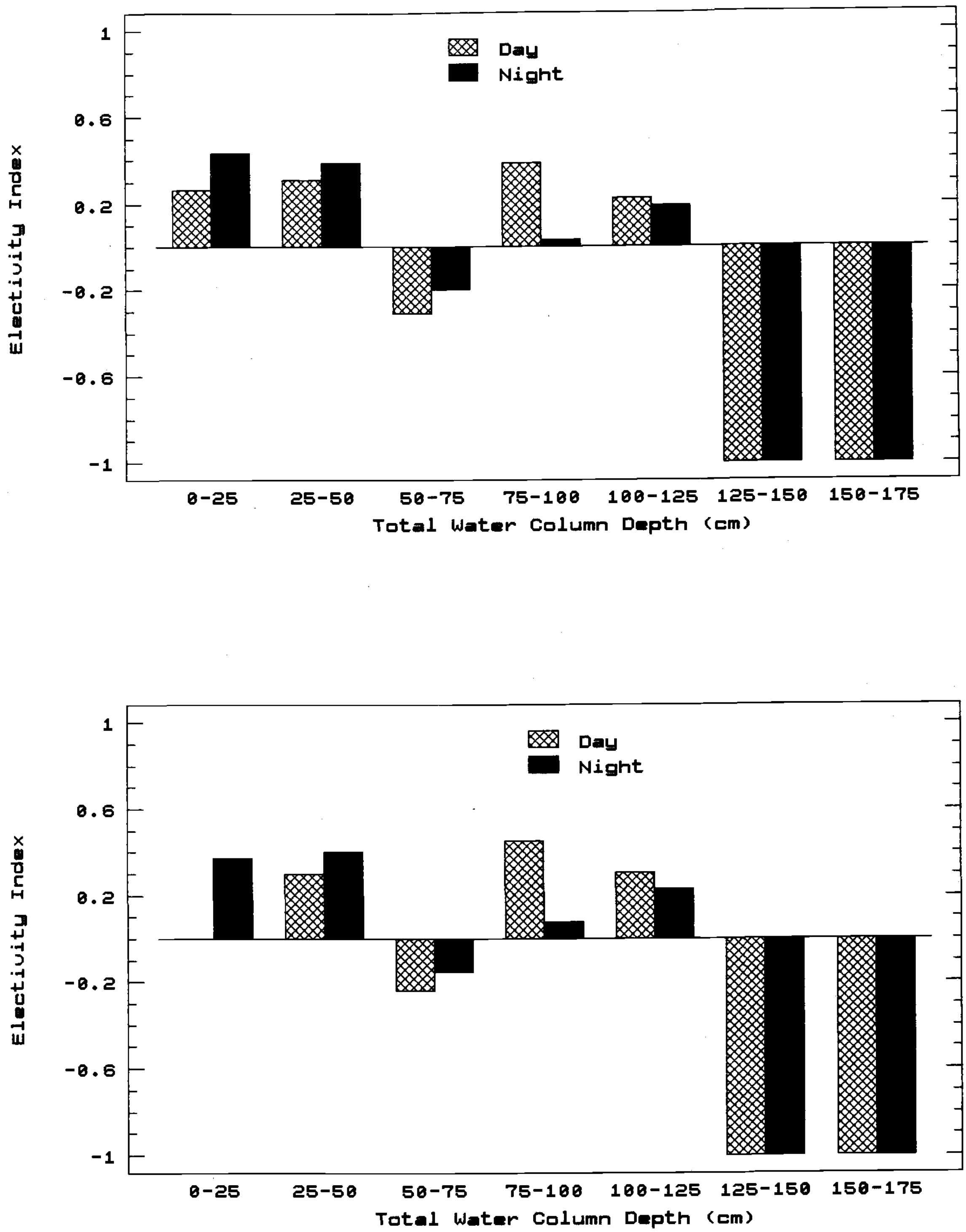


Figure 24. Electivity index (Vanderploeg and Scavia 1979) for total water column depth (in cm) selected by (1) bull trout (top figure) and (2) juvenile bull trout (bottom figure) in five microhabitat sites in Jack Creek during summer 1989. Positive values indicate selection for a depth stratum; negative values indicate avoidance.

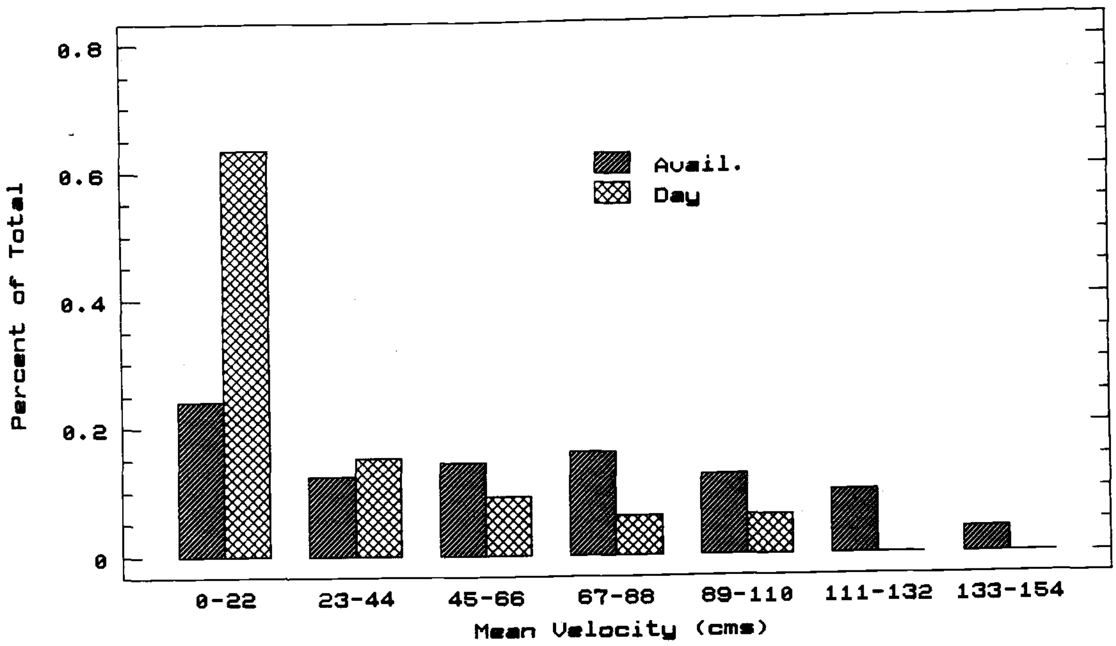
(Fig. 24). Fry were observed in these shallow water areas during the day.

Mean Velocity. Bull trout used a wider range of available mean velocities during the day than at night (Fig. 25). During the day, juveniles were observed in faster water, feeding from benthos and the drift. Bull trout elected to use the three lowest velocity classes during the day (0-22 cms, E_i*=0.66; 23-44 cms, E_i*=0.39; 45-66 cms, E_i*=0.10). At night, bull trout were found in lower velocity water and only elected the two lowest velocity classes (0-22 cms, E_i*=0.74; 23-44 cms, E_i*=0.45).

Cover Type. Bull trout used five of eight available cover types during the day and six of eight types at night (Fig. 26). Depth and turbulence were not used day or night. All three sizes of woody debris were elected during the day (CWD, E_i*=0.52; LWD, E_i*=0.39; FWD, E_i*=0.09), while woody debris (LWD, E_i*=0.38; FWD, E_i*=0.16; CWD, E_i*=0.10) and undercut banks (E_i*=0.40) were elected at night. In undercut banks at night, juveniles were found resting or holding in low velocity pocket pools.

Substrate. Bull trout used all substrate types during the day and the two smallest types at night (Fig. 27). Sand was elected both day (E_i*=0.36) and night (E_i*=0.57), and cobble was elected during the day (E_i*=0.19). Juveniles were observed feeding during the day in faster water over cobble substrate. The diel electivity of sand corresponds to the low velocity water in which bull trout were found.

Embeddedness. Bull trout used four of five embeddedness categories during the day and at night, although most fish were found in highly embedded areas (81-100% class) (Fig. 28). The highest



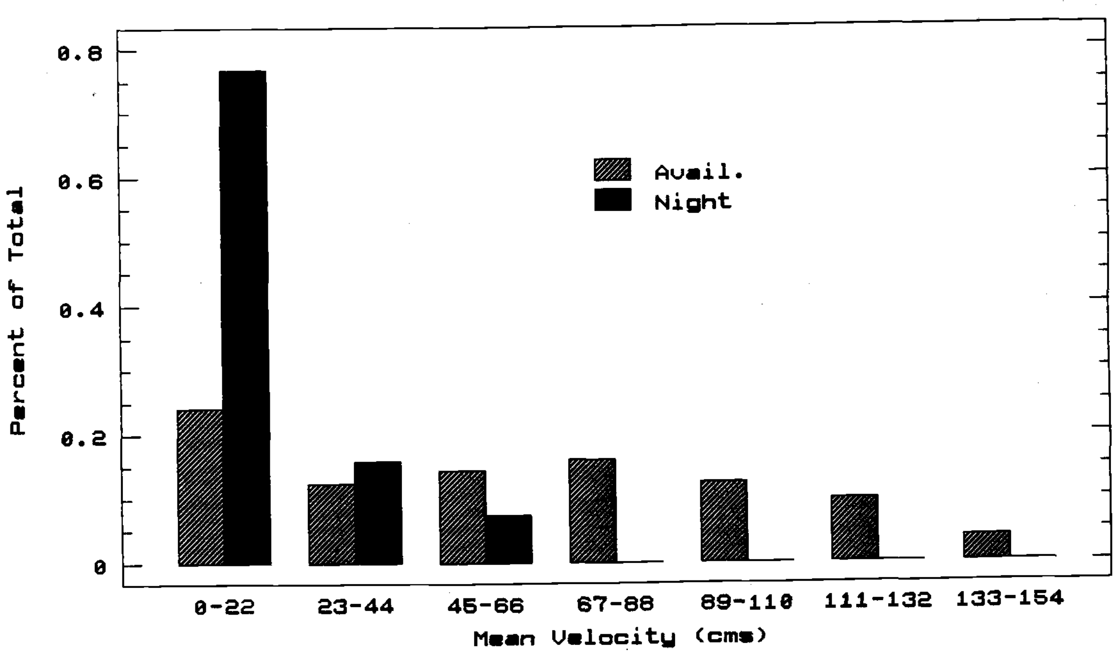
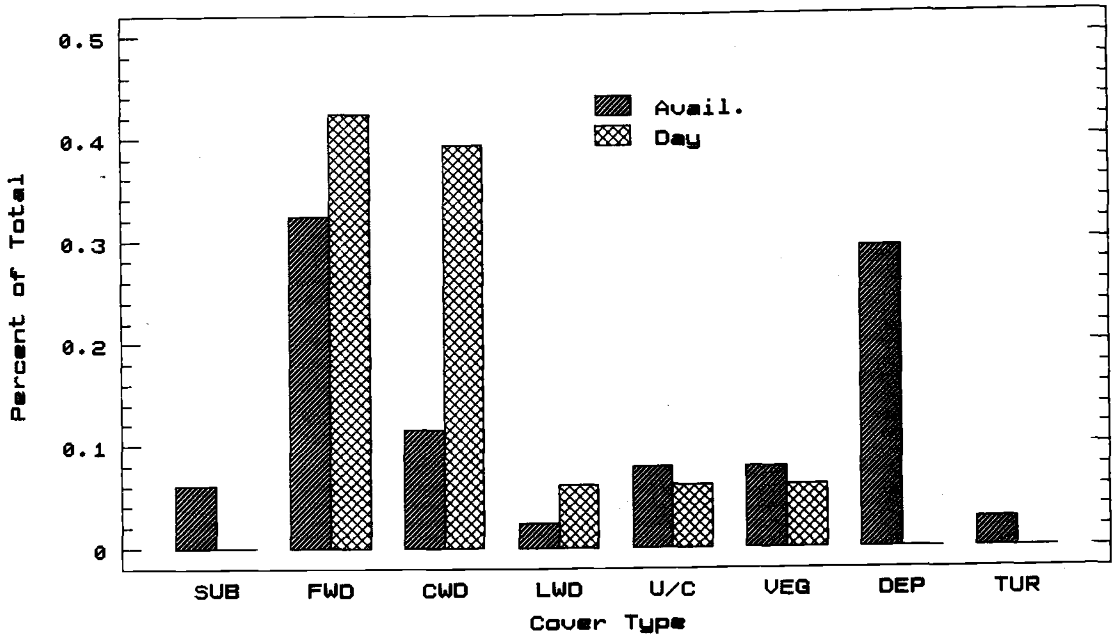


Figure 25. Mean velocities (in cm per second) used by bull trout (top figure=day, n=35; and bottom figure=night, n=82) and velocities available (Avail=Available, n=331) in the five microhabitat sites in Jack Creek during summer 1989.



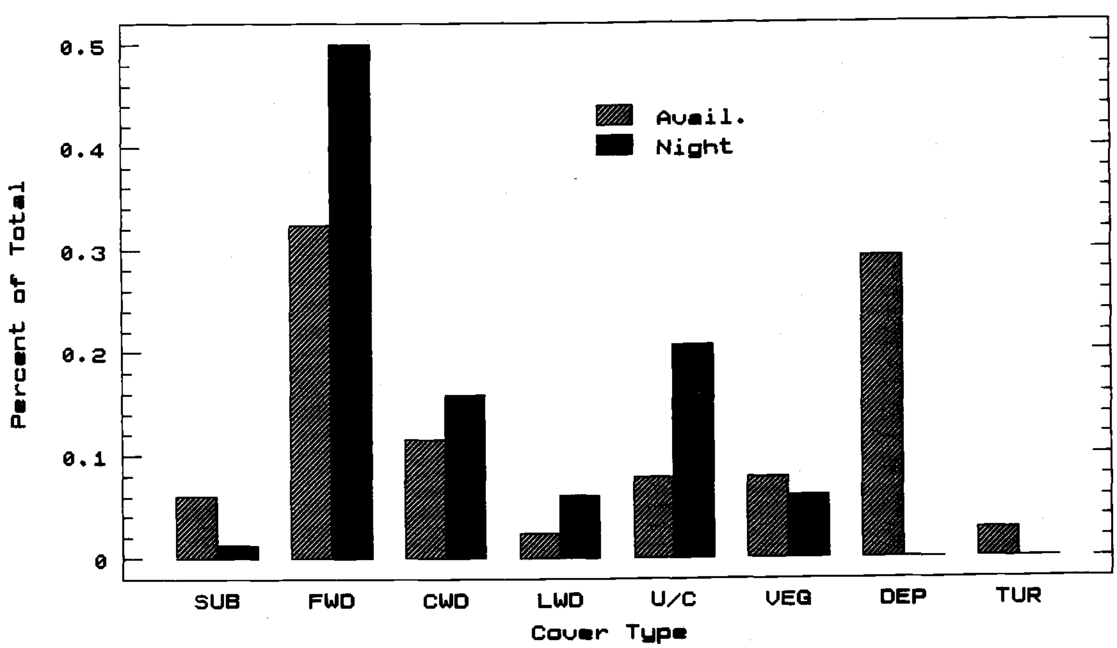
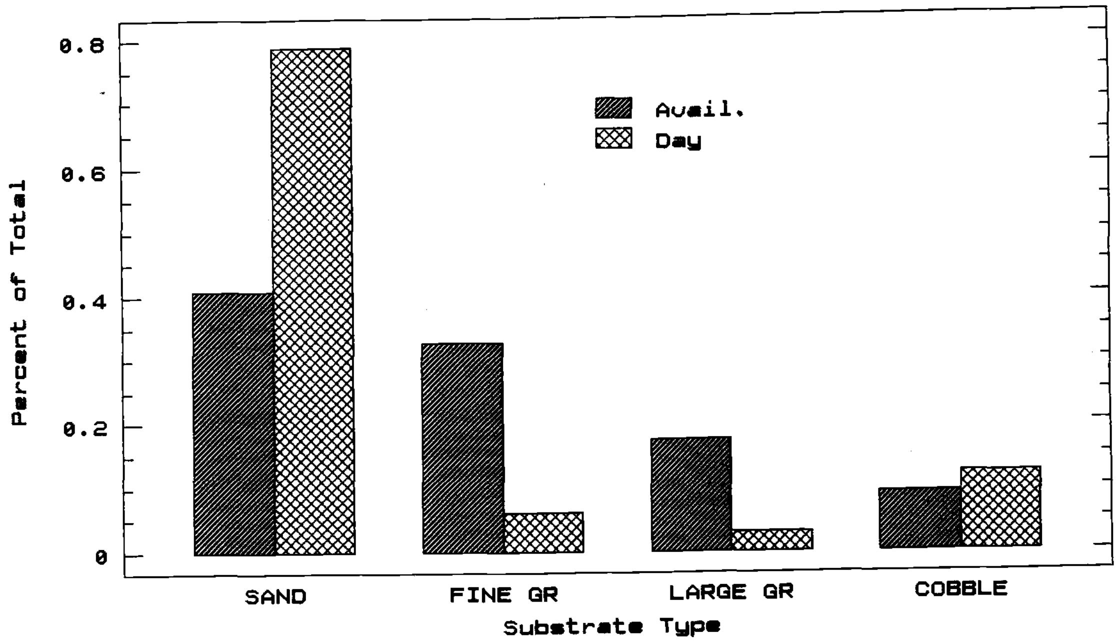


Figure 26. Cover used by bull trout (top figure=day, n=35; and bottom figure=night, n=82) and cover available (Avail.=Available, n=331) in the five microhabitat sites in Jack Creek during summer 1989. SUB=Substrate; FWD=Fine Woody Debris; CWD=Coarse Woody Debris; LWD=Large Woody Debris; U/C=Undercut Banks; VEG=Vegetation; DEP=Water Depth; TUR=Turbulence.



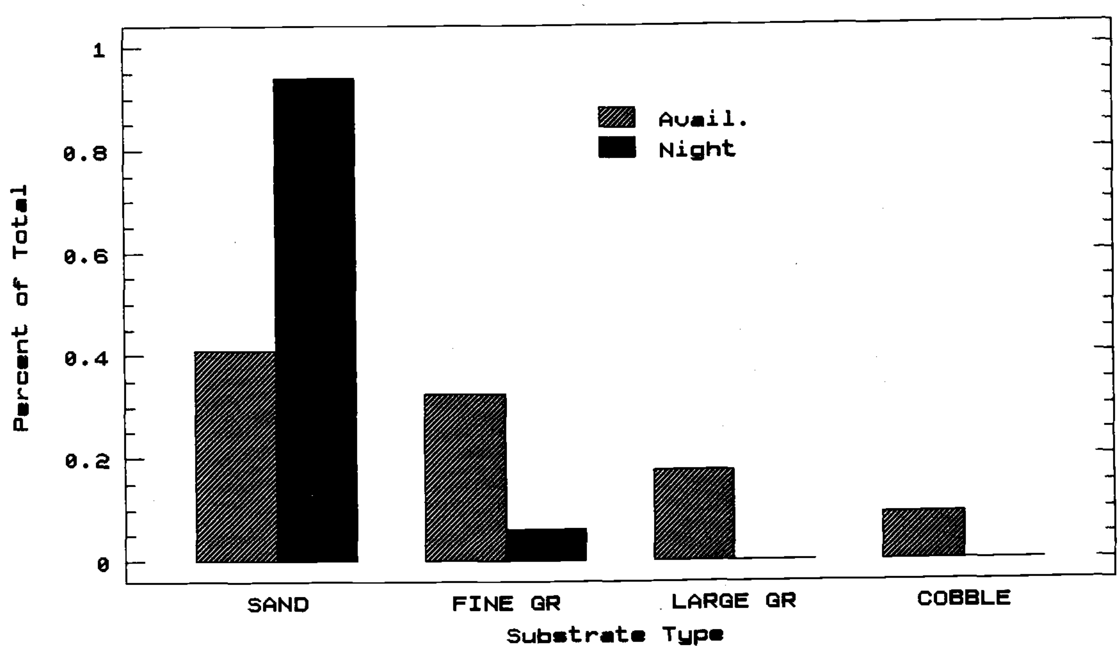
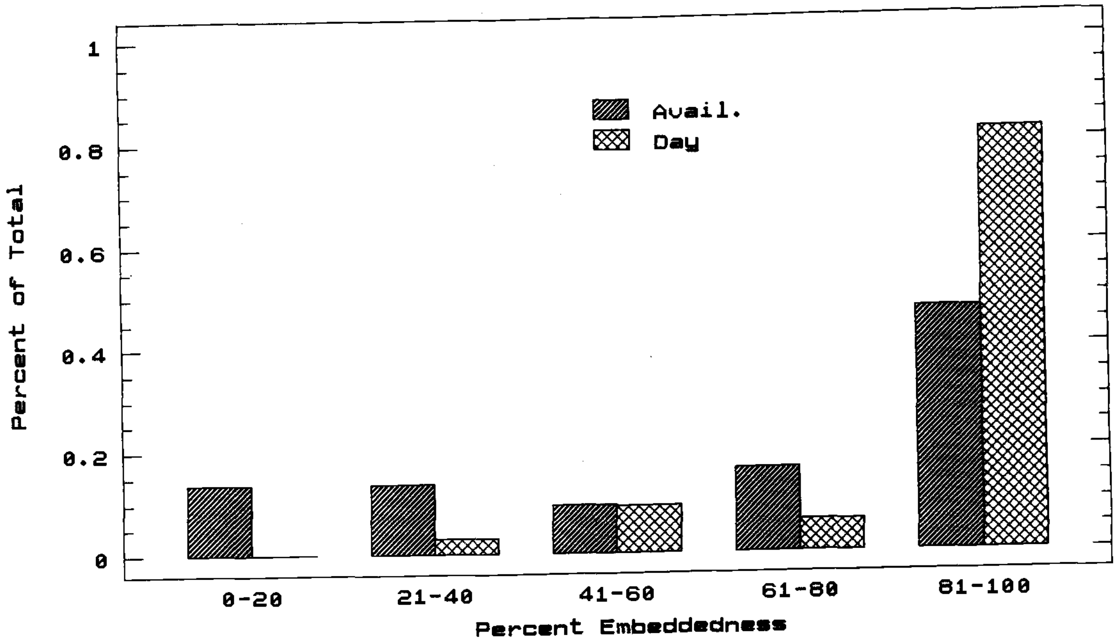


Figure 27. Substrate used by bull trout (top figure=day, n=35; and bottom figure=night, n=82) and substrate available (Avail.=Available, n=331) in the five microhabitat sites in Jack Creek during summer 1989.



