Distribution and Microhabitat Use of Drift-feeding Rainbow (*Oncorhynchus mykiss*) and Brown Trout (*Salmo trutta*) and Their Relationship to Cover in a Spring Creek

by

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DISTRIBUTION AND MICROHABITAT USE OF DRIFT-FEEDING RAINBOW (*ONCORHYNCHUS MYKISS*) AND BROWN TROUT (*SALMO TRUTTA*) THEIR RELATIONSHIP TO COVER IN A SPRING CREEK

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ABSTRACT

Summer distribution and microhabitat use of drift-feeding rainbow (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), 100-760 mm TL, in lower Hat Creek (LHC), California were examined by measuring microhabitat variables associated with observed trout. Study units were selected using a random sampling design based on water depth and post-stratified by the percent of submersed macrophyte cover per unit. Tower and bankside observations were used to locate trout within study units, while snorkel surveys and aerial photographs supplied additional habitat information. Young-of-the-year trout (YOY) <150 mm represented 58.8% (*N*=512) of the trout sampled, juvenile trout (150 mm-200 mm) 8.8% (*N*=81) of the sample, and adult trout (≥250 mm) 35.3% (*N*=324).

The temporal distribution of trout in LHC during 1993-94 primarily reflected the distribution and abundance of submersed macrophyte growth. Patterns of trout distribution could be explained by the availability of spatially discreet substrate patches within a submersed macrophyte matrix. Macrophyte density appeared inversely related to the presence or larger trout: an increase in macrophyte density probably had a negative effect on larger trout survival through loss

of suitable habitat. An increase in macrophyte density increased the availability of YOY trout habitat through concealment cover, influencing survival.

The spatial variability in trout distribution could be attributed to creek morphology and geomorphic characteristics of the creek, particularly larger substrate elements. The combined interaction of large substrate elements, high mean water column velocity, and absence of submersed macrophytes explained the greatest amount of variation seen in the focal point locations of larger trout. Concealment cover (submersed macrophytes) was the most important factor influencing YOY location. Pair-wise multiple logistic regression models described 88-90% of the differences in habitat use between the size-classes of trout sampled. The availability of suitable, habitat for larger trout was further confounded by a fine sediment influx which buried substrate complexity.

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INTRODUCTION

Lower Hat Creek (LHC) is a spring creek in northeastern California that hosts self-sustaining populations of rainbow (*Oncorhynchus mykiss*) and brown (*Salmo trutta*) trout. LHC is considered a premier wild trout fisheries in California (Becker et al. 1989). A substantial decline in both trout populations (73% decrease from 1983 to 1991) became apparent from the results of electrofishing studies conducted by the California Department of Fish and Game (CDFG) (Table 1, CDFG 1993). Such declines prompted a study to understand the dynamics of LHC trout. Prior to this study there was no information on the distribution of trout in LHC, nor, their microhabitat use.

Environmental factors may have played a significant role in the decrease of trout populations in LHC. A large influx of fine sediment was transported into the creek over the past few years beginning about 1987 (CDFG 1993). The sediment has probably degraded trout habitat, including the smothering of submersed macrophytes, loss of depth, and loss of substrate complexity (CDFG 1993). A survey conducted in 1993 (CDFG 1993) indicated that both populations of trout >300 mm (rainbow trout N=2497±446, brown trout N=333±85) may be recovering from the lowest numbers seen in 1991, perhaps due to the return of the submersed macrophyte beds and/or sediment passing through the system.

Table 1. Population estimate of trout surveyed in lower Hat Creek, California for years 1983, 1984, 1988, 1991. Estimates were derived from electrofishing surveys conducted by California Department of Fish and Game.

Year	Estimated Number of Trout		
	Rainbow Trout	Brown Trout	Total Trout
1983	5846	308	6154
1984	3766	326	4092
1988	3892	302	4194
1991	1282	384	1665

The northeastern area of California also experienced drought conditions from 1987 through 1994. An increase in precipitation occurred during the seventh year (1993) of the drought. A return to drought conditions occurred the eighth year (1994), once again followed by a large increase in precipitation in 1995.

Microhabitat selection by salmonids is highly dependent on benefits derived from various types and elements of cover. Cover, both as refuge from water velocity and concealment from predation, is an integral characteristic of the focal location of an individual salmonid (Cunjak and Powers 1987 b, Fausch 1993, Griffith and Smith 1995). Mesick (1988) found that larger standing stocks of trout may be supported in creeks which have abundant cover next to high velocity flows. Baltz and Moyle (1984), Fausch (1984), and Wilzbach (1985) indicated that energy efficient locations in a stream are those in which trout use cover as a refuge from water velocity. Kalleberg (1958) and Mesick (1988) pointed to the importance of instream and riparian vegetation, and turbidity as a source of visual isolation between trout, thereby lessening agonistic behavior. Shading from overhead cover also reduces the risk of predation to trout by aquatic and terrestrial predators by decreasing visibility (Gibson and Power 1975; Helfman 1981).

Trout habitat requirements are reflections of energetic costs and gains, that is, the potential net growth rate that would be realized by living in an optimal location (Li and Brocksen 1977; Bachman 1984; and Fausch 1984). Rainbow and brown trout in streams choose focal points that provide energy efficient, low velocity locations adjacent to fast flowing water, maximizing the drift of food passing overhead (Shirvell and Dungey 1983; Bachman 1984; Fausch 1984). Egglishaw and Shackley (1982) suggested that salmon and trout associated with fast flowing water may require less space to obtain their food requirements. Water depth has also been shown to be highly correlated to the distribution and relative abundance of different size-classes of trout (Egglishaw and Shackley 1982; Kennedy and Strange 1982, 1986; Baltz et al. 1987; Heggenes 1988; Hayes and Jowett 1994; Li et al. 1994; Shuler et al. 1994). Larger trout usually utilize the deeper water available within a body of flowing water (Heggenes 1988, Heggenes and Saltveit 1990, Baltz et al. 1991, Lohr and West 1992, Hayes and Jowett 1994, Li et al. 1994).

The focal point of a trout is located where the trout has a clear, unobstructed view of the drift overhead (Shirvell and Dungey 1983; Bachman 1984; Fausch 1984). LHC experiences extreme increases in submersed macrophyte abundance in some years, brought on by seasonal changes in solar radiance. Dense vegetation fills the entire water column in some locations, negating a clear view of the drift for trout. Conversely, this seasonal increase in submersed macrophyte abundance provides additional cover for YOY trout (Griffith and Smith 1993, Griffith and Smith 1995).

A population survey of the LHC glide section (Hat Creek No. 2 Powerhouse, to just above the lower riffle) in 1991 by CDFG found few trout in the smaller size-classes, compared to larger size trout (Figure 1, CDFG 1993). The failure to recruit all size classes may reflect limiting or negative factors in salmonid life history. Griffith and Smith (1995) observed a decline in 0-age trout density when macrophyte cover was reduced during winter. McMahon and Hartman (1989) and Hillman et al. (1987) observed a decrease in trout emigration when cover complexity was increased. Cunjak and Powers (1987b) stated that the addition of cover to streams with stable flow is likely to enhance over-winter survival of trout. Past declines in the trout populations in LHC might be explained by the poor recruitment into the adult population as a result of habitat loss through sedimentation and extreme fluctuations in submersed macrophyte cover availability prior to 1993.

Suitable habitat is differentially selected depending on life stage (Everest and Chapman 1972; Baltz and Moyle 1984; Bozek and Rahel 1991; Hillman et al. 1992) and season (Chapman 1966; Soloman and Templeton 1976; Cunjak and Powers 1986; Dolloff 1987; McMahon and Hartman 1989; Baltz et al.