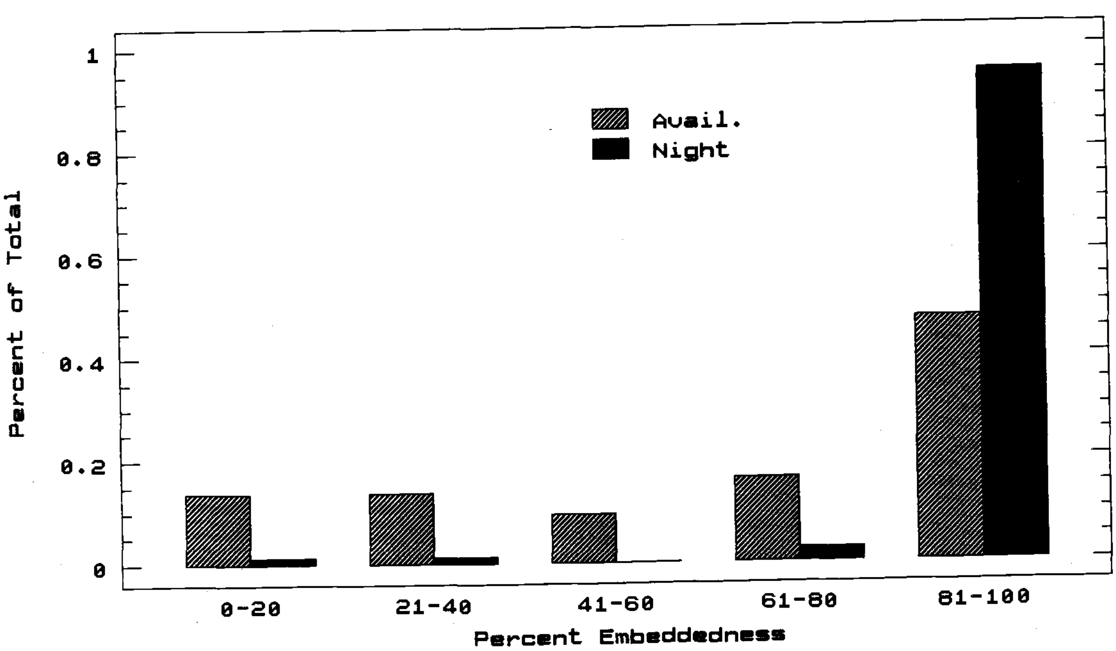


Figure 28. Embeddedness (in percent) used by bull trout (top figure=day, n=35; and bottom figure=night, n=82) and embeddedness available (n=331) in the five microhabitat sites in Jack Creek during summer 1989.

embeddedness category was elected during the day (E_i*=0.45) and at night (E_i*=0.62).

Diel and Seasonal Microhabitat Use

The total sample sizes showed a large variation in numbers of fish counted by day and night. Counts were much lower during the day, averaging 18-43% of seasonal night counts for fish. By season, total counts for winter and spring averaged about 50% of total counts in summer. The lowest count was during the day in winter, and the highest during the night in summer (Table 12). In winter, the only fish found during the day were buried deep under cover.

Table 12. Number of bull trout observed by day and night snorkeling during the diel and seasonal microhabitat use study on Jack Creek.

Season	Total[a] Day	Total Night	Juvenile Day	Juvenile Night
Summer	35	82	27	76
Winter	9	49	6	41
Spring	17	40	11	32

a. Total=fry and juvenile bull trout.

There were significant differences between diel site density estimates for fish during summer (day mean=0.032/m^2, night mean=0.071) (t=-2.78, df=8, P<0.05) and winter (day mean=0.001, night mean=0.043) (t=-3.76, df=8, P<0.001). There were significant differences between diel site density estimates for juveniles during summer (day mean=0.026, night mean=0.66) (t=-2.88, df=8, P<0.05) and winter (day mean=0.004, night mean=0.036) (t=-5.30, df=8, P<0.001).

Total Depth

Seasonal Differences. There was no significant difference between summer and winter, and summer and spring total depth measurements for bull trout observed during the day in the five sites. There was a significant difference between summer (mean=40.34 cm) and winter night (mean=48.9) total depth measurements (Table 13). At night, bull trout were found at deeper depths during the winter than the summer.

Table 13. Seasonal diel microhabitat use at five sites on Jack Creek for observed bull trout. Mean values and standard error is listed for depth, focal point elevation, focal point velocity, mean velocity, and DTNC.

Variable	Summer Day (n=33)	Summer Night (n=82)	Winter Day (n=9)	Winter Night (n=49)	Spring Day (n=17)	Spring Night (n=40)
Depth (cm)	47.7 ± 4.4	20.7 ± 4.1	57.8 ± 11.2	48.9 ± 2.9	51.9 ± 6.8	43.3 ± 3.2
Focal Elevation (cm)	4.85 ± 2.4	0.45 + 0.3	0.9 ± 0.5	1.4 ± 0.5	7.8 ± 2.4	1.4 ± 0.3
Mean Velocity (cms)	10.0 ± 2.3	3.8 ± 2.5	7.4 ± 3.8	6.2 ± 1.5	21.3 ± 8.6	8.2 ± 2.34
DTNC (cm)	21.0 ± 5.0	35.6 ± 3.4	0.0	23.6 ± 5.0	1.8 ± 0.8	21.8 ± 5.5
Embeddedness (%)	93	100	71	92	91	85
Substrate (% Occurrence)						
Sand	78	100	67	80	12	75
Fine Gravel	6	0	33	14	88	0
Large Gravel	3	0	0	2	0	15
Cobble	12	0	0	4	0	10
Cover Forms (% Occurrence)						
Vegetation	6	6	11	2	0	3
Fine Woody Debris	42	50	11	31	41	30
Coarse Woody Debris	39	16	22	14	18	10
Large Woody Debris	6	6	11	27	29	30
Substrate	0	1	0	4	0	0
Undercut Bank	6	21	44	22	12	27.5

Focal Elevation.

Seasonal Differences. There was a significant difference (P<0.05, K-S test) between (1) summer (mean=4.85 cm) and winter (mean=0.89) day, and (2) summer and spring (mean=1.4) day focal elevation measurements for fish. There was a significant difference (P<0.001, K-S test) between (1) summer (mean=0.45) and winter (mean=1.43) night and (2) summer and spring (mean=1.4) night focal elevation measurements for fish (Table 13). Fish were found significantly closer to the substrate during both day and night in summer than in winter and spring.

Diel Differences. There was a significant difference (P<0.001, K-S test) between (1) summer day (mean=4.85 cm) and night (mean=0.45), (2) winter day (mean=7.82) and night (mean=1.4), and (3) spring day (mean=7.82) and night (mean=1.4) focal elevations for fish (Table 13). At night, most fish were observed resting directly on the bottom.

Velocity

Seasonal Differences. There was no significant difference between any season and mean velocity estimates for the day. There was a significant difference (P<0.05, K-S test) at night between (1) summer (mean=5.45 cms) and winter (mean=6.20) and (2) summer and spring (mean=8.18) mean velocities. Fish were found at significantly faster mean water velocities at night in winter and spring than in summer (Table 13).

Diel Differences. There was a significant diel difference (P<0.05. K-S test) between day and night mean velocity measurements during all seasons. During summer, mean water column velocity was 1.85 times greater for day observations than at night. Fish were found at lower velocities at night for all seasons, either in small backwater areas, or behind large velocity obstructions (Table 13).

Cover

Seasonal and Diel Differences. There was a significant difference between the cover type used by season during day and at night (P<0.001, P-D test). The cover type used most frequently during the day by all fish was the combined categories of woody debris (fine, coarse, and large). This combined category accounted for 54-88% of cover types used during the day for all seasons. Undercut banks was the second most-used type during the day in winter (44%) and spring (12%). Woody debris was also used most frequently at night for all seasons (70-72%). Undercut banks was the second most-used type at night for all seasons (21-27.5%) (Table 13). There were no significant differences between cover type used during the day and night for any season (P<0.27, P-D test).

Distance to Nearest Cover (DTNC)

Seasonal Differences. There was a significant difference between (1) the summer (mean=21.0 cm) and winter (mean=0.0 cm) (t=0.58, P<0.05) day DTNC and (2) summer and spring (mean=1.82) (t=0.46, P<0.05) day DTNC for bull trout. Fish were directly within or immediately adjacent to cover during the day for winter and spring. There was a highly significant difference between (1) the summer (mean=35.6) and winter (mean=23.6) (t=0.89, P<0.001) night DTNC and (2) summer and spring (21.8) (t=0.38, P<0.001) night DTNC. Bull trout were found further from cover during summer evenings than in winter or spring (Table 13).

Diel Differences. There was a significant difference between DTNC measurements for bull trout for (1) summer day (mean=21.0 cm) and summer night (mean=35.6)(t=0.42, P<0.001), (2) winter day (mean=0.0) and winter night (mean=23.6)(t=1.0, P<0.001), and (3) spring day (mean=1.82) and spring night (mean=21.8)(t=0.71, P<0.001). Fish were always found closer to cover during the day than those found at night.

Substrate

Seasonal and Diel Differences. There was a significant difference between substrate type used by season during the day and at night (P<0.001, P-D test). Sand was the substrate used most frequently by bull trout during the day (67-88%) and at night (75-100%) for all seasons (Table 13). The lowest percentage use for sand was in winter during the day (67%). All fish found during this period were under dense cover. There was also a highly significant difference between substrate used during the day and at night (P<0.001, P-D test).

Embeddedness

Seasonal and Diel Differences. Percent embeddedness for bull trout was greater than 71% for every season, day or night. The highest value was summer night (100%) while the winter day (71%) was the lowest (Table 13). In winter during the day, all fish were found under dense cover.

Diel Activity

Seasonal and Diel Microhabitat. In summer, almost all fish observed at night were resting directly on the substrate. When conspecifics were present, they were often found within 10-15 cm of each other. In winter during the day, all fish were under cover. At night, 86% of juveniles were holding just above or resting on the bottom, 10% were actively swimming and 4% were feeding.

In spring during the day, juveniles were found actively swimming and feeding (18%). At night in spring, 63% of juveniles were resting on the substrate, 16% were feeding, 16% were holding, and 6% were actively swimming.

DISCUSSION

Macrohabitat Use

Bull trout electivity of habitat unit types appears to vary by drainage basin and season. In summer, juvenile and adult resident bull trout elected to use pools in spring-fed Sun Creek, Oregon (Dambacher et al. 1992), and juvenile density estimates were highest in pools for tributaries of Flathead Lake, Montana (Fraley and Shepard 1989). I found juveniles electing to use side channels in all basins during the summer (Fig. 21). Pools were elected in Gold and Trapper Creeks in summer and in Jack Creek for all seasons (Fig. 22). Riffles were avoided in all basins in summer and were avoided or randomly elected during all seasons in Jack Creek.

Influence of Low Water Temperatures

Although winter hiding behavior during the day has been documented for other salmonids, this study is the first in which seasonal habitat use has been documented day and night (1) for bull trout and (2) for a spring-fed stream. My data suggest that bull trout use of habitat units is related to cold water temperatures (mean=7.7°C, Table 2) of the spring-fed streams in which bull trout are found (Chapter 3).

Bull trout displayed behavior typical of salmonids found in non-spring-fed streams at low temperatures (< 8.0°C) in winter (Everest et al. 1986; Hillman et al. 1987; Griffith and Smith 1993). They hid under cover during the day and emerged at night. In Jack Creek at night, they were found further from cover, primarily in low velocity areas, and in close association with conspecifics (microhabitat section). This diel behavior resulted in higher rates of occurrence and density estimates by habitat unit at night than for day in all basins (Figs. 14-18).

The seasonal differences in habitat type electivity found in Jack Creek are similar to the changes observed for other salmonids at low water temperatures. Brook trout and brown trout use pools and slow areas of glides at night during the winter (<6°C) and appear to avoid riffles, which are typically used during summer feeding (Cunjak and Power 1986). In Jack Creek, summer was the only period where riffles were not avoided while pools were elected throughout the year (Fig. 22).

Griffith and Smith (1993) believed juvenile salmonids at low temperatures hide during the day and only emerge from "concealment cover" at night every second or third night to minimize their metabolic expenditures. Presumably, many of the bull trout in my study streams hid under "concealment cover" within the units during the day and emerged at night. For instance, after systematically lifting available substrate in an isolated pool in Gold Creek, I found a single juvenile under cobble substrate during the day. That night, I found 13 juveniles resting on the substrate.

<u>Influence of Light Levels</u>

Emergence timing at night and daytime hiding of bull trout may also be related to light levels (Chapter 1). Contor (1989) found rainbow trout in Idaho streams emerging 30-60 minutes after sunset during winter. This emergence timing at dusk is very similar to my results from the diel study in Jack and Trapper Creeks (Chapter 1). Day hiding behavior of Arctic char in northern latitudes (50-60 N) during summer and other seasons has been related to high light intensity (Adams et al. 1988). Linner et al. (1990) believed this hiding behavior is a natural adaptation of char to the several months of darkness found at these high latitudes. Bull trout may show a similar adaptation to low light intensities with associated high light avoidance. Bull trout at northern latitudes in Washington state (47° 30' N) have been found to avoid shallow depths during moonlit nights (Wyman 1975).

Relationship of Habitat Unit Area and Bull Trout Numbers

Pratt (1984) found that bull trout numbers increased with habitat unit area during the day in larger riffle-run habitat units (>200 m^2) for large streams in Idaho. I found no significant relationship between bull trout number and habitat unit area during the day, but did find a significant correlation between increasing numbers with increasing habitat unit area at night (Fig. 19). This relationship occurred in slower water units -- glides, pools, and side channels.

Increasing habitat area in glides, pools, and side channels may, therefore, be an important method of increasing bull trout numbers. Use of woody debris may be appropriate for streams in Oregon and Washington since bull trout may elect to use this habitat type (microhabitat section). Woody debris can improve habitat by creating more pools, side channels, low velocity pockets, visual isolation, and overall habitat complexity (Dolloff 1983; Lisle 1986; Sullivan et al. 1987).

Dolloff (1986) found much lower Dolly Varden numbers when woody debris was removed from a stream. Bull trout numbers increased markedly in a stream section of Anderson Creek after instream woody debris was added (J. Capurso, U.S. Forest Service unpublished data, McKenzie Bridge, Oregon 1993). I found the highest density estimates of bull trout in larger, complex habitat units. The highest pool and side channel density estimates occurred in complex units that had a large amount of woody debris cover. Pratt (1984) believed that higher numbers of bull trout in larger units was due to increased habitat complexity.

Influence of Methods on Evaluating Habitat Use

The type of sampling method can also influence the evaluation of habitat use (Heggenes et al. 1991). Side channel density estimates were highest for all habitat types in this study (Fig. 18); however, these densities still appear to be low in relation to the side channel density estimates computed by electrofishing (Chapter 1). These low density estimates can be attributed to the types of units surveyed by electrofishing and snorkeling. Most of the side channel units electrofished in Jack Creek were very shallow, small glides filled with fine sediments. This type of unit could not be sampled effectively by snorkeling. The side-channel units surveyed by divers were more apt to resemble main-channel units, being larger, faster and deeper than those electrofished.

The time period, as well as the method of observation, is also important. Other underwater studies of bull trout have reported daytime habitat use and noted the difficulty in observing juveniles (Pratt 1984; Fraley and Shepard 1989). The coldwater temperatures in my study streams appear to induce daytime hiding which necessitated using night snorkeling as the primary observation method. Using this method, more fish were counted than during the day, and distinct differences in macrohabitat and microhabitat electivity were noted.

Just as the sampling or observation method can bias habitat evaluation, so can measurement of habitat variables. The upper temperature-range bull trout were found at (11-14°C) in nonspring-fed areas (upper Canyon and Gold Creeks, Chapter 2) could be inaccurate. Water temperatures were recorded at the stream surface, while bull trout were found at the stream bottom. In areas of low water flow and high insolation, maximum summer surface water temperatures may be warmer than benthic water temperatures actually used by bull trout. In an Idaho stream meadow, the benthic water temperature of a 1.2 m deep pool where bull trout were found was 2.5°C colder (17.5°C) than the surface water temperature (20°C) (Adams and Bjornn, in press). Therefore, benthic, focal point measurements of water temperature might more accurately define the maximum summer temperatures used by bull trout in areas with low flow and high insolation.

Microhabitat Use

Bull trout elected to use a specific range of available summer habitat in Jack Creek. There was a strong electivity for shallow water depth, low velocity, instream woody debris cover, and small substrates for day and night. The electivity of these habitats was even more pronounced at night. Bull trout were found resting on sandy substrates, out of cover, and in close association with conspecifics.

There was temporal partitioning of the shallowest, low velocity habitat by different age groups during the day and night. Fry were observed actively feeding in side channels and nearshore habitat during the day (diel study, Chapter 1). Juveniles elected to use only the shallowest water depths at night (Fig. 24), where they were found resting on the substrate.

The habitat electivity of different age classes appears to be heavily influenced by intraspecific competition and avoidance of predation by younger individuals. Because bull trout are often the only fish inhabiting small headwater streams, they frequently prey on members of their own species (Aquatico Environmental Consultants 1976; Cavender 1978; Armstrong and Morrow 1980). Juveniles greater than 100 mm are primarily piscivorous (Shepard et al. 1984a). Johnson (1980) and Brenner (1980) suggest that intense intraspecific competition for food exists in allopatric Arctic char populations between larger and smaller individuals, resulting in cannibalism. Horner (1978) observed small adult bull trout actively digging in substrate to capture or chase young cutthroat trout hiding under cover. In this study, bull trout juveniles ate fry when held in the same bucket, and one captured-juvenile had a fry already in its stomach.

Bull trout most often elected to use woody debris both day and night, and also elected undercut banks at night. The visual isolation provided by this instream (woody debris) or overhead (undercut banks) cover may be necessary for juvenile bull trout to avoid intraspecific competition during the day (Pratt 1984). Instream cover can increase visual isolation for juvenile Dolly Varden, and removal of instream woody debris can greatly reduce stream densities of juvenile Dolly Varden (Dolloff 1986). In coastal streams of Alaska, Dolly Varden juveniles are almost always found under cover during the day (Dolloff 1983). At night, darkness may provide the necessary visual isolation and could be considered another cover type (Cunjak and Power 1986).

The type of substrate available and the amount of embeddedness could be influencing juvenile substrate use in Jack Creek and other Cascade Mountain streams. Unlike areas of Idaho and Montana, where dominant substrates are often rubble to boulder-size, available substrates in Cascade Mountain streams were most often gravel to cobble-size (Table 2). This substrate size range could be too small for larger juveniles to use. Heggenes (1988) believed substrate as a cover type is important for salmonids only when fish can use the interstitial areas. At low temperatures silted substrate is considered unusable (Bjornn 1971).

In Jack Creek, bull trout were found most frequently over sand or smaller-sized substrate and in highly embedded areas (Fig. 27 and 28). In the Cascade Mountains, the constant flow of the spring-fed streams where bull trout are found may be contributing to buildup of fine material. Unlike run-off or snow-melt streams that can flush fine sediments, the nearly uniform flow of these spring-fed streams may increase accumulations of fine sediments (Jackson and Beschta 1982). This buildup of fines may ultimately lead to declines in bull trout abundance or extirpation from specific areas (Fraley and Shepard 1989). For example, the streambed of Crystal Creek, an historical bull trout stream in Odell Lake (Appendix), was covered by a 2-8 cm layer of fine material. During this study, no bull trout were found in Crystal Creek (Fig. 31), and numbers of spawning kokanee appeared considerably lower than those in nearby Trapper Creek.

In summary, this is a first look at habitat use for a rare and "elusive" fish. The habitat types are unique (spring-fed), but the habitat used and diel behavior observed may be similar to what occurs in winter for other salmonids. Low temperature appears to be a controlling factor for other salmonids during winter, while temperature may be influencing juvenile bull trout habitat use year-round in these spring-fed streams because of the constant, cold temperatures. Future research should include experimental comparisons of habitat selection with available habitat, and interaction of bull trout with other species under varying temperature regimes. This experimental work could further define the range of available habitat conditions that remaining bull trout populations could tolerate (Rieman and McIntyre 1993).

Chapter 3. Distribution

INTRODUCTION

The range of bull trout in the Pacific Northwest once extended from northern California in the United States to the Yukon in Canada (Cavender 1978). In Oregon and Washington, bull trout were found in most mountainous river basins except for the Coast Range (Fig. 29). (See Appendix for a list of historical locations and last year of record of bull trout in Oregon and Washington.)

An apparently serious decline in bull trout numbers and geographic distribution in all areas of the Pacific Northwest has renewed interest in determining their current distribution in Oregon and Washington (Ratliff and Howell 1992; Mongillo 1993). This decline may ultimately lead to more restrictive protection of the species from its current status as a Sensitive Species (Category 2 of the U.S. Fish and Wildlife Service) to Threatened or Endangered.

The importance of bull trout to the coldwater ecosystems of the Pacific Northwest makes protecting this species especially important. Because of their special habitat requirements and ecological role, char are excellent "indicators" of ecosystem health and pristine conditions of northern temperate aquatic systems (Regier 1980; Hartmann 1983; Hammar 1989; Edwards et al. 1990). Like other char species, bull trout are recognized as an apex predator (Li et al. 1987), and bull trout are currently an indicator species in National Forest management plans throughout the Pacific Northwest.