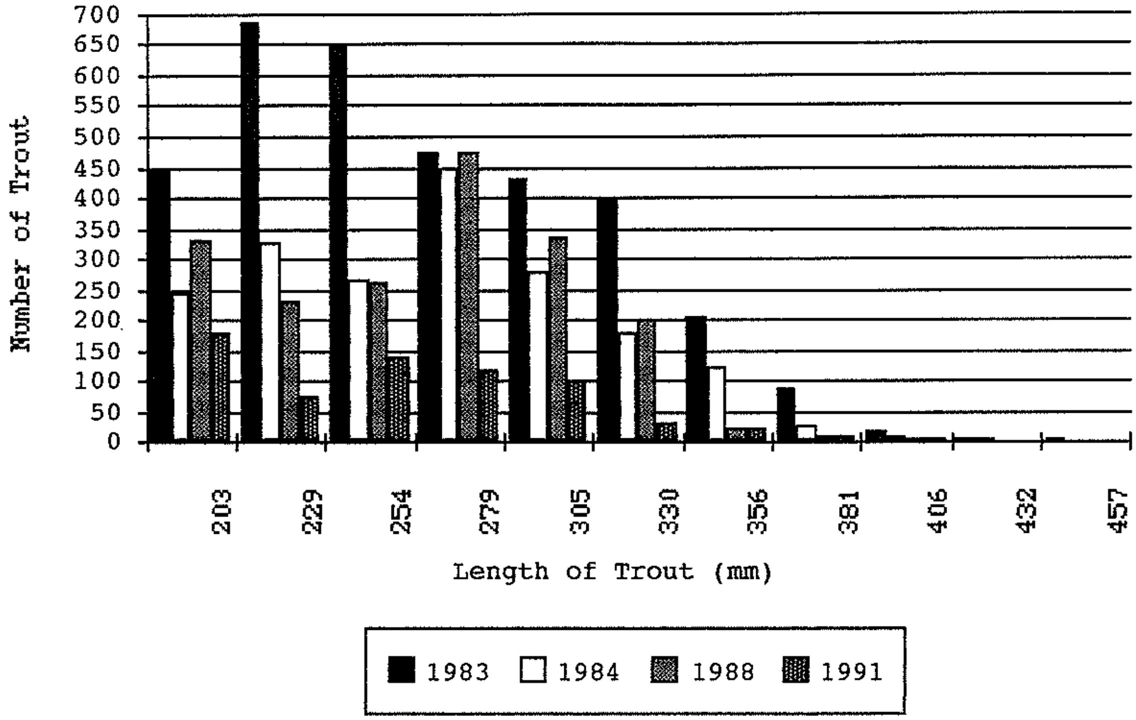


Figure 1. Length distribution of trout in lower Hat Creek, recorded from years 1983, 1984, 1988, and 1991. Total length collected during electrofishing survey of trout population estimate (CDFG 1993).

1991; Riehle and Griffith 1993). Access to food and space is a factor that regulates growth and distribution of salmonids (Chapman 1966), yet the mechanisms of this factor drives the reactions of each individual's reaction to the environment and to each other (Larkin 1956; Jenkins 1969; Griffith 1972; Bjornn 1971; Everest and Chapman 1972; Li and Brocksen 1977; Fausch and White 1981; Tabor and Wurtzbaugh 1991). Habitat use and the social behavior of trout in streams are influenced by the species and ages (size) of the fish present and the availability of suitable habitat. Understanding relationships between fish and their habitat in streams helps determine which factors limit standing stock (Egglishaw and Shackley 1982; Bozek and Rahel 1991). A variety of habitat types, corresponding to microhabitat requirements at each life stage, are needed to ensure self-sustaining wild trout populations.

Many studies have been conducted to determine what physical characteristics influence habitat selection by trout (Hawkins et al. 1982; Baltz et al. 1987; Beard and Carline 1991; Tabor and Wurtsbaugh 1991; Nelson et al. 1992). Selected microhabitat can be described by determining the focal point of a trout and the size of its home-range. The availability of such selected microhabitats within an area, can then be quantified by determining the range of the microhabitat use variables that were selected. The proportion of area exhibiting those combined microhabitat use variables can then be divided into suitable microhabitats based on some averaged home-range size. In this way, habitat use compared to availability, is quantified as the number of microhabitats used within suitable, or available areas.

Hayes and Jowett (1994) used variable kernel-smoothed density estimates and Bozek and Rahel (1991) used logistic regression to compare frequency of habitat use by frequency of habitat available to develop preference curves. However, "use" curves may be more correct than "preference" curves. Others have used probability-of-use curves to compare habitat used to habitat available (Bovee 1978) and habitat suitability criteria (Bovee 1986; Wesche et al. 1987). Reeves et al. (1987) grouped classes of depth and velocity and drew isopleths on a map of the study area to obtain densities of trout per given isopleth, or contour.

Identifying the variables that influence selection of specific microhabitats by trout can lead to inferences concerning carrying capacity, particularly when selected microhabitats are limited. The objective of this study was to describe the specific microhabitat use by three different size-classes of trout in LHC and determine how microhabitat selection influenced trout distribution. I examined the influence that type and abundance of cover, particularly submersed macrophytes, had on three size-classes of trout in LHC. These objectives addressed the following questions:

(1) What is the distribution of the size-classes of trout, YOY (<150 mm), juvenile (150-200 mm), and adult (≥250 mm), in LHC?

(2) Is habitat use different between different size-classes of trout in LHC?

(3) What is the relationship between trout distribution in LHC and instream variables? What instream variables are correlated to focal point?

(4) As instream complexity (cover elements) increases, does trout abundance increase? What is the relationship between the amount and type of instream and riparian complexity to trout density?

(5) What is the relationship between submersed macrophytes and trout distribution? Is trout distribution correlated to substrate patches where submersed macrophytes are absent or sparse?

(6) What is the availability and distribution of suitable microhabitat in LHC? Is suitable microhabitat limited in LHC?

(7) Does the proportion of submersed macrophyte cover per unit area provide sufficient information to estimate the trout population of LHC?

The hypothesis was tested that stream sections with limited cover (low habitat complexity) support fewer trout than stream sections with larger quantities and a variety of cover elements. A second hypothesis, to address the objectives, tested whether dense submersed macrophytes that fill the water column and extend over the substrate, decrease the number of large trout in that area. These two hypotheses, though similar, test the effects of two extremes: too little cover and too much cover.

Patch dynamics and disturbance theory (Pickett and White 1985; White and Pickett 1985) were also explored as tools to help interpret and predict the density and distribution of trout in LHC. The influence of patch dynamics was inferred by avoidance of particular habitat variables, primarily submersed macrophytes, as well as the converse, habitat free of submersed macrophytes. Impacts on trout disturbance were investigated by comparing differences in environmental conditions coupled with trout distribution, and population estimates from previous years to the present. Quantitative differences in distribution were explained by using the intrusion of fine sediment as a mechanism of disturbance, as well as seasonal, patchy growth of aquatic macrophytes.

STUDY SITE

Description

Lower Hat Creek (LHC) is located in northeastern California approximately 90 kilometers east of Redding, California (Figure 2). It is bisected by US Highway 299, 13.5 kilometers east of Burney, California. Since 1967, the 5.6 km reach of Hat Creek below Hat Creek No. 2 Powerhouse has been managed as a wild trout area. An event time-line appears in Appendix A.

The headwater of Hat Creek and its tributary Lost Creek are located on the lower northeastern slope of Mt. Lassen. Both streams are maintained by snowmelt and small springs. Big Spring enters Hat Creek 20 km downstream from the headwaters of Hat Creek. Big Spring generally contributes more water than upper Hat Creek itself during the fall and winter. The upper 61 km of Hat Creek, above its confluence with Rising River, flows down Mt. Lassen then meanders through Hat Creek Valley where it typically remains a low flow channel during most of the year.

The majority of water in LHC (the wild trout area) is supplied from Rising River and its tributary Rising River Lake. Rising River originates as a series of large springs on the edge of a lava field. About one kilometer below its confluence with Rising River, Hat Creek enters a high-