Because loss of this indicator species may signal a continued decline in all coldwater adapted species, collecting information on its

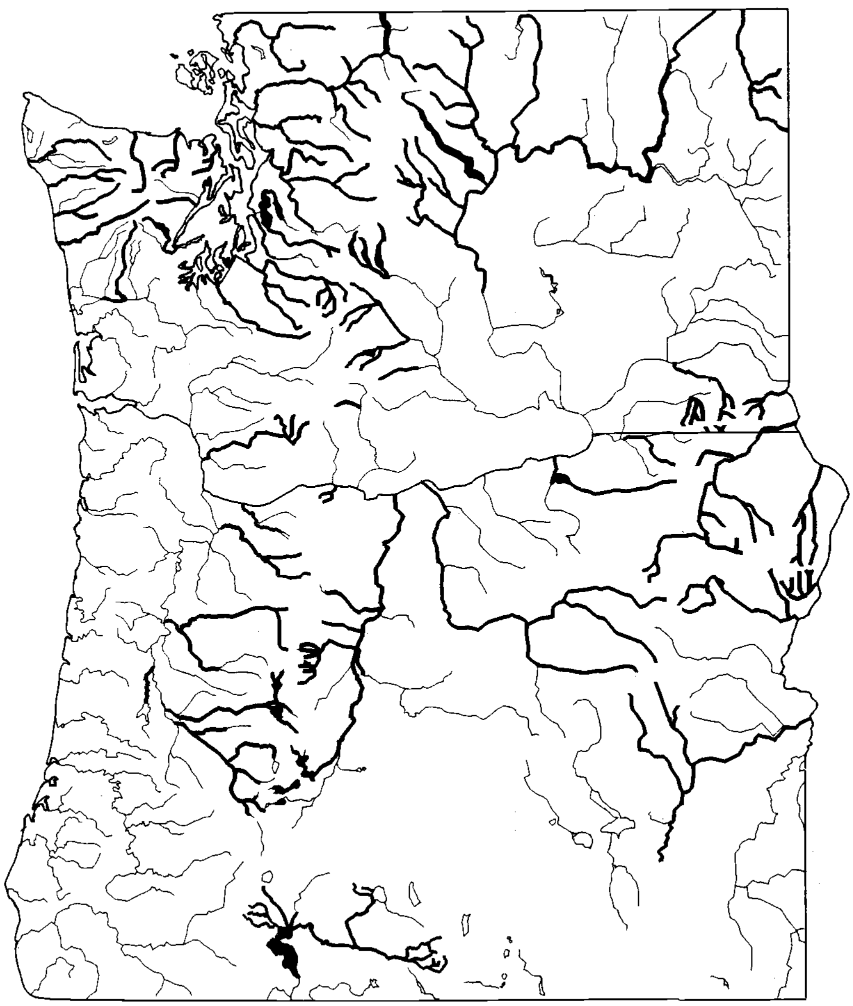


Figure 29. Bull trout historical distribution in Oregon and Washington (see Appendix for historical records, solid lines=bull trout distribution). Base map modified from Franklin and Dyrness (1973).

current range is becoming critical. Knowledge of factors explaining bull trout distribution is also needed. While bull trout are found in most major river basins in the Cascade Mountain range of Oregon and Washington, factors related to their selection of particular first and second order tributaries within these larger basins are not completely understood. In some river systems of the Pacific Northwest, they may only occupy one or two tributaries in an entire basin (Maughan 1976; Long and Bond 1979; Horton 1985; Dambacher et al. 1992; Ziller 1992). Understanding the distribution pattern of bull trout in Oregon and Washington as a whole, and within specific drainage basins, could help explain the decline of the species and predict future distribution.

Using the data from the historical review (Appendix) and distribution surveys, I will discuss bull trout distribution in relation to major geographic and geomorphic features. Geographic variables include (1) elevation, latitude, and longitude, and (2) the relation of these variables to groundwater temperature. Geomorphic features of interest are physiographic province (Franklin and Dyrness 1973) and stream water source.

This study, therefore, had four objectives:

1. Identify bull trout distribution in (i) selected streams in Oregon and Washington, and (ii) Oregon and Washington as a whole;
2. Identify factors influencing that distribution;
3. Compare current distribution to historical distribution to determine bull trout demise in selected river basins; and
4. Identify factors contributing to that demise.

METHODS

Distribution Surveys

To determine the current distribution of bull trout in selected streams in Oregon and Washington, presence/absence surveys were conducted from March 24, 1989 to September 30, 1991 in tributaries of the Deschutes, Willamette, Cedar, and Yakima River basins (Table 14). Sampling dates for most surveys were selected to correspond to presumed bull trout spawning periods.

Table 14. Sampling periods, methods and number of sampling sites for distribution surveys in several Cascade Mountain drainages.

Basin	Drainage	Sampling Period	Number of Sites	Methods
Deschutes	Metolius	6/19-9/5/89	23	D,N,E[a]
		7/26-11/7/90		
	Odell Lake	8/14-8/18/89	10	D,N
		5/21-5/26/91		
	Crescent Lake	8/14-8/18/89	2	D
Willamette	U McKenzie	3/24-11/15/89	33	D,N,E
		5/20;8/17/91		
	S Fk McKenzie	9/2-9/28/89	11	N,E
		9/20-10/28/90		
	M Fk Willamette	10/16-11/24/89	12	N,E
		10/7-11/16/90		
L Washington	Upper Cedar	9/3-9/30/91	8	D,N,E
Yakima	Gold Creek	7/26-9/28/91	9	D,N

a. Methods were day snorkeling (D), night snorkeling (N), and electrofishing (E).

Sites to be sampled were determined by (1) the presumed presence of bull trout based on historical records (Fig. 29, Appendix), and (2) site habitat characteristics such as water temperature and presence of coldwater springs. Based on this information, surveys were restricted to (1) the upper Metolius River, Odell Lake, and Crescent Lake drainages in the Deschutes River basin; (2) the upper Middle Fork Willamette, McKenzie, and South Fork McKenzie River drainages in the Willamette River basin, (3) the upper Cedar River, and (4) Gold Creek in the upper Yakima River basin.

Survey methods depended on the size and type of water body. Each site was sampled by electrofishing, day snorkeling, night snorkeling, or a combination of these methods (Table 14). Tributary streams and side channel habitat were usually small enough to sample with backpack electrofishers. Night and day snorkeling were used in larger tributaries, mainstem rivers, and lakes.

If no fish were found in areas with recent reports of bull trout by using a single method, more intensive follow-up surveys were conducted with a combination of techniques. In some larger flow streams or rivers, for example, a combination of electrofishing in shallow nearshore habitat and snorkeling in deeper water habitat was used.

Stream sites sampled by electrofishing varied in length from 50 to 1000 m. Typically only one pass was made at a site, moving upstream. Lake, large tributary, and mainstem river sites sampled by night and day snorkeling varied in length from 0.2 to 1.6 km. Snorkel surveys were usually continuous; Metolius River tributaries, Trapper Creek, and Gold Creek were exceptions. These streams were segmented by reach and sampled by "n" habitat units (Chapter 1). Lake sites followed the shoreline and were generally limited to areas less than 5 m in depth. Sampling times by technique are discussed in Chapter 1. Spacing and length of sample sites were based on available bull trout habitat and site access. Stream flow source (springs) was documented by field observation or from examination of topographic maps. Bull trout length was recorded for all sample sites. Bull trout were separated into juveniles and adults based on size: juveniles < 300 cm and adults > 300 cm. Age class differences were described in Chapter 1.

Stream Characteristics

Discharge, dominant substrate, water temperature, gradient, and presence of fish species other than bull trout were measured or observed in selected streams (Table 2). Discharge was recorded at tributary mouths with either a Pygmy or Swoffer current meter. Flow for the upper McKenzie River above Trailbridge Reservoir was provided by Dale Hagy (Eugene Water and Electric Board, Eugene, Oregon, pers. comm. 1990) and flows for Metolius river streams were provided by Mike Riehle (U.S. Forest Service, Sisters Ranger District unpublished data, Sisters, Oregon, 1989). Gradient was determined by clinometer reading or from quadrangle map measurement.

Simple linear regression with double-tailed t-tests was used to compare selected stream characteristics (discharge, water temperature, and gradient) with density estimates calculated from night snorkeling (Chapter 1). Multivariate linear regression was also used to see if including more variables in the model could better describe the relationship. All data were analyzed with STATGRAPHICS statistical software (STSC, Inc. 1989).

Geographic Factors and Groundwater Temperature

Stream data were analyzed to (1) delineate a low elevation margin in the southern part of the historical bull trout range (Fig. 29) and (2) determine whether the low elevation margin is related to groundwater temperature.

Geographic Factors

The variables of interest in the geographic analysis were stream elevation, latitude, and longitude. Streams selected for study were the lowest elevation spawning and rearing areas within each major basin and/or sub-basin of Oregon and Washington; all were current or historical bull trout streams (Appendix). I included the McCloud River in the analysis since it was historically the southernmost bull trout population (Rode 1990). If the lower range of spawning or rearing habitat was not clearly defined for a drainage, I assumed that the lower limit for smaller streams was the confluence of the smaller tributaries with the next largest one. For large systems, the point-of-sample reported in the Appendix was assumed to be the lower limit.

Elevation, latitude, and longitude coordinates were not provided with most bull trout stream inventory data. I used 7.5 minute quadrangle maps from the U.S. Geological Survey to collect these data for distribution sites. When quadrangle maps were not available, I used the Washington Atlas and Gazetteer or Oregon Atlas and Gazetteer (1988; 1991 Delorme Mapping Co.).

Groundwater Temperature

After determining the lower elevation margin of the historical bull trout range, I developed a model predicting groundwater temperature for a bull trout stream at a given elevation, latitude, and longitude. The climate data used to develop the model were obtained from the National Oceanic and Atmospheric Administration of the United States. The climate normals used were the 20-30 year average of mean annual air temperature at meteorological stations throughout the historical bull trout range (n=402). From these data, mean annual air temperature at each bull trout distribution point was estimated with equation (1).

(1) Mean annual air temperature (degrees C) = 74.63 - 0.0048 Elevation - 0.64 Latitude - 0.28 Longitude N=402, $R_a^2=0.87$, $P<0.0001$.

Equation (1) was found by regressing meteorological station elevation, latitude, and longitude against mean annual air temperature for stations located within and adjacent to the historical bull trout range. In considering the climate data for the regression, I looked at the residual plot and normal probability plot and found no unusual patterns or outliers.

Collins (1925) found that the temperature of groundwater is from 1-2°C higher than local mean annual air temperature. The same relationship holds true for groundwater temperature in the native eastern brook trout range. Meisner (1990a) found that adding 1.5°C to local mean annual air temperature approximates groundwater temperature.

For this study I assumed that the same general relationship holds for groundwater temperature and mean annual air temperature within the historical bull trout range. Therefore, adding 1.5°C to the mean annual air temperature predicted for bull trout distribution sites will approximate groundwater temperatures for bull trout streams.

I collected either groundwater (spring) or actual stream temperatures for 13 of 15 spring-fed streams of the Oregon Cascades and Southern Washington Cascades. I assumed there was little variation between the groundwater and actual stream temperature because Metolius River spring-fed stream temperatures do not vary more than 1-2°C daily (M. Riehle, U.S. Forest Service, Sisters Ranger District unpublished data, Sisters, Oregon, 1989). Groundwater data were collected during the distribution surveys and from Thompson (1965), C. Campbell (Portland, Oregon, pers. comm. 1992), F. Shrier (Pacific Power and Light unpublished data, Portland, Oregon, 1992), Armantrout and Shula (1975), and M. Fritsch (Warm Springs Indian Tribe unpublished data, Warm Springs Reservation, Oregon, 1989).

I used two-sample tests to compare predicted groundwater temperatures for nonspring-fed streams (n=37) vs. (1) west slope spring-fed streams (n=7) and (2) all spring-fed streams (n=13). Two-sample tests were also used to compare predicted groundwater temperatures against actual groundwater temperatures for west slope spring-fed streams and predicted temperatures against actual temperatures for all spring-fed streams.

<u>Geomorphic Factors</u>

To aid in analyzing the major factors responsible for the distribution of bull trout spawning and rearing habitat, the states of Oregon and Washington were divided into separate geomorphic or physiographic provinces forming broad stratifications of fairly uniform areas. These 15 provinces are defined by Franklin and Dyrness (1973) and are based on earlier divisions by Baldwin (1964), Fenneman (1931), and Easterbrook and Rahm (1970). Franklin and Dyrness (1973) provide detailed descriptions of the physical characteristics of each province.

RESULTS

Distribution Surveys

Distribution of Juvenile Bull Trout

Juvenile bull trout were found in 40% of all sampled streams (spring-fed and nonspring-fed, n=43) and 35% of all sites (n=108). Juveniles were found in 52% of spring-fed streams (n=23), at 46% of spring-fed sites (n=61), and 21% of nonspring-fed sites (n=47). By major river basin, juveniles were found at 57% of all Deschutes sample sites (n=35), 16% of all Willamette sites (n=56), 25% of all Cedar sites (n=8), and 78% of all upper Yakima River Basin sites (n=9).

Metolius River Basin. Juvenile bull trout were found in seven of nine spring-fed streams or areas, at 90% of all spring-fed sites (n=20), and at 80% of all sites sampled (n=23). Juveniles were also found in both spring-fed mainstem river sample sites. No bull trout were found in sample sites on Abbot, upper Canyon, Parker, and Cabot Creeks (Fig. 30).

The uppermost sample site on Jefferson Creek was the highest elevation site (1170 m) at which bull trout were found in the Metolius basin. Juveniles were found in the lower Jefferson Creek sample sites up to a series of small waterfalls located 3.2 km upstream of the Metolius River confluence.

Upper Deschutes River Basin. In the Odell and Crescent Lake basins, juvenile bull trout were found in one of four spring-fed streams, at 14% of spring-fed sites (n=7), and 9% of all sites sampled (n=12). Juveniles were observed in the lower 1.2 km of Trapper Creek up

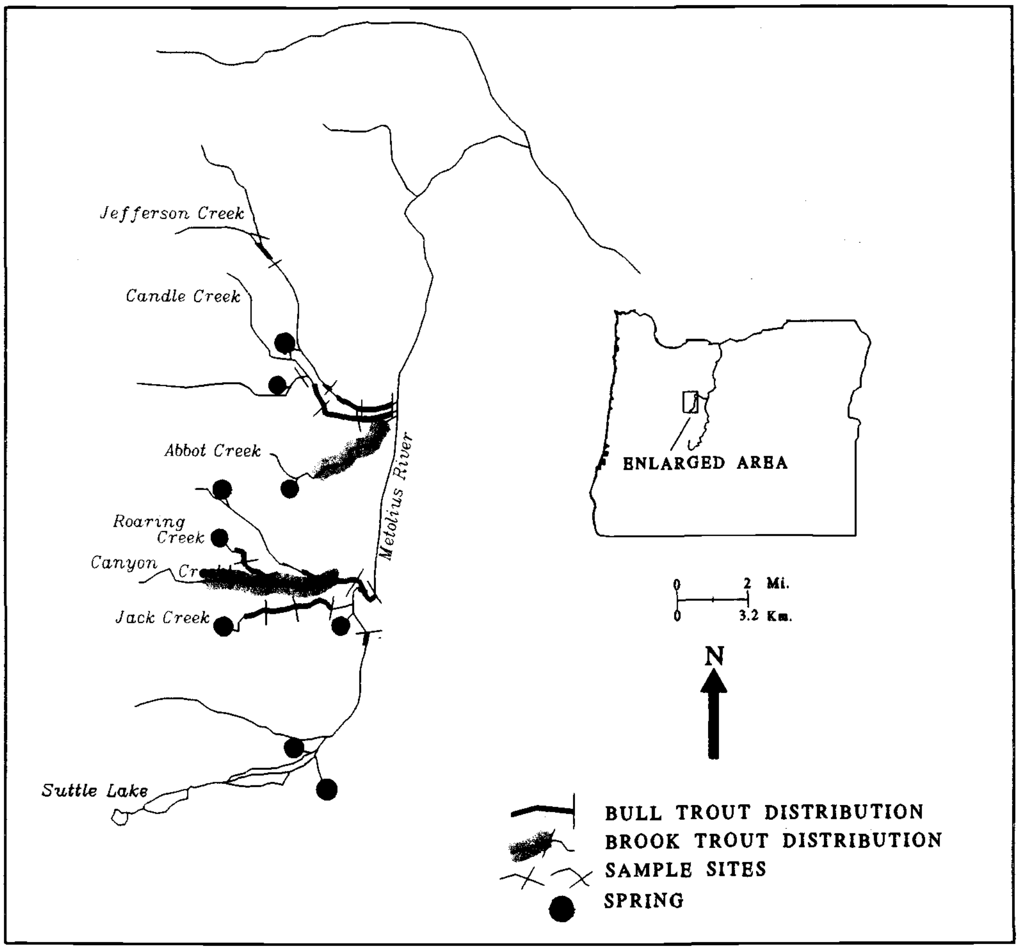


Figure 30. Sample site locations with bull trout distribution, brook trout distribution, and spring-source areas in the Metolius River basin.

to a series of 2-3 m high waterfalls. Bull trout were not found in three other spring-fed streams: Crystal, Maklaks, and Ranger Creek (Fig. 31).

McKenzie River Basin. In the upper McKenzie, juvenile bull trout were found in three of five spring-fed streams, 29% of spring-fed sites (n=21), and 18% of all sites sampled (n=33). Juveniles were also observed in Trailbridge Reservoir and in two mainstem sample sites below the reservoir which were near springs or spring-fed tributaries. Above the reservoir, no bull trout were found in (1) the spring-fed mainstem sample sites below Tamolitch Falls, (2) spring-fed Carmen Reservoir, or (3) any area in the Smith River drainage. No bull trout were found in two other spring-fed streams, Sweetwater Creek and Lost Creek (Fig. 32).

In the South Fork McKenzie River, juvenile bull trout were found in one of two spring-fed streams, at 50% of spring-fed sites (n=4), and 18% of all sample sites (n=11). Juveniles were observed in the lower 1.2 km of Roaring River and at one mainstem sample site just upstream of the South Fork/Roaring River confluence. Bull trout were not found in McBee Creek, the other spring-fed stream sampled (Fig. 33). The McBee Creek site was approximately 1.9 km upstream of the last juvenile observed in lower Roaring River.

Middle Fork Willamette River. Juvenile bull trout were found in one of 12 sites sampled. A single juvenile was observed at the head of Hills Creek Reservoir. Bull trout were not found in any of the spring-fed sites (n=6) in the upper river (Fig. 34).

Cedar River Basin. Juvenile bull trout were found only in the two mainstem sample sites in the upper Cedar River basin, which represented 25% of the sites sampled (n=8). They were not found in any North Fork

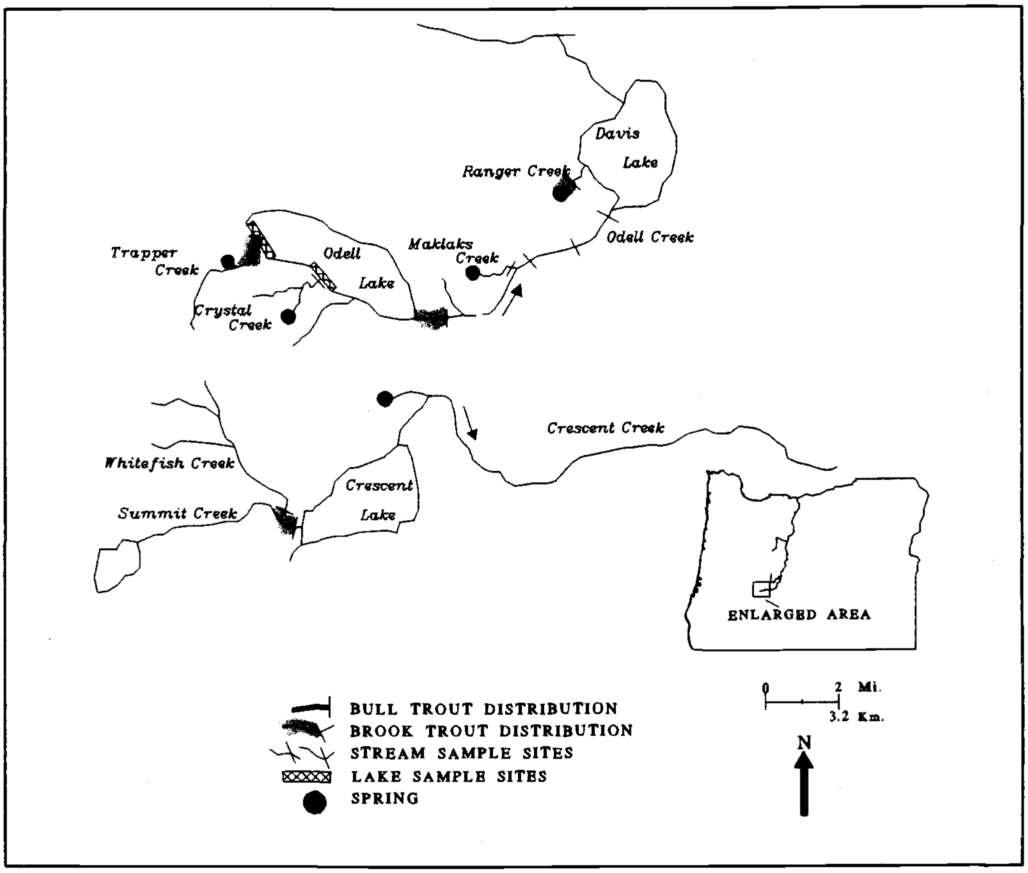


Figure 31. Sample site locations with bull trout distribution, brook trout distribution, and spring-source areas in the Odell and Crescent Lake basins.