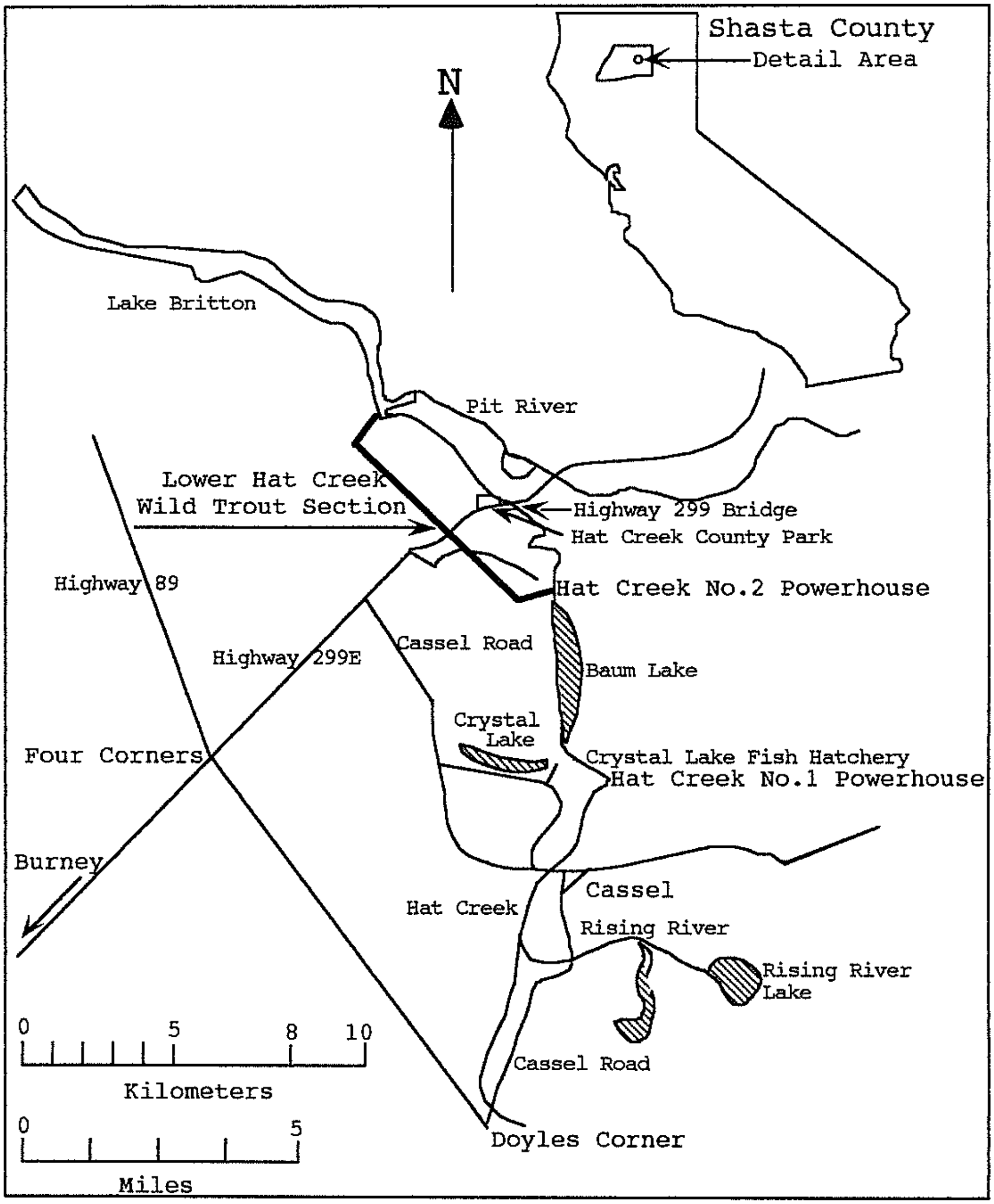


Figure 2. Location map of lower Hat Creek Wild Trout Section.

gradient, bouldered canyon at the town of Cassel. Most of the water, however, is now diverted at Cassel to Hat Creek No. 1 Powerhouse, owned and operated by Pacific Gas and Electric (PGE). About 5.5 km of Hat Creek below Hat Creek No. 1 Powerhouse is now impounded to form Baum Lake, the reservoir that supplies water to PGE's Hat Creek No. 2 Powerhouse.

The second major source of spring water in lower Hat Creek is Crystal Lake, which flows into Baum Lake. Below Baum Lake, Hat Creek enters another high-gradient canyon. A fairly constant flow of 0.227 cubic meters per second (cms) (8 cfs) is released through the canyon (the original Hat Creek channel) while the majority of water is diverted through a flume, into an elevated concrete canal, and then into a second flume at Hat Creek No. 2 Powerhouse. Hat Creek No. 2 Powerhouse is operated as a run-of-the-river type project, with little storage capacity in Baum Lake (Dave Bowers, pers. comm.). A large portion of middle Hat Creek is drawn off for irrigation as well as providing water for Crystal Lake Fish Hatchery operated by CDFG.

Below Hat Creek No. 2 Powerhouse LHC flows at a fairly constant rate of release, though in recent years under drought conditions releases have been less. The creation of Lake Britton in 1925 provided additional habitat for nongame fish which then had access to LHC. A three meter high fish barrier was built in 1968 and now prevents the movement of both nongame species and trout from Lake Britton into the wild trout area of LHC. It is not known whether trout move downstream over the barrier, thus entering Lake Britton.