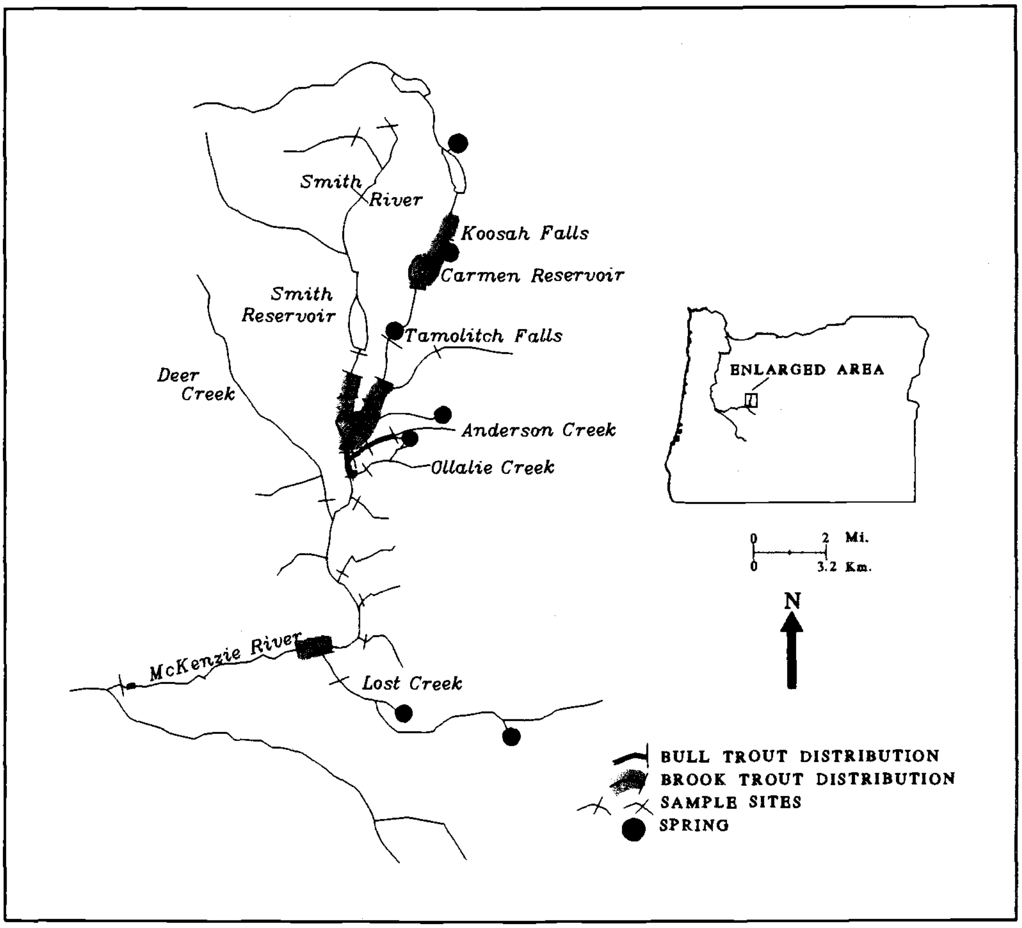


Figure 32. Sample site locations with bull trout distribution, brook trout distribution, and spring-source areas in the upper McKenzie River basin.

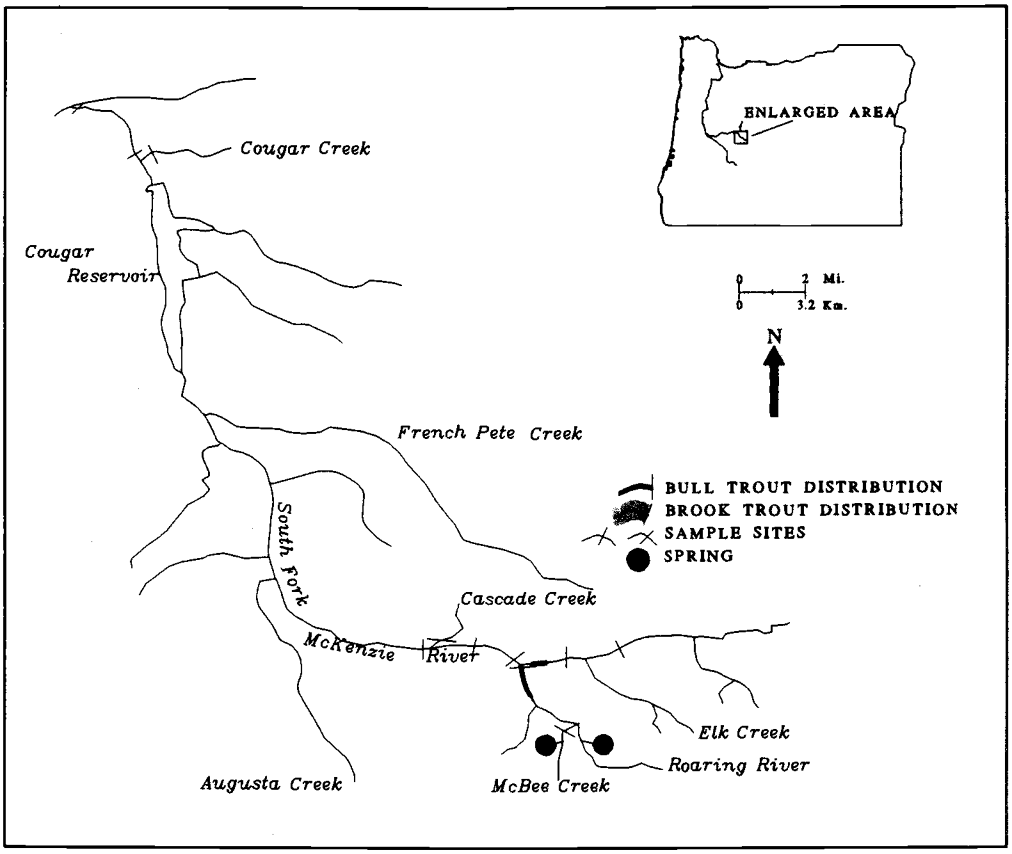


Figure 33. Sample site locations with bull trout distribution and spring-source areas in the South Fork McKenzie River basin.

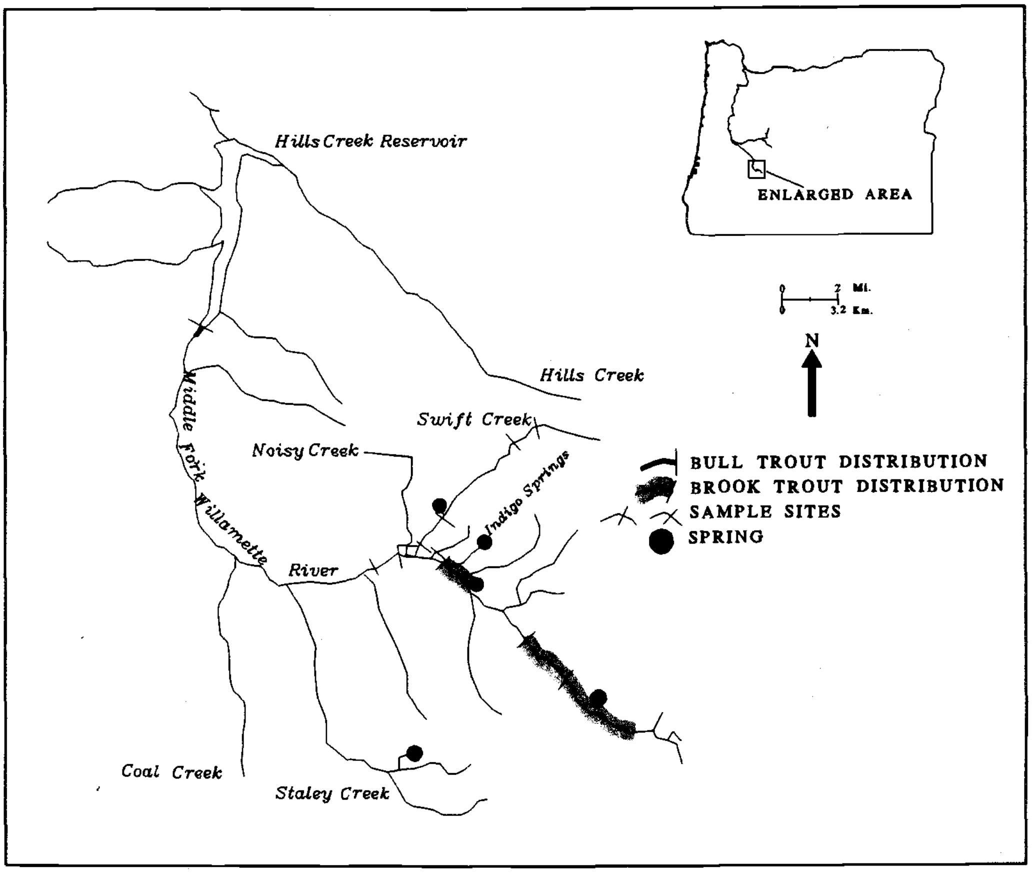


Figure 34. Sample site locations with bull trout distribution, brook trout distribution, and spring-source areas in the Middle Fork Willamette River basin.

sample sites including Tinkham Creek, the one spring-fed tributary sampled (Fig. 35).

Upper Yakima River Basin. In Gold Creek, juvenile bull trout were found in 78% of sampled sites (n=9). Juveniles were not found in the outlet channel of Gold Creek Pond or in the lowest sample site on Gold Creek. In Gold Creek Pond, juveniles were only found in seepage areas along the north shore (Fig. 35).

In conclusion, juvenile bull trout were documented for the first time in a number of new areas: upper Jefferson Creek, upper Canyon Creek, Trapper Creek, Trailbridge Reservoir, Anderson Creek, upper mainstem McKenzie River, South Fork McKenzie, Roaring River, Hills Creek Reservoir, upper Gold Creek, and Gold Creek Pond. Juvenile presence was documented only by night snorkeling in nine of these new areas. Bull trout adults and juveniles were consistently found in very coldwater habitat and usually in spring-fed sites.

Distribution of Adult Bull Trout

Migratory adult bull trout were found in the Metolius, Upper Deschutes, McKenzie River, and upper Yakima River basins. Spawning fish or completed redds were found in all these basins. Adult spawners were found earlier in Deschutes River sites (mid-July to early September) than in upper McKenzie and Yakima River sites (September). Possible resident adults were found in upper Jefferson Creek, Metolius River basin.

Adult bull trout were found at 18% of all sample sites (n=23) in the Metolius River basin, and 15% of McKenzie River basin sample sites (n=33). In the Yakima River basin, adults were found at 50% of sample

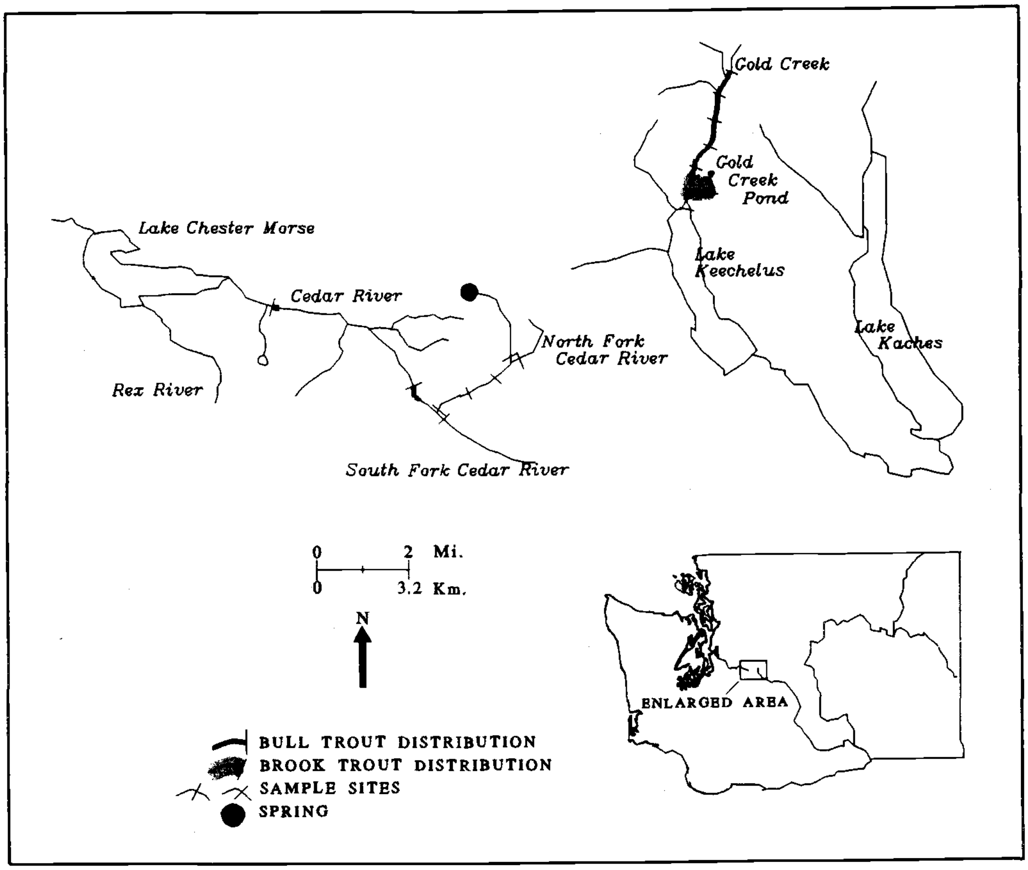


Figure 35. Sample site locations with bull trout distribution, brook trout distribution, and spring-source areas in the Cedar and upper Yakima River basins.

sites (n=12), at the lowest sample site on Gold Creek (including the lowest section of the Gold Creek Pond outlet channel), and at four upper sample sites. Two adults were found near seepage areas at night in Gold Creek Pond. One fish was actively preying on nearby rainbow trout while the second was resting on the lake bottom in water 25-30 cm deep.

Stream Characteristics

Streams containing bull trout in the Metolius, upper McKenzie, Odell Lake and upper Yakima drainages were compared with respect to gradient, flow, water temperature, and substrate (Table 2). All streams are spring-fed except Gold Creek.

Although not significant, there was a moderately high correlation ($r=0.66$, $t=2.31$, $0.05<P<0.10$) between flow and stream density estimates (from Chapter 1). The relationship was positive, indicating a possible increase in density estimates with larger flows. Flow averaged 2.49 cms (SD=3.09), with a range of 0.51 (Gold Creek) to 10.48 (upper McKenzie at Tamolitch Falls). The high value for the upper McKenzie may be misleading, as juveniles and a possible spawning adult female were found only in slack water at the head of Trailbridge Reservoir and not in the upper river itself. However, the upper river was a historical bull trout location (Appendix). Without the upper McKenzie flow value, the average was 1.49 cms (SD=0.79), range 0.51-2.8, with Jefferson Creek having the highest flow. Gold Creek, a snow-melt and lake-fed stream, had the lowest flow of bull trout streams at 0.51 cms.

Although not significant, there was a negative relationship between stream gradient and bull trout density estimates calculated by day and night snorkeling ($r=0.-0.40$, $t=-1.15$, $P<0.30$). The average stream gradient was 2.62% (SD=1.61), with a range from 1.4% (Jack Creek) to 6.1% (Anderson Creek). While fish were found in three of four sample sites on Anderson Creek, the main spawning and juvenile rearing area was in a lower gradient section (2.0-3.0%). Juveniles were not found in the uppermost sample site, where the stream gradient was 6%.

Although not significant, there was a negative relationship between average maximum daily water temperature and juvenile bull trout density estimates ($r=-0.24$, $t=-0.66$, $P<0.54$). The average maximum daily water temperature was 8.03°C (SD=1.87), with a range of 5.0°C (Candle Creek) to 11.0°C (Gold Creek). Most streams had a daily range in temperature of less than 1.0°C. Trapper Creek, the highest elevation site and the Oregon stream least influenced by spring-flow, displayed the widest range in minimum and maximum temperatures (5-9°C). The highest temperatures at which bull trout were found were (1) 13°C for juveniles, at the second highest sample site on Canyon Creek (above the confluence with spring-fed Roaring Creek) and (2) 16.5°C for adults, in the lower site in Gold Creek. Both areas were outside main spawning and rearing areas and were dominated by brook trout.

Multivariate regression of the three variables -- gradient, flow, and temperature -- did not improve the correlation. Flow was selected as the single factor best describing the relationship ($R_a=0.35$, $t=2.31$, $P<0.06$; R_a is the adjusted correlation coefficient).

Cobble was the dominant substrate in eight of the nine streams, with sizes ranging from gravel to boulder. Trapper Creek had co-dominance of cobble and small boulders while Trailbridge Reservoir was boulder-dominated.

Fish Species Associated with Bull Trout

Native taxa found in association with bull trout in both the Deschutes and Willamette drainages included rainbow trout, mountain whitefish (Prosopium williamsoni), and sculpins (Cottus sp.) (Table 15). Bull trout were the only native salmonid found in Brush, Candle, and upper Jefferson Creeks. Exotic salmonids found co-occurring with bull trout were brook trout, lake trout (Salvelinus namaycush), and brown trout.

Table 15. Species associated with the bull trout in the Deschutes and Willamette drainages (n=total number of sites).

Species	Percent of sites Deschutes (n=33)	Percent of sites Willamette (n=56)
Oncorhynchus clarki	0	84
Oncorhynchus mykiss	52	45
Oncorhynchus nerka	6	0
Oncorhynchus tshawytscha	0	11
Salvelinus fontinalis	33	29
Salvelinus namaycush	10	0
Prosopium williamsoni	33	18
Salmo trutta	9	0
Ictalurus sp.	0	2
Pomoxis annularis	0	2

Brook trout were found in 26% of all streams sampled (n=43), and 27% of all sample sites (n=108). They were found in 26% of spring-fed streams (n=23) and 30% of all spring-fed sample sites (n=61). Brook trout were found at 29% of all sites expected (historical or spring-fed) to have bull trout (n=92), including 33% of the Willamette sites (n=42) and 30% in the Deschutes (n=33). They were present at one or more sites in every major drainage except the South Fork McKenzie and Cedar River.

Hybrids of brook trout and bull trout and possible spawning pairs were observed in the upper McKenzie, Trapper Creek, and Gold Creek. Most exotic species other than brook trout were found in reservoir and lake sample sites.

Metolius River Basin. Brook trout were found in three of nine spring-fed streams, at 20% of spring-fed sites (n=20), and in 22% of all sites (n=33). They were the only species found in Abbot Creek and were the dominant species in upper Canyon Creek (Fig. 30). Brown trout were found at both mainstem river sites and at one site on Jack Creek.

Upper Deschutes River Basin. Brook trout were found in two of four spring-fed streams, at 29% of spring-fed sites (n=7), and at 42% of all sample sites (n=12). They were the only species seen in Ranger Creek. Brook trout were also found in Trapper Creek (both above and below the falls), upper Odell Creek, and lower Summit Creek. Four brook trout/bull trout hybrids were also observed at the mouth of Trapper Creek (Fig. 31). Lake trout fry were abundant in both Odell Lake sample sites, with a single juvenile found in lower Trapper Creek.

McKenzie River Basin. Brook trout were present at 38% of spring-fed sites (n=21), 25% of nonspring-fed sites (n=12), and at 33% of all upper McKenzie sample sites (n=33). They were the most abundant species in all three reservoirs, in the mainstem sample sites above Carmen Reservoir, and below Trailbridge dam. In the lower mainstem McKenzie, four brook trout were found 0.8 km below the confluence with Lost Creek. In transect 1 of Trailbridge Reservoir, several juvenile brook/bull trout hybrids were observed (Fig. 32).

Middle Fork Willamette River Basin. Brook trout were found in 25% of the sites sampled (n=12) and were the dominant species in the two uppermost spring-fed mainstem sites (Fig. 34).

Upper Yakima River Basin. Brook trout were found in 44% of sample sites (n=9), primarily in the higher temperature areas (the outlet channel of Gold Creek Pond and the two lower Gold Creek sites) (Fig. 35). In late summer, these areas are fed by surface flow from Gold Creek Pond, with temperatures ranging from 12.0° to 16.5°C.

Geographic Factors and Groundwater Temperature

Geographic Factors

The lowest elevation of bull trout spawning and rearing habitat in Oregon and Washington rises steadily from approximately 100 m south of 48° 05' N to approximately 1800 m at the southeast margin of the range (Fig. 36). There was a significant negative correlation between latitude and elevation (r_a=-0.744; F=62; P<0.001). The elevation of bull trout habitat also rises from its minimum at 123° 35' W to a maximum of 1798 m at 117° 20' W at the eastern margin of the range (Fig. 37). The relationship between elevation and longitude was not significant (r_a=-0.222; F=1.5; P<0.223). Each point in Figures 36 and 37 represents one stream site at the lowest point in major sub-drainages where spawning and rearing is assumed; no stream is represented more than once.

Spring-fed streams appear to vary from the negative relationship between elevation and latitude. The lower stream boundary for latitude is defined by west slope spring-fed streams of the Cascade Mountains of

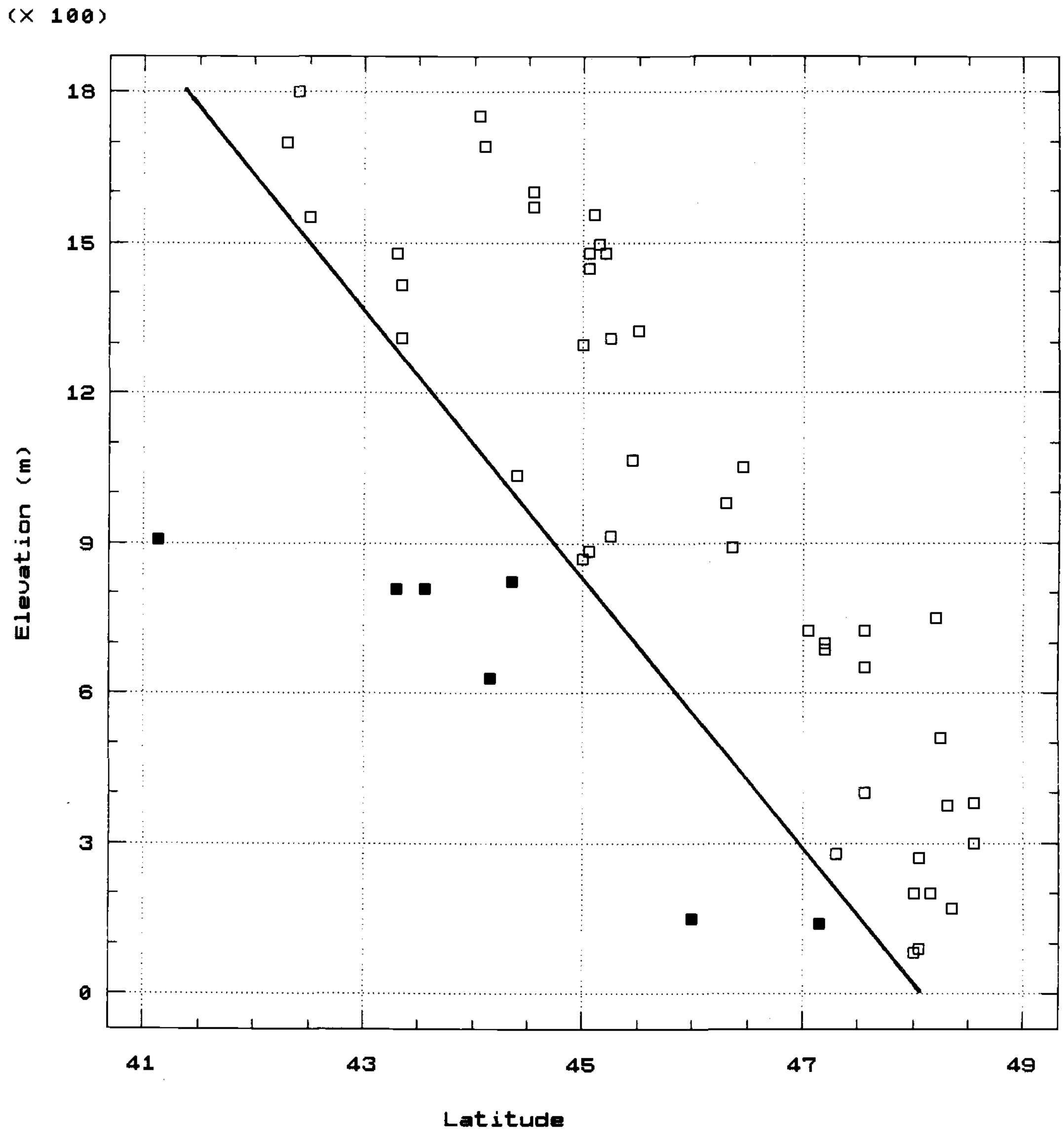


Figure 36. Comparison of elevation and latitude of bull trout spawning and rearing habitat in Oregon and Washington streams (n=52). Diagonal line separates west slope spring-fed streams (filled points) from nonspring-fed streams and east slope spring-fed streams.

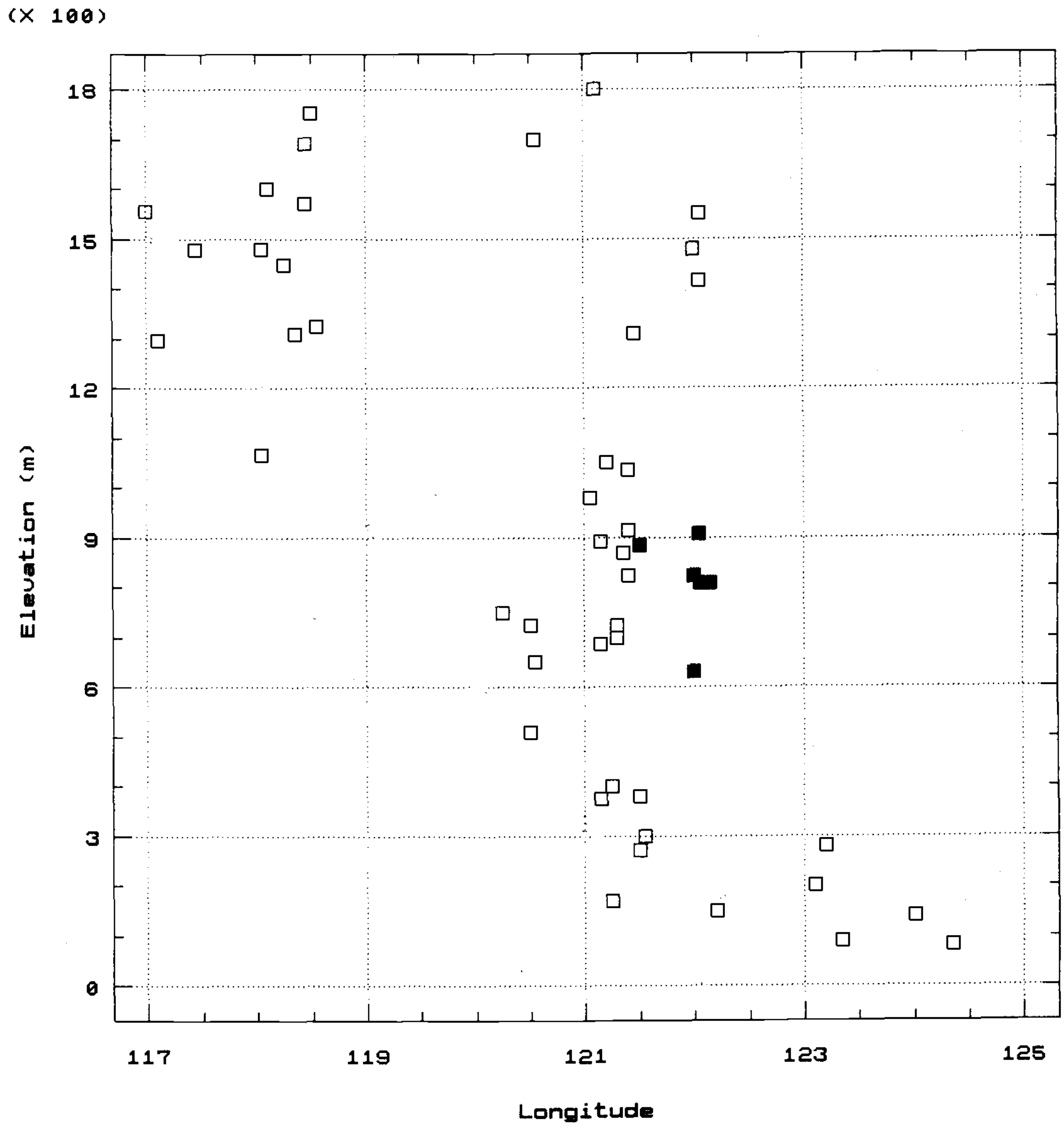


Figure 37. Comparison of elevation and longitude of bull trout spawning and rearing habitat for Oregon and Washington streams (n=52). West slope spring-fed streams are filled points.

Northern California (McCloud River) to Southern Washington (Fig. 36). Removal of these lowest elevation points (n=7) increased the correlation between elevation and latitude for Cascade Mountain streams from r_a=-0.73 (F=34; P<0.001) to r_a=-0.906 (F=111; P<0.001).

In combination, the distribution pattern in Oregon and Washington for elevation, latitude, and longitude follows a southeast to northwest trend with maximum elevations south and east and minimum elevations north and west. The spring-fed McCloud River stands out as a clear outlier to this pattern. At an elevation of 906 m and 41° 13' N, the next closest streams to the north range from 1500-1800 m, or 600-900 m higher. Combining the effects of latitude and longitude appears to explain 84% of the variation in elevation (R_a^2=-0.84; F=176.5, 93.35; P<0.001). Other variables are probably affecting this relationship, however, since longitude was not significantly correlated with elevation when considered separately.

<u>Groundwater temperature</u>

Predicted groundwater temperatures did not exceed 11.75°C for any stream (Fig. 38). These predicted temperatures suggest that groundwater-fed streams with temperatures above 12°C may be too warm in summer to support bull trout. The pattern of groundwater temperature also shows that the effect of decreasing latitude (increasing temperature) on bull trout habitat is counteracted by a general increase in elevation (Fig. 36). Latitude and elevation (and longitude to a lesser extent) appear to interact to maintain low temperatures in bull trout streams.

However, west slope spring-fed streams varied from the predicted pattern, with predicted groundwater temperatures (mean=10.42°C, SD=0.93)

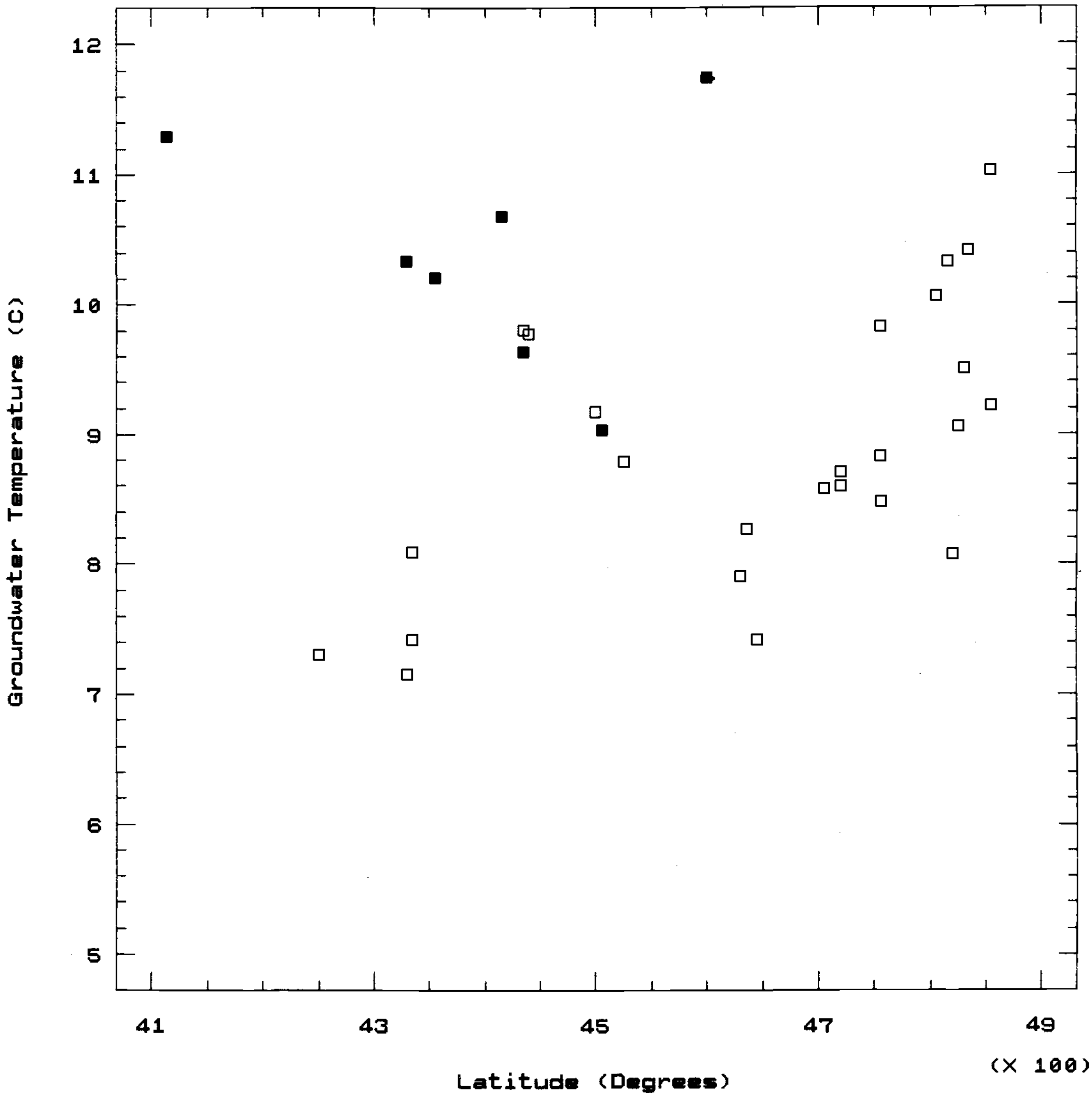


Figure 38. Scatter plot of predicted groundwater temperatures vs. latitude of bull trout streams (n=32) in the Cascade Mountains of Oregon and Washington. West slope spring-fed streams are filled points.

that were significantly greater than predicted nonspring-fed groundwater temperatures (mean=8.50, SD=1.34) (t=3.60, df=42, P<0.001). Predicted groundwater temperatures for all spring-fed streams were also significantly greater than predicted nonspring-fed streams (t=2.47, df=48, P<0.05). This difference is related to the lower than expected elevations west slope spring-fed streams were found at these southern latitudes and western longitudes.

There were significant differences between predicted and actual groundwater temperatures. Actual groundwater temperatures for west slope spring-fed streams (mean=5.87, SD=1.05) were significantly lower than predicted temperatures (t=8.58, df=12, P<0.001). Actual groundwater temperatures for all spring-fed streams (mean=6.42, SD=1.60) were also significantly lower than predicted temperatures (mean=9.58, SD=1.37) (t=6.13, df=24, P<0.001). Actual groundwater temperatures for all spring-fed streams increased with increasing elevation while predicted groundwater temperatures decreased with increasing elevation (Fig. 39).

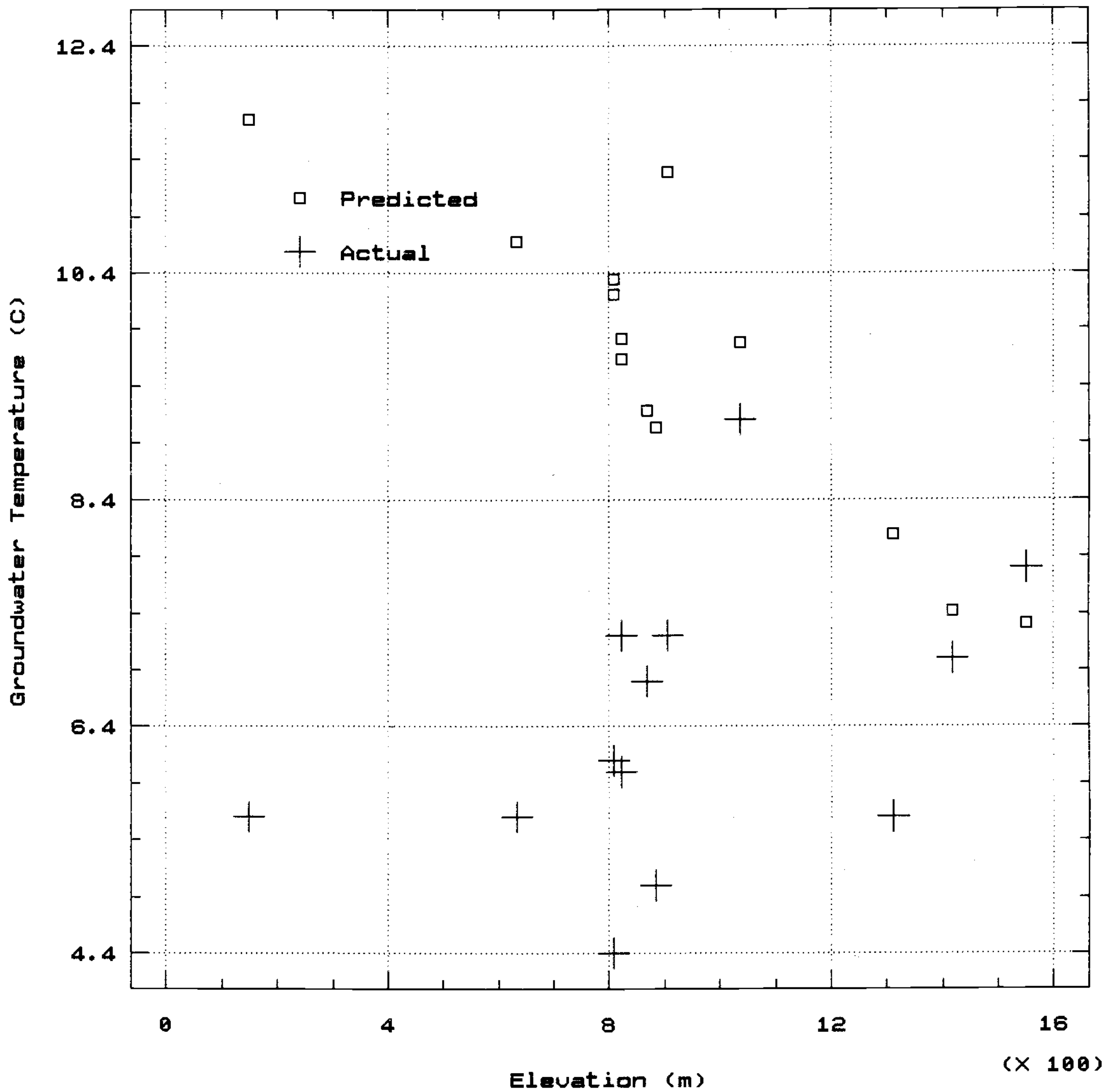


Figure 39. Scatterplot of predicted groundwater temperature, actual groundwater temperature, and latitude for spring-fed streams (n=13) of the High Cascasdes and Southern Washington Cascade Provinces.

DISCUSSION

Factors Explaining Distribution Survey Results

Metolius River Basin. Of all the drainages surveyed, juvenile distribution was most widespread in the Metolius River basin (Fig. 30). This widespread distribution can be attributed to the abundant spring-fed streams and closure of these tributaries to angling since 1984 (Ratliff 1992). Flow source, water temperature, and presence of brook trout may explain absence from sample sites on upper Canyon, Parker, Cabot, and Abbot Creeks. Upper Canyon and Parker Creek were the only nonspring-fed sites sampled. Their flow source is predominantly runoff. Cabot Creek was the coldest stream sampled (4°C), and it was sampled only by day snorkeling. As noted in Chapter 1, cold water temperatures may bias day snorkeling. In contrast, upper Canyon was the warmest stream (13°C), with a temperature that is 5.4°C higher than the average (mean=7.7) of all other spring-fed streams sampled in the Oregon Cascades (Table 2). Brook trout were the only species found in Abbot Creek and were dominant in upper Canyon. Abbot Creek was the only historical stream location where bull trout were not found.

Upper Deschutes. Although Crystal Creek and Odell Creek are historical bull trout locations, no bull trout were found in three streams: Crystal, Maklaks (a tributary of Odell), and Ranger Creeks (Fig. 31). Habitat degradation, flow, and brook trout presence may explain their absence from these spring-fed sites. The entire streambed in the lower 0.8 km of Crystal Creek was covered by a 2-12 cm layer of silt. Maklaks Creek had only 0.09 cms flow, or 18% of the flow of Gold Creek (0.51 cms) which was the lowest flow stream in which juvenile and adult bull trout were found in this survey. Brook trout were the only species found in Ranger Creek.

McKenzie River. No bull trout were found in spring-fed Sweetwater and Lost Creeks (Fig. 32), or above Trailbridge Reservoir in sample sites below Tamolitch Falls, in Carmen Reservoir, or any area in the Smith River drainage. Bull trout absence from these historical and spring-fed sites is primarily explained by barriers and brook trout presence. Passage for fish from Trailbridge Reservoir to Sweetwater Creek is prevented by a 2.5 m drop from the culvert outlet to the high-water mark of the reservoir. In lower Ollalie Creek, bull trout were not found above a culvert at the 0.5 km mark. There are no known barriers on Lost Creek. Bull trout have recently been found in Separation Creek, a large spring-fed stream of Horse Creek and the next adjacent drainage to Lost Creek (M. Wade, Oregon Department of Fisheries and Wildlife, Springfield, Oregon, pers. comm. 1993). Brook trout were the dominant species in Smith River Reservoir and Carmen Reservoir.

In the South Fork McKenzie River, no bull trout were seen in the McBee Creek spring-fed site which is upstream from the Roaring River sites (Fig. 33). The river section between these two points may represent an upstream migration barrier, since overall gradient increases from one to 12%.

Middle Fork Willamette. Bull trout were not found at any of expected spring-fed or historical locations (Swift Creek, Middle Fork below Swift Creek) in the upper river while a single juvenile was found at the head of Hills Creek Reservoir (Fig. 34). Rotenone was applied to more than 70 miles of upper Middle Fork stream habitat in 1961 in an effort to control rough fish (Oregon Game Commission 1961). After this treatment, dead bull trout were found in Swift and Staley Creeks (R. Swan, Oregon Game Commission unpublished data, Springfield, Oregon 1961).

<u>Cedar River Basin.</u> In my 1991 survey, bull trout were not found in any North Fork sample site including Tinkham Creek (Fig. 35), the one spring-fed tributary sampled. Flooding may explain their absence since the Cedar River basin was impacted in November of 1990 by the most severe flood on record (Ketcheson 1992). Before the flood, U.S. Forest Service crews recorded several age classes of bull trout at the headwaters of the Cedar River in the North Fork during the summers of 1989 and 1990. Re-colonization of the North Fork may have occurred in the year following the flood, however. During a fall 1993 survey, E. Conner (R2 Associates, Kirkland, Washington, pers. comm. 1993) found age 1 bull trout juveniles.

<u>Upper Yakima River Basin.</u> Temperature and flow source may explain juvenile distribution in Gold Creek, where juvenile bull trout were found in 78% of sampled sites (n=9) (Fig. 35). Juveniles were not found in the outlet channel of Gold Creek Pond or in the lowest sample site on Gold Creek, although adults were found in both. These areas are fed by surface flow from Gold Creek Pond, with temperatures ranging from 12.0° to 16.5°C. Upstream areas above Gold Creek Pond, where juveniles were found, ranged from 10.0° to 12.0°C. In Gold Creek Pond, juveniles were found only in seepage areas along the north shore, in temperatures of 5.5-7.7°C. Surface water temperatures in the pond outside the seepage areas ranged from 14.0° to 16.5°C. Brook trout were found in 44% of sample sites, primarily in higher temperature areas.

Distribution Patterns of Bull Trout in Oregon and Washington

Current Distribution

The distribution of spawning and rearing habitat for bull trout in Oregon and Washington follows a clear trend when analyzed by geomorphic province, being restricted to the highest relief areas in each state (Fig. 40). On the Oregon and Washington Coast, bull trout have never been recorded from creel census or stream surveys from Klamath Mountain or Coast Range Province streams. On the north Pacific Coast, bull trout are found in most river basins originating in the Olympic Mountains of the Olympic Peninsula Province. In the Willamette Valley and Western Cascades, bull trout have been reported or recorded in creel census but spawning and rearing habitat have never been documented. Except for the Umpqua and Rogue rivers, spawning and rearing populations have been recorded for most major drainages of the High Cascades from upper Klamath Lake to the Hood River.