Over the few years previous to 1992, the glide section of LHC became shallower, filled with fine sediment from nonpoint sources (Kondolf et al. 1994). In the seventies and early eighties there were few places shallow enough to cross the creek without water going over chest waders (Terry Roelofs, pers. comm.). At present, the mean depth of the glide section of LHC, the upper reach of the wild trout area, is approximately 0.8 m with a few deeper pools and holes at maximum depths from 1.7 m to 2.2 m. In 1991 the leading edge of recent sediment intrusion was located in the straight section of the channel below the Carbon bridge site (CDFG 1993).

Submersed macrophytes are abundant throughout the creek and provide important concealment cover as well as visual isolation for trout. Many YOY trout hold within and near the vegetation. Juveniles and adults use this cover when they have been disturbed from their focal points. Submersed macrophytes also provide habitat for a dense population of aquatic invertebrates.

Typically, five species of macrophytes are most abundant in LHC: *Zannichellia palustrus* (grass wrack), *Myriophyllum exalbescens* (milfoil), *Elodea canadensis* (waterweed), *Potamogeton crispus* (pondweed), and *Rununculus* *aquatilis* (aquatic buttercup). Macrophytes are less dense or missing over diatomite bedrock and cobbled areas. A document prepared for California Trout, Inc. (Becker et al. 1990) reported a lack of major "weedbeds" at the Hat Creek No. 2 Powerhouse riffle in 1990. The decrease in abundance of macrophytes continued through 1992, particularly during the fall and winter of 1992-93. During mid- to late summer of 1993 macrophytes increased and did not 'die back' over the winter of 1993-94, possibly due to a milder winter, the sediment's partial dispersion downstream through the system, and the growth of new macrophytes up through recent sediment deposits.

Three major reaches are commonly recognized in LHC. The upper riffle reach (Powerhouse Riffle) extends approximately 200 m downstream from Hat Creek No. 2 Powerhouse. Approximately half of the riffle substrate is composed of coarse cobbles and small boulders, commonly about 150-250 mm in diameter. The remainder of the substrate is sand and fine gravel. A long glide reach or run extends about 3.4 km from the Powerhouse riffle reach, downstream 400m past Hat Creek County Park which, is located adjacent to US Highway 299. The bed of the glide is composed principally of sand with some pebbles and fine gravel, large clumps of submersed aquatic plants, and diatomite outcroppings. There are a few small pool areas, most notably formed from large woody debris, bedrock outcroppings, and Wood Duck Island.

The glide reach is also lined intermittently with bulrush (*Scripus* sp.) marshes. The lower 1.7 km of LHC is a continuous riffle (Lower or Boulder Riffle Section). The bed of the riffle is composed almost entirely of rounded, coarse cobble. Elevations and changes in gradient throughout LHC are referenced in Kondolf et al. (1994).

Geology and Hydrology

LHC presently flows through valley walls underlain, in large part, by outcroppings of diatomite visible throughout the creek. The banks of the creek are principally grass-covered alluvial sediments. Both the alluvial and diatomaceous banks contribute small to moderate amounts of sediment to the creek (Kondolf et al. 1994).

The geologic history of northeastern California is punctuated by the formation of a large lake (early and late Tertiary) and the volcanic activity during the middle to late Tertiary and early Quaternary Period, 7-2.5 mya (MacDonald 1966). Lava flows from both the Medicine Lake Highlands of the Modoc Plateau and Cascade Range contributed to the geology of the area. The Modoc Plateau encompasses approximately 26,000 square km of volcanic terrain bordered to the west by the Cascade Range, south into the Sierra Nevada, and east into the Basin and Range Provinces (Norris and Webb 1990). Mt. Lassen lies just southwest of the Modoc Plateau, where Hat Creek originates as a freestone creek on its northeastern slope.

The lake which covered the Fall River Valley and Hat Creek area during the Pliocene/Pleistocene, deposited the clay soils and underlying diatomaceous bedrock seen throughout LHC (MacDonald 1966; Daniels and Courtois 1982; Norris and Webb 1990). The runoff of Hat Creek is a result of the geologic layering of older basement basalt and lake bed sediments overlain with younger volcanic basalt. Precipitation percolates into the ground through porous basalt where it meets the more impermeable lake bed/volcanic layer interface. Cold water subsequently resurfaces at numerous springs in the midreaches of Hat Creek, most notably, Rising River Lakes, Crystal Lake, and Rock Spring. Ellison (1984) refers to this unique aquatic environment as "lava spring pools", the result of stable flows and low gradient.