In the Southern Washington Cascades Province, bull trout are found in the uppermost watersheds of most rivers draining Mt. Rainier, in selected streams in watersheds east of the Cascades, and in streams draining Mt. St. Helens. Bull trout have not been recorded from the Cowlitz or the headwaters of the Chehalis, rivers draining the west-central half of the province. An isolated population has been reported in the Columbia Basin Province in Satus Creek, a tributary of the lower Yakima River. The headwaters of this system originate in the Southern Washington Cascades Province, and it is unclear whether the population is located in the headwater area or further downstream in the Columbia Basin Province.

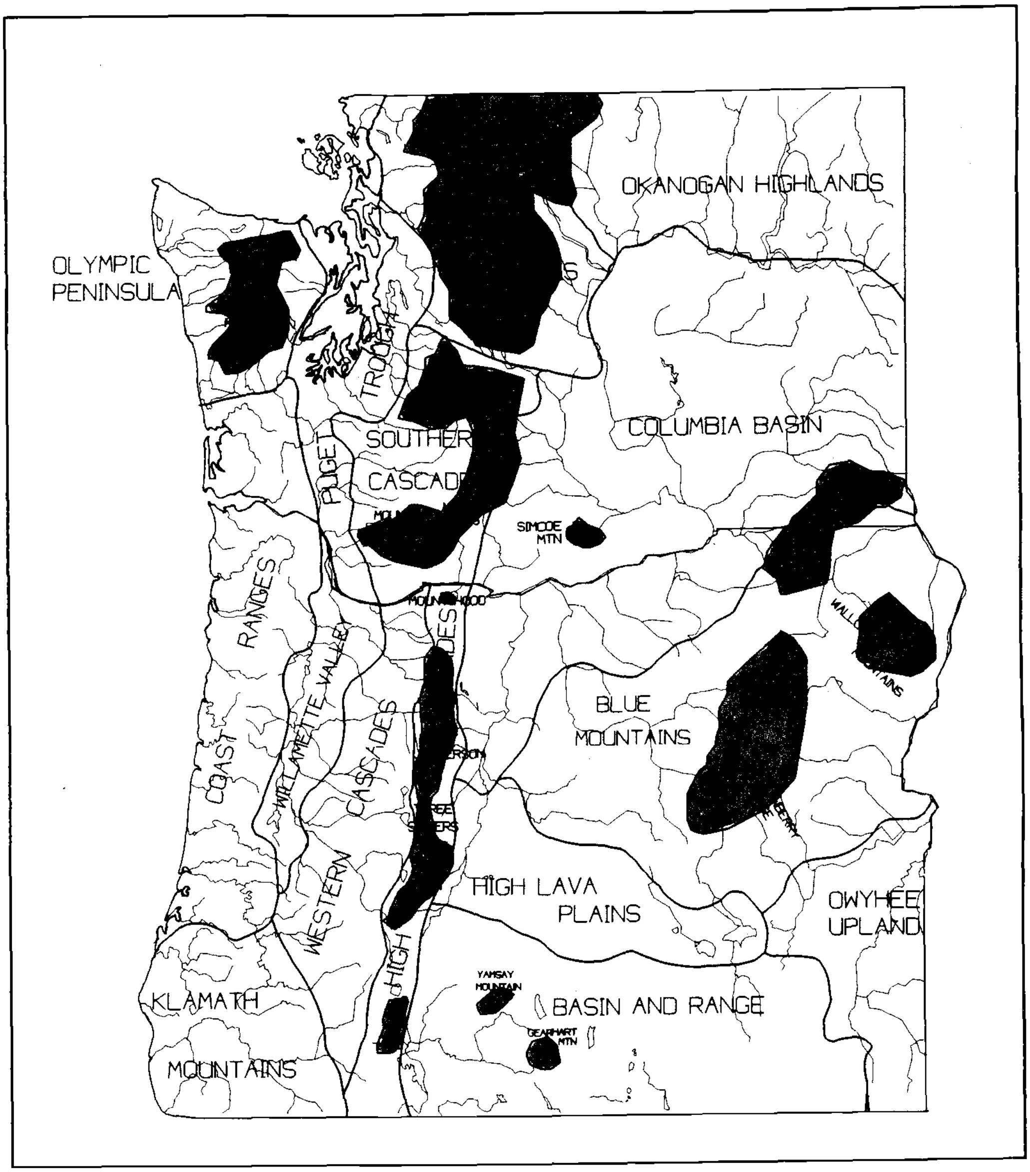


Figure 40. Distribution of bull trout spawning and rearing habitat (shaded area) by geomorphic province in Oregon and Washington (see Appendix for historical records).

Bull trout populations are found in most major drainages of the Northern Cascades Province. Spawning and rearing areas have not been documented in the Puget Trough. Several bull trout populations are found in drainages of the Methow River that originate in the Northern Cascades and may have downstream habitat extending into the Okanogan Highlands.

In the southern and eastern parts of Oregon and Washington, bull trout populations are more disjunct and isolated than those found in the western half. In the Basin and Range Province, there are only two elevation "islands" of coldwater habitat where bull trout are still found. The streams found in these two islands originate on two of the highest mountains in the area (elevations exceeding 2440 m), and bull trout in these streams are found in the uppermost stream sections. Behnke (1981) believed bull trout absence in the Great Basin was because of increasing temperatures and restriction of coldwater stream habitat.

The Blue Mountains is the only other area in eastern Oregon and Washington where bull trout populations are found. Disjunct islands are found in the headwater streams of the Strawberry, Wallowa, and Blue Mountain Ranges. Populations in streams originating in the Blue Mountains of southeast Washington appear to extend into the Columbia Basin Province. The downstream limit of spawning and rearing for these areas is not clearly defined and may be more generally restricted to the Blue Mountains. Bull trout have not been recorded from drainages of the High Lava Plains or the Owyhee Uplands.

Demise of Bull Trout in the Oregon Cascades

Bull trout in the lower Columbia once inhabited every major tributary draining the High Cascades (Figs. 41 and 42). In the two major basins in Oregon, the Willamette and Deschutes, bull trout are currently found in only 26.2 and 56.2% of their former ranges (204.8 out of 781.3 km, and 390.4 out of 694.4 km, respectively). This is a large loss not only in longitudinal distribution, but also in total available stream habitat. While spawning and rearing areas were located in headwater tributaries, some adults previously made downstream migrations exceeding 220 km in length.

The primary areas of reduction are in the lower Willamette and the upper Deschutes. Until 1976, bull trout were found in the Clackamas and the North Santiam from their confluence with the Willamette upstream to spring-fed headwater areas. Bull trout are now confined to 15.2% of their former habitat in the Middle Fork of the upper Willamette, being restricted to the uppermost 39.7 km. In the McKenzie River, bull trout still occupy a significant amount of their former range (88.1% or 166.4 of 188.8 km).

In the upper Deschutes, bull trout now occupy less than 0.5% (1.5 out of 288 km) of their former stream habitat range. The lower reach of Trapper Creek is the only remaining stream habitat in the upper Deschutes where bull trout are found. Bull trout are still seen in 95.7% of their former range in the lower Deschutes, or 388.8 out of 406.4 km.

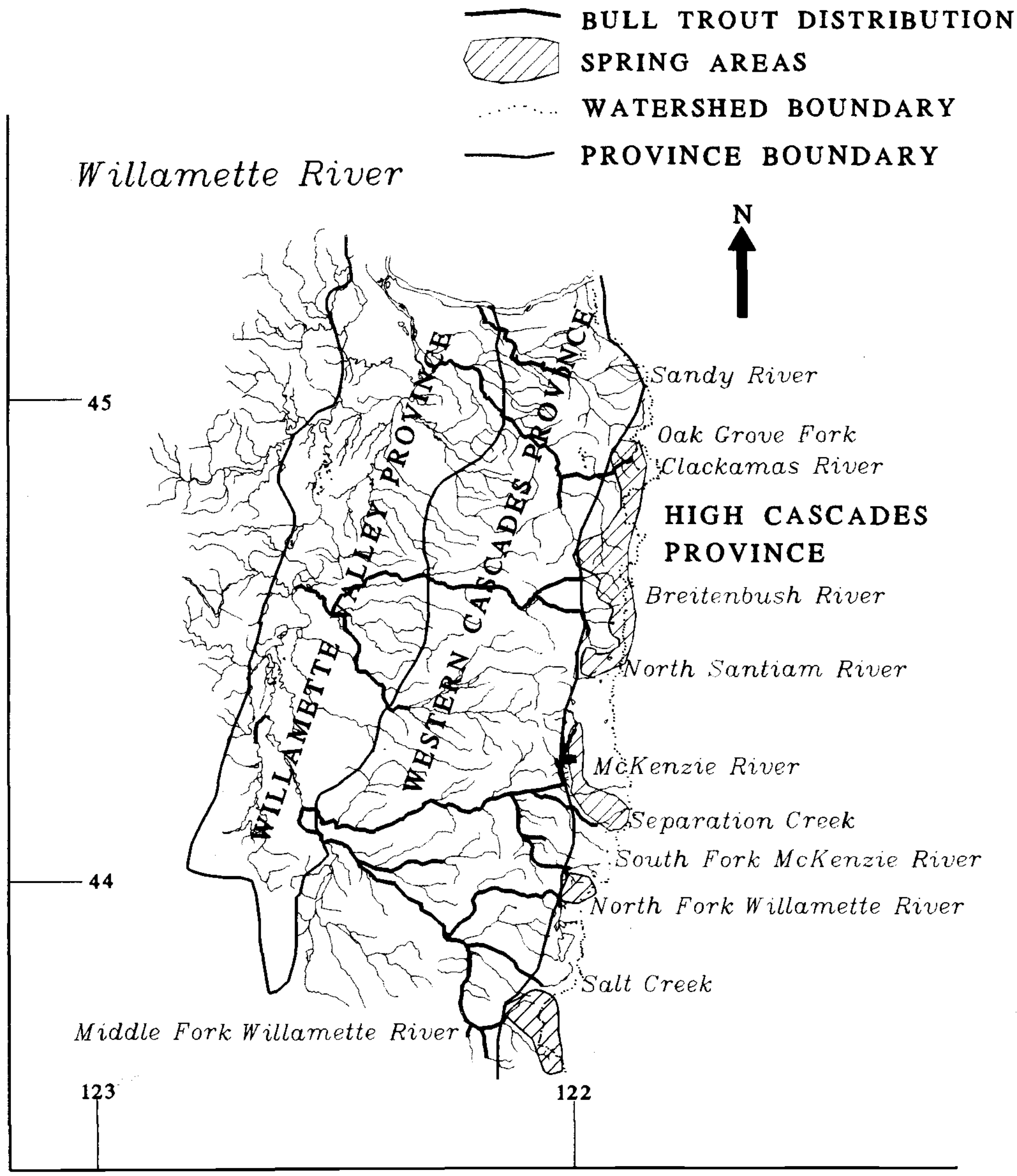


Figure 41. Bull trout historical distribution in the Willamette River basin and association with spring-fed streams in the High Cascades Geomorphic Province (see Appendix for historical records).

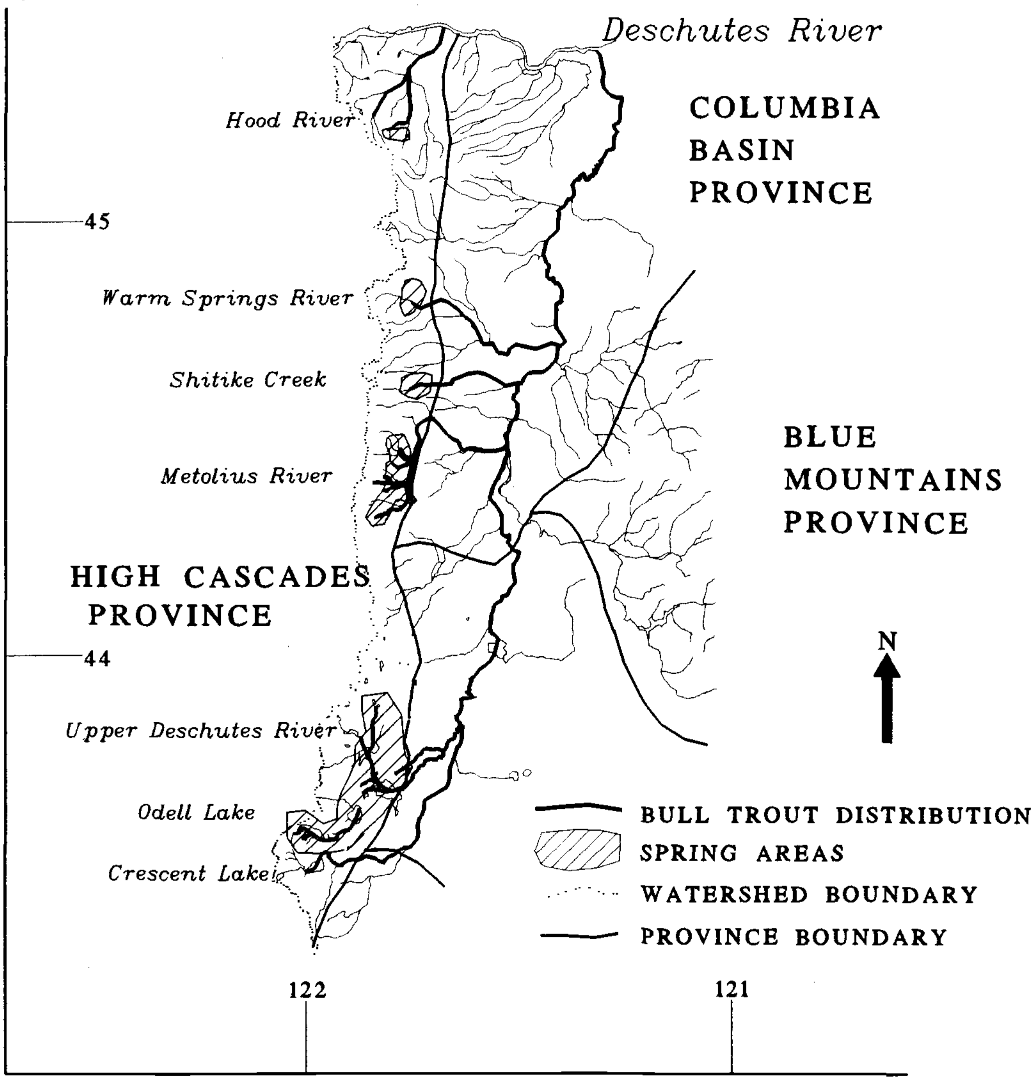


Figure 42. Bull trout historical distribution in the Deschutes River basin and association with spring-fed streams in the High Cascades Geomorphic Province (see Appendix for historical records).

Factors Influencing Bull Trout Distribution

Site-Specific Association of Bull Trout and Springs

Historical and current spawning and rearing habitat areas for bull trout in the Willamette and Deschutes basins are in, or closely associated with, spring-fed areas (Appendix, Figs. 41 and 42). The Pacific Northwest has more than half of the largest springs in North America, and the High Cascades has springs with the greatest flow of any region in the Pacific Northwest (Back et al. 1986). The high precipitation and highly permeable volcanic rocks of the region create exceptional amounts of groundwater recharge, storage, and flow.

The bull trout spring-fed areas of the High Cascades and the Southern Washington Cascades were generally created by action of recent lava flows. Volcanism of the past 3,000 to 6,000 years has created most of the volcanic springs in the Deschutes and Willamette drainages (High Cascades Province) (Benson 1966; Corcoran 1976; Alt 1978). Lava flows from volcanic cones covered or blocked the old stream course of tributaries in these areas. The blocky, permeable surface of the lava diverted the water-flow of the old stream sub-surface; the stream then re-appears at the downslope edge of the lava flow as a spring. The resulting stream typically has a large, cold, constant flow unlike the warmer, lower, and more variable flows of streams draining the Western Cascades (Fig. 43). Within a river basin, these spring-fed streams stand out from other streams with their cold water temperatures and larger base flows (Fig. 44).

The predominance of spring-fed spawning and rearing habitat is also found for bull trout populations in other drainages and geomorphic

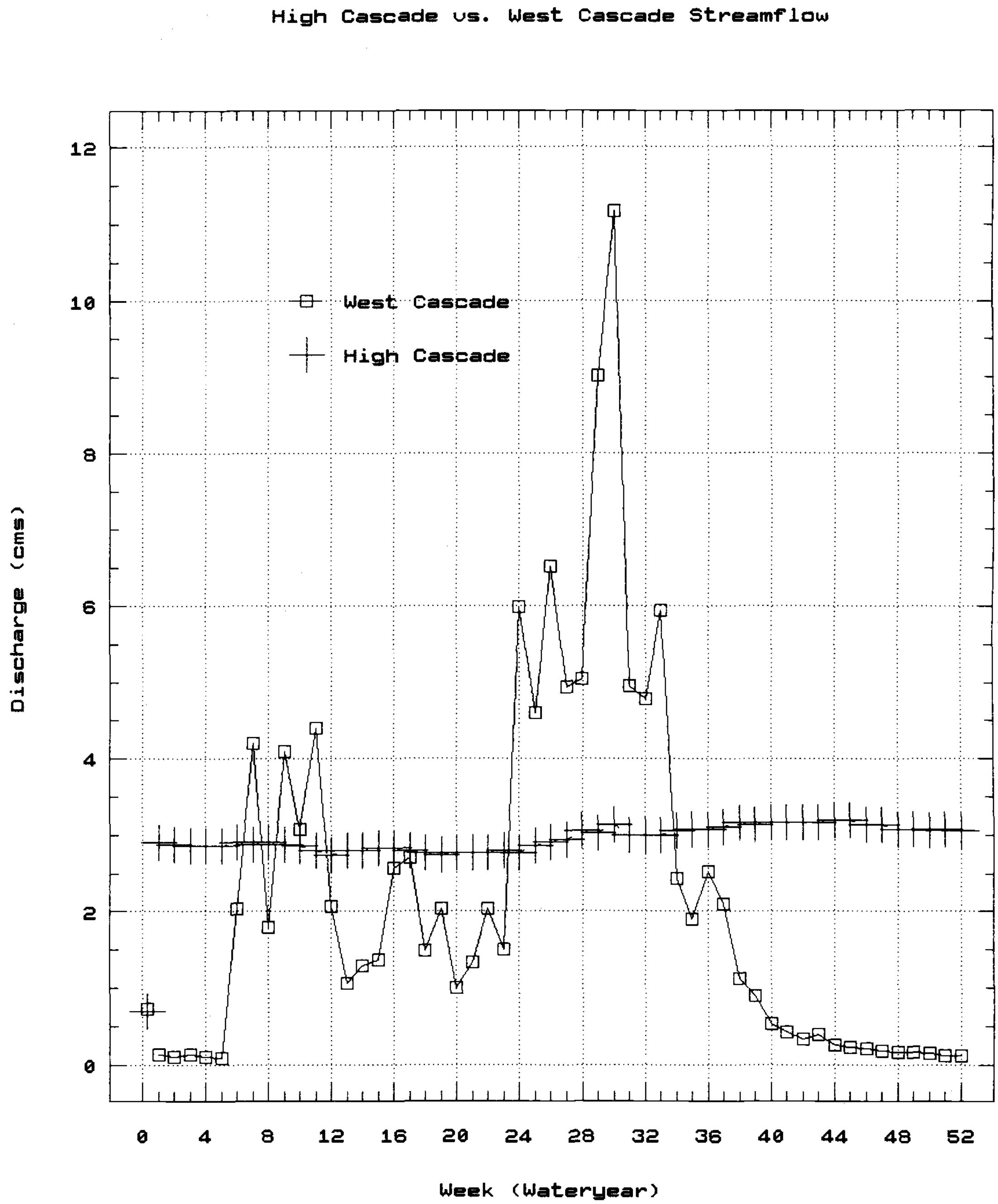


Figure 43. Daily discharge in cubic meters per second (cms) for a West Cascade nonspring-fed stream (Smith River) and a High Cascade spring-fed stream (Fall River) for the water year October 1, 1988 to September 30, 1989. Values are for every seventh day beginning October 1. Data from Hubbard et al. 1989a and 1989b.

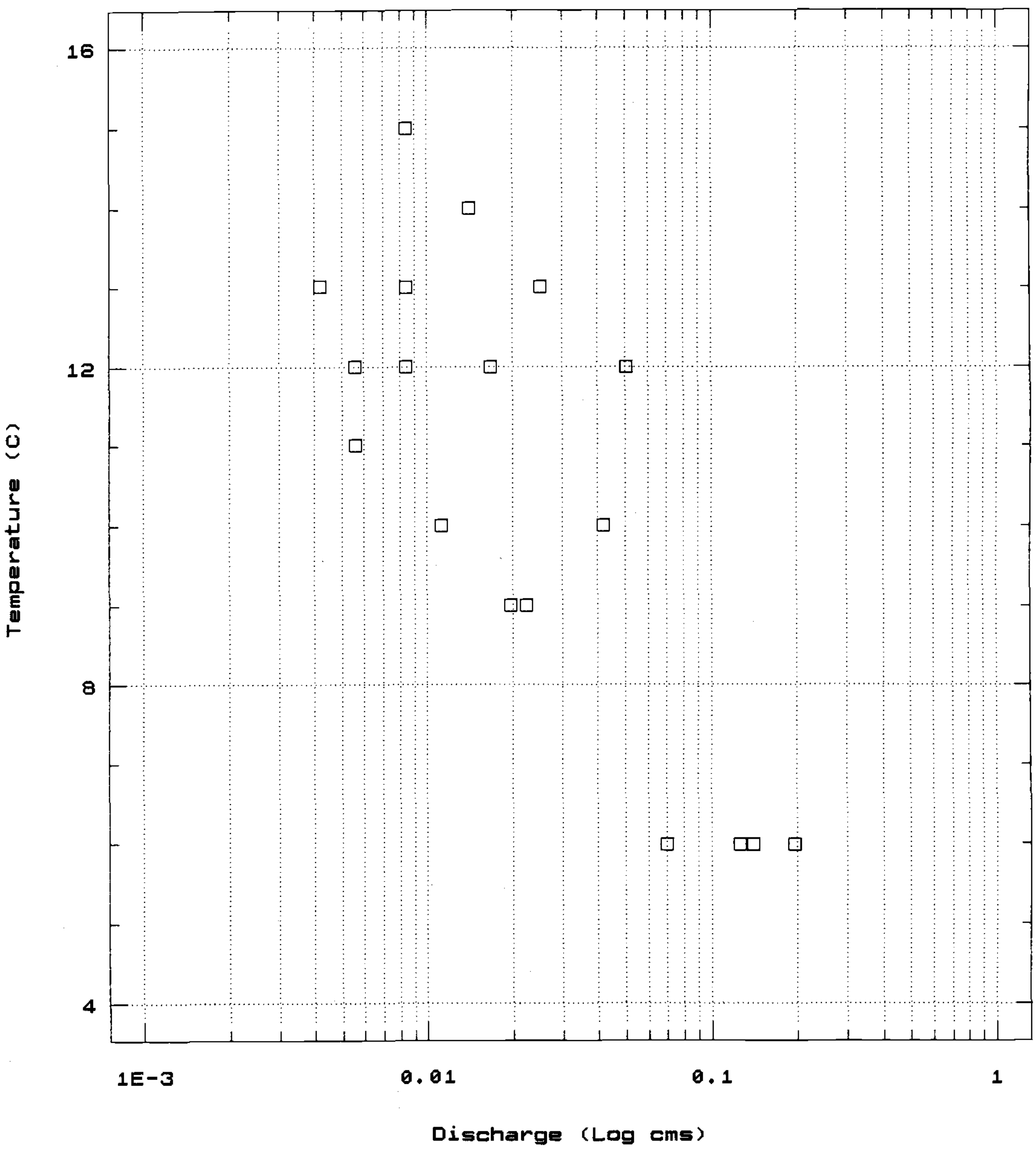


Figure 44. Scatter plot of summer temperature and discharge (log) for spring-fed streams (filled points) and nonspring-fed streams (open points) of the upper McKenzie River. Data from Armantrout and Shula (1975).

provinces of Oregon and Washington. Bull trout spawning and rearing areas in Sun Creek and Cherry Creek of the Wood River drainage are found in spring-fed areas draining the southern High Cascades (Dambacher et al. 1992; J. Dambacher, ODFW, pers. comm. 1993). Bull trout populations in the Basin and Range, parts of the Blue Mountain, and the Southern Washington Cascade Provinces are closely associated with spring-fed areas (M. Fahler, U.S. Forest Service, Gifford Pinchot National Forest, Washington, pers. comm. 1993; Buckman et al. 1992; Ziller 1992), although springs in the Southern Washington Cascade Province are the only ones formed by the volcanic processes described above. Springs in the Blue Mountains and the Basin and Range Provinces are smaller and typically originate from alluvial or glacial deposits.

Bull trout and Dolly Varden are also closely associated with springs in areas outside of Oregon and Washington. The McCloud River (Northern California) bull trout spawned in an area called Big Springs. These springs emerge at a temperature of 7.2°C from a lava flow originating from Mt. Shasta (Rode 1990). In the upper Flathead River, Graham et al. (1982) found the highest concentration of redds in one spring-fed tributary. Fraley and Graham (1981) and Graham et al. (1982) also correlated the selection of bull trout spawning and rearing areas in Flathead River tributaries with springs or areas of groundwater influence. In northern Japan, at the southern boundary of Dolly Varden, K. Fausch (Colorado State University, Ft. Collins, Colorado, pers. comm. 1993) found distribution of Dolly Varden to be related to temperature and groundwater influence. Dolly Varden populations found at the lowest elevations were typically in cold spring-fed streams.

Influence of Groundwater Temperature

In addition to the site-specific association of bull trout and springs, the overall pattern of bull trout distribution in Oregon and Washington follows a trend of decreasing elevation with increasing latitude and longitude, or a general Southeast to Northwest trend. The highest elevation areas were in the lowest latitudes and longitudes in the southern and eastern margins of the range, while the lowest elevation areas were at the highest latitudes and longitudes in the far north and northwest (Figs. 36 and 37). All spring-fed streams, and in particular west slope spring-fed streams, in the Cascade Mountains from northern California to southern Washington are an exception to this pattern, being at lower elevations and lower temperatures for a given latitude than would otherwise be expected (Fig. 36, 37, and 39).

With the exception of the High Cascades and Southern Washington Cascade spring-fed streams, the pattern of decreasing elevation with increasing latitude can be explained by groundwater temperature. Meisner (1990a) found a pattern of a general increase in elevation with decreasing latitude for brook trout, and defined the lower elevation and latitude of brook trout stream populations by the 15°C groundwater isotherm identified by Collins (1925). My results show bull trout may be adapted to even colder water temperatures, given the maximum 12.0°C groundwater temperature predicted and the significantly lower actual temperatures they were found at in spring-fed streams.

In the Basin and Range and Blue Mountain Provinces, Buckman et al. (1992) and Ziller (1992) reported 100% occurrence of bull trout in areas with average water temperatures of 6.6-6.9°C, which is within the range of temperatures for the spring-fed bull trout streams I surveyed in the Cascade Mountains (mean=7.7, Table 2).

All members of the genus Salvelinus are recognized as coldwater adapted species, with their wide distribution in Arctic and northern temperate regions (Banarescu 1990). Bull trout may require colder water temperatures for various life stages than practically every other lotic species native to the continental United States (Scott and Crossman 1973; McPhail and Murray 1979; Wydoski and Whiting 1979; Fraley and Shepard 1989).

Cold water temperatures are requisite for various bull trout life stages. The maximum threshold temperature at which bull trout spawning begins is 9°C (McPhail and Murray 1979; Weaver and White 1985; Fraley and Shepard 1989), while the most intense spawning activity has been recorded at temperatures from 5.0-6.5°C (Scott and Crossman 1973; Wydoski and Whitman 1979). The highest survival and growth rates of incubating eggs for bull trout occur at temperatures from 2° to 4°C (Blackett 1973; McPhail and Murray 1979). Thus, the relation of bull trout to elevation, latitude, and longitude appears to be intimately tied to this cold water requirement.

The southwest distribution boundary for bull trout is defined by cold, volcanic spring-fed streams. Without these streams, bull trout probably would not be found in these low elevation and low latitude areas. Therefore, expected warmer groundwater temperatures and lack of volcanic coldwater springs most likely explains the absence of bull trout from other southwestern areas of Oregon and Washington such as the Western Cascades and the Coast Range. Increases in stream temperature from changes in the forest canopy or reduced water yield may ultimately lead to further restriction of the range of bull trout (Rieman and McIntyre 1993).

Factors Explaining Bull Trout Demise

In the Cascade Mountains of Oregon, specifically the Deschutes and Willamette River basins, the demise of bull trout can be attributed to the influence of humans. The principal factors reducing the range and distribution of bull trout are (1) water control structures (dams, weirs, and culverts) which inundate stream habitat or block access to spawning and rearing habitat and interchange between migratory populations, and (2) the introduction of exotic salmonids (primarily brook and brown trout). Flooding and associated habitat degradation also affect populations of bull trout to an unknown extent.

Dams. The primary factor in the reduction of bull trout range and distribution appears to be construction of water storage structures. From 1953 to 1968, 11 structures were completed on historical or current bull trout streams in the Willamette and upper Deschutes River basins (Table 16). While smaller structures were built in the upper Deschutes as early as 1909, three large irrigation structures were completed between 1940 and 1964 in areas formerly inhabited by bull trout. Only three known bull trout populations still exist above these barriers -- Trailbridge Reservoir, South Fork McKenzie, and upper Middle Fork Willamette. Ratliff and Howell (1992) listed the status of the latter two populations as facing a high risk of extinction. For the eight populations that are now gone, the longest time to extirpation was 15 years while the average time was 8.75 years after dam construction. A number of interrelated factors associated with the construction, operation, and management of these structures have contributed to the decline of bull trout (Table 16).

Table 16. Water control structures built in the Deschutes and Willamette River Basins near current and historical bull trout habitat (last year of bull trout record from Appendix).

River Basin	River	Lake	River Mile	Year of Dam Construction	Last Year of Bull Trout Record	Factors Associated with Demise[a]
Willamette	Middle Fork	Hills Creek	232.5	1961	1991	R, M, E
		Look-out Point	206.9	1954	1969	M
		Dexter	203.8	1954	1969	M
	Fall Creek	Fall Creek	7.2	1966	1970	R, M
	McKenzie	Carmen	85	1965	1965	E, I, D
		Trailbridge	81.5	1963	1994	I, M, E, D
	Smith	Smith	2.1	1963	1963	E, M, D
	South Fork McKenzie	Cougar	4.5	1963	1994	M, T
	North Santiam	Detroit	60.9	1953	1955	M, R, E
		Big Cliff	58.1	1953	1955	M, R
	Oak Grove Fk Clackamas	Timothy	15.8	1956	1960	M, E, I
Deschutes	Little Deschutes	Crescent	30.0	1956[b]	1959	M, E, D, T
	Upper Deschutes	Crane Prairie	238.3	1940[c]	1955	I, M, E, D, T
		Wickiup	226.8	1949[c]	1957	I, M, E, D, T

a. Factors associated with decline or demise -- R=rotentone or other toxic chemical treatment; M=migration barrier to spawners, juveniles, between population groups, to prey areas; E=exotic fish introduction in previous spawning/rearing areas; I=inundation of spring-fed spawning/ rearing areas; D=water diversion for hydroelectric generation or irrigation; T=change in temperature in downstream spawning/rearing areas.

b. A small dam was built in 1909, the final 40 ft. high dam was built in 1956.

c. Small dams were built in the 1920's, the final larger structures were completed in 1940 and 1949.

Other Physical Barriers. Culverts and weirs are smaller physical barriers than the structures used for hydropower, irrigation, and flood control, but can still reduce or eliminate fish migrating upstream. These smaller barriers may have decreased populations in the upper McKenzie and contributed to the elimination of the upper North Santiam run. In the McKenzie basin, Sweetwater, Anderson, and Ollalie Creeks share a common spring-source area (Taylor 1965), but only Anderson Creek and lower Ollalie Creek contain bull trout. Sweetwater Creek is isolated from Trailbridge Reservoir by a 2-3 m drop from a culvert to the reservoir high water mark, while bull trout in Ollalie Creek are only found in the lower 0.8 km up to another culvert. In the North Santiam, bull trout were caught up to Marion Forks until the early to mid-1950s (M. Lavine, Toledo, Oregon, pers. comm. 1992; H. Farmen, Mill City, Oregon, pers. comm. 1992). The Marion Forks Fish Hatchery was completed in 1950, using spring-fed Horn Creek as its primary water source. A weir and water diversion structure were built, creating a low flow barrier to late summer and early fall upstream migrants (A. Girard, Mill City, Oregon, pers. comm. 1992).

Several endangered and extinct bull trout populations in the Oregon Cascades could be protected or resurrected with improved passage facilities at existing water control structures. In the areas where bull trout are restricted by dams, weirs, or culverts, retrofitting of these structures for migratory bull trout passage may be the key factor for successful reintroduction. At Mud Mountain Dam on the White River, Washington, a trap and haul facility for migratory salmonids has been in operation below the dam for more than 35 years. Adult bull trout have been recorded and successfully hauled around the structure for the past eight years (F. Goetz, pers. obs.). On Sweetwater Creek, a tributary to Trailbridge Reservoir (Fig. 32), an improved culvert and fish ladder have been constructed recently with the goal of reestablishing bull trout using fry from Anderson Creek (Capurso, in press). Conservation of these migratory populations could have the highest potential for sustaining the species in the Pacific Northwest (Rieman and McIntyre 1993).

Introduction of Other Species. Dams not only diverted water flow and created migration barriers, they also inundated much critical habitat while providing excellent cool water lotic habitat for exotic salmonids.

Brook trout, brown trout, and lake trout have been implicated in the extirpation and decline in range of bull trout throughout their distribution (Leary et al. 1983 and 1985; Carl 1985; Rode 1990; Donald and Alger 1993). Brook trout have been found to hybridize with bull trout (Leary et al. 1983 and 1985; Markle 1992), and possibly out-compete bull trout when in sympatry (Dambacher et al. 1992; Ziller 1992).

Brown trout and brook trout are now found in every major historical bull trout drainage except the South Fork McKenzie (Johnson et al. 1985; Casali and Diness 1988; T. Fies, ODFW unpublished data, Bend, Oregon; J. Fortune, ODFW unpublished data, Klamath Falls, Oregon; W. Hunt, ODFW unpublished data, Salem, Oregon, 1989; T. McAllister, Oregonian Newspaper, Portland, Oregon, pers. comm. 1990; R. Swan, Oregon State Game Commission unpublished data, Springfield, Oregon). Lake trout are also present in Odell and Crescent Lakes. Brook trout and brown trout now occupy approximately 21 and 28% of former bull trout stream habitat in the Willamette (164.4 of 781.3 km) and Deschutes basins (194 of 694.4 km), respectively. Brown trout introduction has also been implicated in the isolation of brook trout to headwater stream habitats and the decline of bull trout populations in Alberta (Brynildson et al. 1964, Carl 1985).

Even if current coldwater habitats are protected, there could be a continual restriction in bull trout range with predicted climate changes. Rieman and McIntyre (1993) believed that if mean annual air temperatures in the Pacific Northwest increase by 2-3°C over the next century, bull trout could be excluded from most coldwater habitat they currently use. Future encroachment by introduced brook and brown trout may push bull trout even further into headwater areas or eliminate them entirely from currently inhabited coldwater habitat. Meisner (1990a) speculated that climatic warming could benefit naturalized populations of brook trout in western North America now constrained by low temperatures. Only in areas with natural barriers or high stream gradients will encroachment into bull trout areas be limited (Dambacher et al. 1992; Ziller 1992).

Flooding. The abundance of bull trout may be greatly reduced by winter flooding (Rieman and McIntyre 1993). Several current and historical bull trout drainages have been impacted by large floods related to precipitation and to glacial sources. Brown (1993) noted that bull trout populations in east Cascade tributaries were severely impacted by the November 1990 flood mentioned above. In 1964, one of the largest storms on record hit the Willamette basin and severely damaged several major trout streams, including the upper Middle Fork and Swift Creek (Skeesick and Jones 1988). On a larger scale, glacial floods may have eliminated bull trout from several areas. Glacial floods from the break-off of large pieces of glaciers, or the collapse of glacial lake outlets, have been reported for several High Cascade drainages (Nolf 1966). The West Fork Hood was impacted by a glacial flood in 1962 (R. Hazeman, Longview, Washington, pers. comm. 1992); bull trout were last recorded from the creel in the West Fork in 1963 and are now considered extinct there (Appendix; Ratliff and Howell 1992). In the North Santiam, a glacial flood that began on the north slope of Mt. Jefferson, where the headwaters of the Breitenbush River originate, was reported in the 1940s. A similar flood during the same time period was reported to have come from the North Sister Volcano and reached the McKenzie River, possibly through the Lost Creek system (Nolf 1966). Bull trout were not found in Lost Creek spring-fed sites, nor have they been recorded in this stream in recent years (Fig. 32, Appendix).

Large scale flood events are a natural occurrence in the Cascade Mountains, and bull trout populations would normally be expected to re-populate disturbed areas. However, with their already depleted numbers and manmade barriers to nearby migratory populations, this may not be possible. Rieman and McIntyre (1993) suggested that migratory populations with less than 100-200 adults face the greatest risk of extirpation. With the exception of the Metolius River population, most of the systems I surveyed likely have far fewer fish than this. Pearsons and Li (1992) believed high habitat complexity may ameliorate the impacts from large scale disturbances. While many of spring-fed streams I surveyed had such complexity, much of the headwater stream habitat used by bull trout in other areas has been heavily impacted by land management activities resulting in channel instability, loss of available cover, and infilling of substrates. The long-term maintenance of high quality stream habitat, restoration of degraded habitat, and improved access to existing habitat is absolutely necessary to insure the persistence of healthy bull trout populations.

GENERAL CONCLUSION

I began this study from the perspective that the bull trout is a rare and sensitive species. With that in mind, I wanted to use my understanding of the ecology of this fish to determine appropriate non-lethal sampling methods. Night snorkeling appears to be an effective method for documenting juvenile bull trout presence or absence, determining abundance, and studying habitat use. This technique can also be applied over a variety of habitats such as streams, rivers, lakes, and reservoirs, and is effective throughout the year. However, this technique may be poorly suited for sampling fry and to survey remote areas.

An increasing number of researchers are utilizing night snorkeling for presence and absence surveys, density estimates, and habitat studies (D. Hann, U.S. Forest Service, Mt. Baker-Snoqualmie National Forest, pers. comm. 1994; R. Spangler, University of Idaho, Moscow, pers. comm. 1994). Night snorkeling is also being added to established distribution survey protocols to verify presence or absence of bull trout following initial surveys by day snorkeling (G. Watson, Plum Creek Timber, Missoula, Montana, pers. comm. 1994).

Night snorkeling may be significant because of the distinct differences in diel behavior observed in juvenile bull trout. Cold water temperatures may be an important factor explaining this day hiding and night emergence with resulting diel differences in presence/absence, abundance, and habitat use. My study presents strong empirical evidence supporting this conclusion. Studies of other salmonids during winter have also shown a strong correlation between low water temperatures and differences in diel behavior. Further study at different temperature regimes may clarify this relationship and could define a water temperature threshold where day and night differences are not as distinct. If such a threshold could be determined, the effectiveness of sampling juvenile bull trout by day snorkeling could potentially be improved. Future studies are currently being planned to investigate the link between temperature and diel behavior in bull trout (E. Conner, R2 Associates, Kirkland, Washington, pers. comm. 1994).

Although it is not the only factor, temperature has been recognized most often by researchers as being a critical factor in determining bull trout distribution and abundance. In the Oregon Cascades, I only found juvenile bull trout in the coldest spring-fed streams. In comparison with predicted groundwater temperatures, bull trout were found at significantly lower elevations and colder than expected water temperatures. Further study of the relationship of bull trout distribution to groundwater temperatures may clarify their selection of specific spawning and rearing areas and could improve prediction of their response to future temperature changes.

This study was the first to document the historical distribution of bull trout in Oregon and Washington. It was also the first research conducted to specifically determine the current distribution of bull trout in several Cascade Mountain river systems. In comparing their past and present distribution in the Oregon Cascades, bull trout were found in only 26.2 and 56.2% of their original distribution in the Willamette and Deschutes River basins, respectively. Several potential factors related to the demise of bull trout were identified, including: physical barriers, introduction of exotic salmonids, and habitat degradation. Recognition of these suppressing factors may help managers improve existing populations and restore extirpated ones.

The results of the habitat use study, where juvenile bull trout were found in close association with cover during all time periods, are also applicable to restoration efforts. To reduce impacts from large scale disturbances and to restore or enhance populations with low abundance, habitat complexity of streams must be maintained, and access to existing habitat must be provided. The addition of woody debris to increase available instream habitat should also be considered. While there have been few efforts to restore migratory bull trout populations in Oregon or Washington, one exception is Sweetwater Creek. Replacement of a single road culvert may double the habitat available to the Trailbridge Reservoir population. The Sweetwater Creek project should be an example to land managers of the many potential opportunities that are at hand to bring back a rare native fish.

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APPENDIX

Appendix: Historical Distribution Records of Bull Trout in Oregon and Washington

To determine the historical distribution of bull trout in Oregon and Washington, an initial literature review of published material, gray literature, and unpublished data pertinent to bull trout was compiled in 1989. Since that time, more current data (stream inventories and point-in-time samples) from the Oregon Department of Fisheries and Wildlife (ODFW), Washington Department of Wildlife (WDW), the U.S. Forest Service (USFS) and other interested parties have been collected. This information is included as much as possible. Distribution data obtained from personal interviews and more recent literature for Oregon (Buckman et al. 1992; Dambacher et al. 1992; Ratliff and Howell 1992; Ziller 1992) and Washington (Mongillo 1993) are also included.

Historical records are listed in Appendix Tables 1 and 2 by river drainages in Oregon and county drainages in Washington.

This is the first summary of historical distribution for Oregon and Washington; therefore, this list should not be considered complete and definitive as more information is being collected and summarized by respective state and federal agencies.

Appendix Table 1. Historical distribution of bull trout in Oregon.

Deschutes River drainages:

1. Abbot Creek, 1957, (Foster 1957)
2. Bakeoven Creek, 1958, (OGC)[a]
3. Blue Lake (and Link Creek), 1940, (Newcomb 1941)
4. Candle Creek, 1989, (Fig. 15)
5. Canyon Creek, 1989, (Fig. 15)
6. Clear Creek, 1954, (OGC)
7. Crane Prairie Reservoir, 1955, (OGC)
8. Crescent Lake, 1959, (OGC)
9. Crooked River, 1992, (RH)[b]
10. Crystal Creek, 1948, (OGC)
12. Davis Lake, 1988, (CD)[c]
13. Deschutes River
    a. Bend-Pringle Falls, 1992, (RH)
    b. Cove, 1992, (RH)
    c. Grandview, 1960, (OGC)
    d. Maupin, 1992, (RH)
    e. Mecca, 1960, (OGC)
    f. Oak Springs, 1960, (OGC)
    g. Pringle Falls-Wickiup, 1960, (OGC)
    h. Sherars, 1960, (OGC)
    i. Trout Creek, 1992, (OGC)
    j. Warm Springs, 1992, (RH)
14. Fall River, 1954, (OGC)
15. Jack Creek, 1992, (RH)
16. Jefferson Creek, 1992, (RH)
17. Lake Billy Chinook, 1992, (RH)
18. Lake Creek, 1942, (Ratliff 1992)
19. Little Lava Lake, 1940, (Newcomb 1941)
20. Metolius River, 1989, (Fig. 15)
21. Odell Creek, 1988, (CD)
22. Odell Lake, 1989, (Fig. 16)
23. Roaring Creek, 1989, (Fig. 15)
24. Sherars Creek, 1955, (OGC)
25. Shitike Creek, 1992, (RH)
26. Spring Creek, 1981, (Ratliff 1992)
27. Suttle Lake, 1961, (OGC)
28. Trapper Creek, 1989, (Fig. 16)
29. Warm Springs River (and major tributaries), 1992, (RH)
30. Wickiup Reservoir, 1957, (OGC)

Grande Ronde River drainages:

1. Bear Creek, 1992, (RH)
2. Big Sheep Creek, 1992, (RH)
3. Catherine Creek, 1992, (RH)
4. Clear Creek, 1992, (RH)
5. Grande Ronde River, 1992, (RH)
6. Hurricane Creek, 1992, (RH)
7. Imnaha River, 1992, (RH)
8. Indian Creek, 1992, (RH)
9. Indiana Creek, 1992, (RH)

10. Kinney Lake, 1972, (ODFW)[d]
11. Lick Creek, 1960, (OGC)
12. Limberjim Creek, 1992, (RH)
13. Little Minam River, 1992, (RH)
14. Little Sheep Creek, 1992, (RH)
15. Lookingglass Creek, 1992, (RH)
16. Lostine River, 1992, (RH)
17. McCully Creek, 1992, (RH)
18. Minam River, 1992, (RH)
19. Snake River (Hells Canyon to Oxbow dam), 1966, (OGC)
20. Wallowa Lake, 1977, (ODFW)
21. Wenaha River, 1992, (RH)

Hood River drainages:
1. Clear Branch Creek, 1992, (RH)
2. Farm Ditch, 1955, (OGC)
3. Hood River, 1992, (RH)
4. Mosier Creek, 1958, (OGC)
5. West Fork Hood River, 1963, (OGC)

John Day River drainages:
1. Big Creek, 1992,(RH)
2. Canyon Creek, 1956, (OGC)
3. Clear Creek, 1963, (OGC)
4. Crane Creek, 1959, (OGC)
5. Davis Creek, 1959, (OGC)
6. Deardorf Creek, 1962, (OGC)
7. Granite Boulder Creek, 1992, (RH)
8. John Day River (upper), 1992, (RH)
9. Middle Fork John Day River, 1992, (RH)
10. North Fork John Day River, 1992, (RH)
11. Rail Creek, 1961, (OGC)
12. Reynolds Creek, 1955, (OGC)
13. Roberts Creek, 1967, (OGC)

Klamath River drainages:
1. Boulder Creek, 1989, (Z)[e]
2. Branchroot Creek, 1979, (Oregon State University Fish Collection)
3. Brownsworth Creek, 1989, (Z)
4. Cherry Creek, 1992, (RH)
5. Coyote Creek, 1987, (Z)
6. Cracker Creek, 1992, (D)[f]
7. Deming Creek, 1989, (Z)
8. Dixon Creek, 1992, (RH)
9. Klamath Lake, 1879, (Cope 1879)
10. Leonard Creek, 1989, (Z)
11. Linn Creek, 1978, (ODFW)
12. Long Creek, 1989, (Z)
13. North Fork Sprague River, 1962, (OGC)
14. Seven-Mile Creek, 1879, (Cope 1879)
15. South Fork Sprague River, 1962, (OGC)
16. Sun Creek, 1989, (D)
17. Sycan River, 1992, (RH)
18. Three-Mile Creek, 1993, (D. Logan, OSU, Corvallis, pers. comm. 1994)

19. Wood River, 1938, (D)

Malheur River drainages:
1. Big Creek, 1990, (B)[g]
2. Bosenberg Creek, 1990, (B)
3. Corral Basin Creek, 1990, (B)
4. Cow Creek, 1990, (B)
5. Crane Creek, 1957, (OGC)
6. Elk Creek, 1990, (B)
7. Flat Creek, 1990, (B)
8. Lake Creek, 1990, (B)
9. Little Crane Creek, 1990, (B)
10. Little Malheur River, 1967, (OGC)
11. McCoy Creek, 1990, (B)
12. Meadow Fork Big Creek, 1990, (B)
13. Middle Fork Malheur River, 1990, (B)
14. North Fork Malheur River, 1990, (B)
15. Sheep Creek, 1990, (B)
16. Summit Creek, 1990, (B)
17. Swamp Creek, 1990, (B)

Pine Creek drainages:
1. East Pine Creek, 1992, (RH)
2. Elk Creek, 1992, (RH)
3. Meadow Creek, 1992, (RH)
4. Middle Fork Pine Creek, 1992, (RH)
5. North Fork Pine Creek, 1992, (RH)

Powder River drainages:
1. Anthony Creek, 1992, (RH)
2. Brownlee Reservoir, 1959, (OGC)
3. Eagle Creek, 1992, (RH)
4. Indian Creek, 1992, (RH)
5. Lake Creek, 1992, (RH)
6. Little Cracker Creek, 1992, (RH)
7. Powder River, 1960, (OGC)
8. Silver Creek, 1992, (RH)
9. West Fork Eagle Creek, 1965, (OGC)

Umatilla River drainages:
1. Little Walla Walla River, 1963, (OGC)
2. Mill Creek, 1992, (RH)
3. North Fork Umatilla River, 1992, (RH)
4. North Fork Walla Walla River, 1992, (RH)
5. South Fork Umatilla River, 1992, (RH)
6. South Fork Walla Walla River, 1992, (RH)

Willamette River drainages:
Lower
1. Buck Creek, 1976, (J. Massey, ODFW, Estacada, pers. comm. 1992)
2. Clackamas River (lower, to RKm 3.0), 1879, (Jordan 1907)
3. Clackamas River (upper), 1960, (OGC)
4. Oak Grove Fork Clackamas River (Lower), 1946, (C. Campbell, OGC, unpublished data)

5. Sandy River, 1964, (Hutchison and Aney)

Middle

1. Breitenbush River, 1966, (D. Hurt, Mehama, Oregon, pers. comm. 1992)
2. North Santiam River (lower, to Willamette River), 1938, (B. Sanderson, Mehama, Oregon, pers. comm. 1992)
3. North Santiam River (upper, to Marion Forks), 1955, (A. Girard, Mill City, Oregon, pers. comm. 1992)
4. South Santiam River, 1953, (OGC)

Upper

1. Anderson Creek, 1989, (Fig. 17)
2. Carmen Reservoir, 1965, (OGC)
3. Cougar Reservoir, 1992, (RH)
4. Dexter Reservoir, 1969, (D. Maher, Dexter Fish Hatchery, Oregon, pers. comm. 1990)
5. Fall Creek Reservoir 1970, (M. Wade, ODFW, Springfield, pers. comm. 1993)
6. French Pete Creek 1964, Kivett 1964
7. Hills Creek Reservoir, 1989, (Fig. 19)
8. Leaburg Lake (and lower McKenzie), 1993, (ODFW)
9. Long Tom River, 1962, (OGC)
10. Lookout Point Reservoir, 1969, (D. Maher, Dexter Fish Hatchery, pers. comm. 1990)
11. McKenzie River, 1989, (Fig. 17)
12. Middle Fork Willamette River, 1992, (RH)
13. North Fork Willamette River, 1962, (OGC)
14. Olallie Creek, 1991, (Fig. 17)
15. Roaring River, 1990, (Fig. 18)
16. Salt Creek, 1960, (OGC)
17. Separation Creek, 1993, (ODFW)
18. Smith Reservoir, 1963, (OGC)
19. South Fork McKenzie River (below Cougar Dam), 1988, (S. Gregory, OSU, unpublished data)
20. South Fork McKenzie River (upper), 1990, (Fig. 18)
21. Staley Creek, 1960, (R. Swan, OGC, unpublished data)
22. Swift Creek, 1960, (R. Swan, OGC, unpublished data)
23. Trail Bridge Reservoir, 1989, (Fig. 17)

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a. Oregon Game Commission Annual Reports
b. Ratliff and Howell 1992
c. Casali and Diness 1988
d. Oregon Department of Fisheries and Wildlife unpublished data
e. Ziller et al. 1992
f. Dambacher et al. 1992
g. Buckman et al. 1992

Appendix Table 2. Historical distribution of bull trout in Washington.

Asotin County drainages:
1. Charley Creek, 1993, (M)[a]
2. Grande Ronde River, 1993, (M)
3. North Fork Asotin Creek, 1993, (M)
4. South Fork Asotin Creek, 1993, (M)

Benton County drainages:
1. Yakima River, 1972, (WDW)[b]

Chelan County drainages:
1. Buck Creek, 1989, (B)[c]
2. Canyon Creek, 1989, (B)
3. Chelan Lake, 1957, (WDW)
4. Chickamin Creek, 1989, (B)
5. Chiquakum Lake, 1947, (WDW)
6. Chiquakum River, 1958, (WDW)
7. Chiwaukum Creek, 1990, (B)
8. Chiwawa River, 1989, (B)
9. Eightmile Creek, 1990, (B)
10. Entiat River, 1989, (B)
11. French Creek, 1990, (B)
12. Icicle Creek, 1990, (B)
13. Ingalls Creek, 1990, (B)
14. Little Wenatchee River, 1971, (WDW)
15. Mad River, 1989, (B)
16. Mill Creek, 1989, (B)
17. Nason Creek, 1959, (WDW)
18. Phelps Creek, 1989, (B)
19. Rock Creek, 1989, (B)
20. Sears Creek, 1989, (B)
21. Steheken River, 1955, (WDW)
22. Tillicum Creek, 1989, (B)
23. Wenatchee Lake, 1993, (M)
24. Wenatchee River, 1993, (M)
25. White River, 1939, (WDW)

Clallam County drainages:
1. Aldwell Lake, 1968, (WDW)
2. Bogachiel River, 1941, (WDW)
3. Dungeness River, 1993, (M)
4. East Fork Dungeness River, 1967, (WDW)
5. Elwah River, 1993, (M)
6. Goodman Creek, 1993, (M)
7. Graywolf River, 1960, (WDW)
8. Hoh River, 1993, (M)
9. Lyre River, 1962, (WDW)
10. Morse Creek, 1993, (M)
11. Solduc River, 1993, (M)
12. South Fork Hoh River, 1993, (M)
13. Sutherland Lake, 1952, (WDW)

Clark County drainages:
1. Beaver Lake, 1962, (WDW)
2. Burnt Bridge Creek, 1938, (WDW)

Columbia County drainages:
1. Armstrong Lake, 1962, (WDW)
2. Big Four Lake, 1971, (WDW)
3. Blue Lake, 1963, (WDW)
4. Butte Lake, 1972, (WDW)
5. Cummings Creek, 1960, (WDW)
6. Curl Lake, 1960, (WDW)
7. Deer Lake, 1964, (WDW)
8. East Fork Butte Creek, 1960, (WDW)
9. New Lake, 1960, (WDW)
10. North Fork Touchet River, 1970, (WDW)
11. Panjab Creek, 1971, (WDW)
12. Rainbow Creek, 1970, (WDW)
13. Rainbow Lake, 1970, (WDW)
14. Sheep Creek, 1960, (WDW)
15. Snake River, 1973, (WDW)
16. South Fork Touchet River, 1970, (WDW)
17. Spring Lake, 1973, (WDW)
18. Touchet River, 1971, (WDW)
19. Trout Creek, 1970, (WDW)
20. Tucannon Lake, 1993, (M)
21. Tucannon River, 1973, (WDW)
22. Twenty-Mile Creek, 1958, (WDW)
23. Upper Tucannon River, 1955, (WDW)
24. Watson Lake, 1962, (WDW)
25. West Fork Butte Creek, 1972, (WDW)

Cowlitz County drainages:
1. Merwin Reservoir, 1993, (M)
2. North Fork Lewis River, 1993, (M)
3. Yale Reservoir, 1993, (M)

Douglas County drainages:
1. Columbia River, 1956, (WDW)

Franklin County drainages:
1. Dalton Lake, 1968, (WDW)
2. Emma Lake, 1968, (WDW)
3. Scootney Lake, 1961, (WDW)
4. Snake River, 1968, (WDW)

Garfield County drainages:
1. Bear Creek, 1945, (WDW)
2. Crooked Fork Creek, 1963, (WDW)
3. Pataha Creek, 1993, (M)
4. Tucannon River, 1993, (M)
5. Watson Lake, 1963, (WDW)

Grant County drainages:
1. Banks Lake, 1972, (WDW)

2. Crab Creek, 1988, (WDW)
3. Moses Lake, 1969, (WDW)

Grays Harbor County drainages:
1. Chehalis River, 1993, (M)
2. Copalis River, 1993, (M)
3. Damon Lake, 1969, (WDW)
4. Elk Creek, 1967, (WDW)
5. Humptulips River, 1958, (WDW)
6. Moclips River, 1993, (M)
7. Quinault Lake, 1969, (WDW)
8. Quinault River, 1993, (M)
9. Raft River, 1993, (M)
10. Wynoochee River, 1993, (F. Goetz, U.S. Army Corps of Engineers, unpublished data)

Island County drainages:
1. Bush Point Lake, 1956, (WDW)

Jefferson County drainages:
1. Duckabush River, 1946, (WDW)
2. Hoh River, 1993, (M)
3. Queets River, 1993, (M)

King County drainages:
1. Cedar River (Lower), 1993, (E. Warner, Muckleshoot Indian Tribe, pers. comm.)
2. Duwammish River, 1980, (F. Goetz, U.S. Army Corps of Engineers, unpublished data)
3. Elliott Bay, 1889, (Cavender, 1978)
4. Green River, 1980, (Meyer et al. 1981)
5. Issaquah Creek, 1992, (B. Furstenburg, King County Surface Water Management, pers. comm. 1993)
6. Lake Chester Morse, 1993, (M)
7. Lake Sammamish, 1960, (B. Furstenburg, King County Surface Water Management, pers. comm. 1993)
8. Lake Washington, 1983, (B. Pfiefer, WDW, pers. comm.)
9. Red Creek, 1956, (WDW)
10. Rex River, 1993, (E. Conner, R2 Associates, pers. comm.)
11. Soos Creek, 1956, (WDW)
12. Upper Cedar River (and major tributaries), 1993, (E. Conner, R2 Associates, pers. comm.)
13. Wilderness Lake, 1971, (WDW)

Kitsap County drainages:
1. Union River, 1957, (WDW)

Kittitas County drainages:
1. Box Canyon Creek, 1991, (K. Staley, USFS, Wenatchee National Forest, pers. comm.)
2. Cle Elum Lake, 1993, (M)
3. Cle Elum River, 1993, (M)
4. Coleman Creek, 1970, (WDW)
5. Gold Creek, 1991, (Fig. 20)

6. Gold Creek Pond, 1991, (Fig. 20)
7. Kachess Lake, 1993, (M)
8. Keechelus Lake, 1993, (M)
9. Waptus Lake, 1993, (M)
10. Yakima River, 1967, (WDW)

Klickatat County drainages:
1. Box Canyon Creek, 1993, (M)
2. Dog Creek, 1990, (B)
3. Drano Lake, 1988, (WDW)
4. Gold Creek, 1993, (M)
5. Hindoo Creek, 1990, (B)
6. Klickitat River, 1993, (M)
7. Rattlesnake Creek, 1943, (WDW)
8. Trappers Creek, 1993, (M)
9. White Salmon River, 1993, (M)

Mason County drainages:
1. Dewatto River, 1966, (WDW)
2. Hamma Hamma River, 1948, (WDW)
3. Lake Cushman, 1968, (WDW)
4. Skokomish River, 1969, (WDW)
5. South Fork Skokomish River, 1970, (WDW)

Okanogan County drainages:
1. Black Pine Lake, 1960, (WDW)
2. Chewack River, 1973, (WDW)
3. Columbia River, 1964, (WDW)
4. Conconully Lake, 1973, (WDW)
5. Davis Lake, 1962, (WDW)
6. Early Winters Creek, 1993, (M)
7. Eight-Mile Creek, 1993, (M)
8. Gold Creek, 1970, (WDW)
9. Hidden Lakes, 1993, (M)
10. Lost River, 1993, (M)
11. Methow River, 1993, (M)
12. Okanogan River, 1953, (WDW)
13. Patterson Lake, 1964, (WDW)
14. Salmon Creek, 1949, (WDW)
15. Salmon Lake, 1953, (WDW)
16. Twisp River, 1973, (WDW)

Pend Oreille County drainages:
1. Pend Oreille River, 1993, (M)
2. Priest Lake, 1993, (M)

Pierce County drainages:
1. Carbon River, 1993, (M)
2. Greenwater River, 1991, (B. Evans, USFS, Mt. Baker-Snoqualmie National Forest,unpublished data)
3. Huckleberry Creek, 1991, (G. Stegner, USFS, Mt. Baker-Snoqualmie National Forest, unpublished data)
4. Nisqually River, 1993, (M)
5. Puyallup River, 1993, (F. Goetz, U.S. Army Corps of Engineers,

unpublished data)

6. Voila Creek, 1991, (G. Stegner, USFS, Mt. Baker-Snoqualmie National Forest, unpublished data)
7. West Fork White River, 1991, (G. Stegner, USFS, Mt. Baker-Snoqualmie National Forest, unpublished data)
8. White River, 1993, (F. Goetz, U.S. Army Corps of Engineers, unpublished data)

Skagit County drainages:

1. Bacon Creek, 1992, (F. Goetz, U.S. Army Corps of Engineers, unpublished data)
2. Baker Lake, 1993, (M)
3. Buck Creek, 1956, (WDW)
4. Cascade River, 1993, (M)
5. Downey Creek, 1956, (WDW)
6. Finney Creek, 1963, (WDW)
7. Gandy Lake, 1961, (WDW)
8. Gilliam Creek, 1953, (WDW)
9. Jordan Creek, 1943, (WDW)
10. Lake Shannon, 1973, (WDW)
11. Marble Creek, 1948, (WDW)
12. Pilchuck Creek, 1972, (WDW)
13. Rocky Creek, 1943, (WDW)
14. Samish River, 1964, (WDW)
15. Sauk River, 1993, (M)
16. Skagit River, 1993, (M)
17. Suiattle River, 1993, (M)
18. Tenas Creek, 1956, (WDW)

Skamania County drainages:

1. Lewis River, 1959, (WDW)
2. Muddy River, 1993, (M. Fahler, USFS, Gifford Pinchot National Forest, pers. comm.)
3. Pine Creek, 1989, (F. Goetz, U.S. Army Corps of Engineers, unpublished data)
4. Rush Creek, 1993, (M. Fahler, USFS, Gifford Pinchot National Forest, pers. comm.)
5. Swift Reservoir, 1993, (M)
6. Yale Reservoir, 1993, (M)

Snohomish County drainages:

1. Boulder River, 1938, (WDW)
2. Canyon Creek, 1993, (M)
3. Clear Creek, 1961, (WDW)
4. Deer Creek, 1993, (M)
5. Fontal Lake, 1973, (WDW)
6. Jim Creek, 1963, (WDW)
7. North Fork Sauk River, 1993, (M)
8. North Fork Skykomish River, 1993, (J. Doyle, USFS, Mt. Baker-Snoqualmie National Forest, pers. comm.)
9. North Fork Stillaquamish River, 1973, (WDW)
10. Olney Creek, 1954, (WDW)
11. Pilchuck River, 1951, (WDW)
12. Sauk River, 1993, (M)

13. Skykomish River, 1989, (K. Kraemer, WDW, pers. comm.)
14. Snohomish River, 1973, (WDW)
15. South Fork Sauk River, 1993, (M)
16. South Fork Skykomish River, 1993, (M)
17. South Fork Stillaquamish River, 1993, (M)
18. Stillaquamish River, 1993, (M)
19. Suiattle River, 1968, (WDW)
20. Sultan River, 1970, (WDW)
21. Troublesome Creek, 1993, (J. Doyle, USFS, Mt. Baker-Snoqualmie National Forest, pers. comm.)
22. Twin Lakes, 1958, (WDW)
23. Wallace River, 1973, (WDW)
24. Whitechuck River, 1959, (WDW)
25. Woods Creek, 1961, (WDW)

Spokane County drainages:
1. Little Spokane River, 1972, (WDW)
2. Long Lake, 1972, (WDW)

Stevens County drainages:
1. Roosevelt Lake, 1993, (M)

Thurston County drainages:
1. Nisqually River, 1993, (M)

Walla Walla County drainages:
1. Blue Creek, 1937, (WDW)
2. Dry Creek, 1959, (WDW)
3. Mill Creek, 1993, (M)
4. Mill Creek Reservoir, 1993, (M)
5. North Fork Touchet River, 1993, (M)
6. South Fork Touchet River, 1993, (M)
7. Walla Walla River, 1940, (WDW)
8. Wolf Fork, 1993, (M)

Whatcom County drainages:
1. Baker Lake, 1993, (M)
2. Bertrand Creek, 1956, (WDW)
3. Canyon Creek, 1993, (M)
4. Canyon Lake, 1968, (WDW)
5. Chilliwack River, 1993, (M)
6. Diablo Lake, 1973, (WDW)
7. Gorge Lake, 1970, (WDW)
8. Little Canyon Creek, 1954, (WDW)
9. Middle Fork Nooksack River, 1993, (M)
10. Nooksack River, 1973, (WDW)
11. North Fork Nooksack River, 1993, (M)
12. Ross Lake, 1973, (WDW)
13. Skagit River, 1964, (WDW)
14. South Fork Nooksack River, 1993, (M)
15. Thunder Lake, 1954, (WDW)

Yakima County drainages:
1. Ahtanum Creek, 1962, (WDW)

2. American River, 1990, (B)
3. Big Rattlesnake Creek, 1949, (WDW)
4. Bumping Lake, 1993, (M)
5. Bumping River, 1990, (B)
6. Canyon Creek, 1993, (M)
7. Clear Lake, 1973, (WDW)
8. Cowiche Creek, 1968, (WDW)
9. Dog Lake, 1950, (WDW)
10. Fish Lake, 1960, (WDW)
11. Middle Fork Ahtanum Creek, 1963, (WDW)
12. Naches Lake, 1973, (WDW)
13. Naches River, 1993, (M)
14. North Fork Tieton River, 1973, (WDW)
15. Oak Creek, 1972, (WDW)
16. Rimrock Lake, 1993, (M)
17. Satus Creek, 1953, (WDW)
18. South Fork Tieton River, 1990, (B)
19. Teanaway River (North Fork), 1993, (M)
20. Tieton River, 1972, (WDW)

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a. Mongillo 1993. Drainages with unknown status are included with 1993 year of record unless other recent records were available with a year.
b. Washington Department of Wildlife unpublished data
c. Brown 1992