Before the creation of Lake Britton, Hat Creek flowed into the Pit River just below the present location of the constructed fish barrier. It has been hypothesized that the ancestral Fall River and upper Pit River drained into the Klamath River to the north (Daniels and Courtois 1982), thereby, allowing Klamath River fauna access to Hat Creek.

The more recent volcanic activity which formed the Modoc Plateau and its present hydrology has since removed all traces of that connection.

Biogeography

Rare and/or endemic species inhabit the unique, volcanic spring environment. Some species are found only within a few springs of the Hat Creek and Pit River drainages, and the Fall River system (Taylor 1981, Moyle and Daniels 1982, Ellis and Hesseldenz 1993). Shasta crayfish (*Pacifastacus fortis*), rough sculpin (*Cottus asperrimus*), bigeye marbled sculpin (*C. klamathensis macrops*), western pond turtle (*Clemmys marmorata*), freshwater mussels (*Anodonta sp.* and *Pisidium sp.*), and several species of snails (Taylor 1981) are some of the endangered, threatened, or species of special concern. Additionally, the strain of rainbow trout endemic to this area, Pit River rainbow, exhibit a selected resistance to *Ceratomyxis shasta*, a parasite common to the area that has proven lethal to introduced strains of rainbow (Schafer 1968). The introduced brown trout is apparently more resistant to the protozoan (Schafer 1968). The distinct zoogeographical region of this area is defined by a constant supply of cold spring water and lava substrate. Moyle and Daniels (1982) refer to this area as the "rough sculpin-marbled sculpin zone" because it hosts a "distinctive association of fishes adapted for a definable set of environmental conditions".

The burrowing activity of muskrats, introduced into the drainage in the 1930's, has caused considerable damage to stream banks. Their burrowing activity has destabilized banks through erosion and increased susceptibility to caving in which further exacerbates the degradation of trout habitat by continuously contributing sediment to the creek. LHC also hosts beavers (*Castor canadensis*) that denude creek banks, by cutting down larger riparian vegetation.

METHODS

Pilot Study

A pilot study was conducted during the summer of 1993. The pilot study formulated and tested usable sampling and experimental design methodology to survey the aquatic habitat and trout population. Two study units, approximately 100m long, were selected from the upper glide section of LHC. Study sites were chosen for their representation of the glide reach and ease of access. Both study units were mapped with reference to the wetted channel. Tower and bankside observation and snorkeling were used to survey the trout population and general physical characteristics of the creek.

Each study unit was divided into transects three meters apart running along the left bank. Flat, orange painted rocks were placed on the bottom of the creek along each transect at three meter intervals. This formed a three meter grid easily viewed from the bank or atop the observation towers, to locate trout within the study unit. The location of observed trout were recorded on a map of the study unit with the gridded pattern overlaid.

Twelve foot aluminum observation towers were moved along the bank over the entire length of the study site. All trout within the study unit were viewed for a 15 minute interval during each day of observation. I recorded their movements and interactions with other trout. Observations took place daily, over a two week period and at opportune times throughout the summer. Known lengths of weighted PVC pipe were placed in the creek during observation and snorkel surveys to use as a reference length and aid in length estimates of trout.

Water depth was measured with a staff gauge along each transect at 3 m intervals. Water velocity was measured in m/sec with a Marsh-McBirney Model 201D current meter to two decimal places and measured along the first three transects at 2 cm above the substrate, 0.6 (60 percent) of the water column depth from the surface (mean water column), and 5 cm below the water surface (surface water). The water velocity measured at the three depths provided a velocity profile which represented water velocity 2 cm above the bottom of the creek, mean water velocity, and the velocity of the water that transported drift respectively.

Study Unit Selection

During the second field season in summer 1994, the glide section of LHC was divided into 63 contiguous 50 m long units and numbered while walking along the left bank, looking downstream (Figure 3). The start of each unit was described for future reference and marked with a stripe of marking paint on the ground and with a wooden stake with flagging

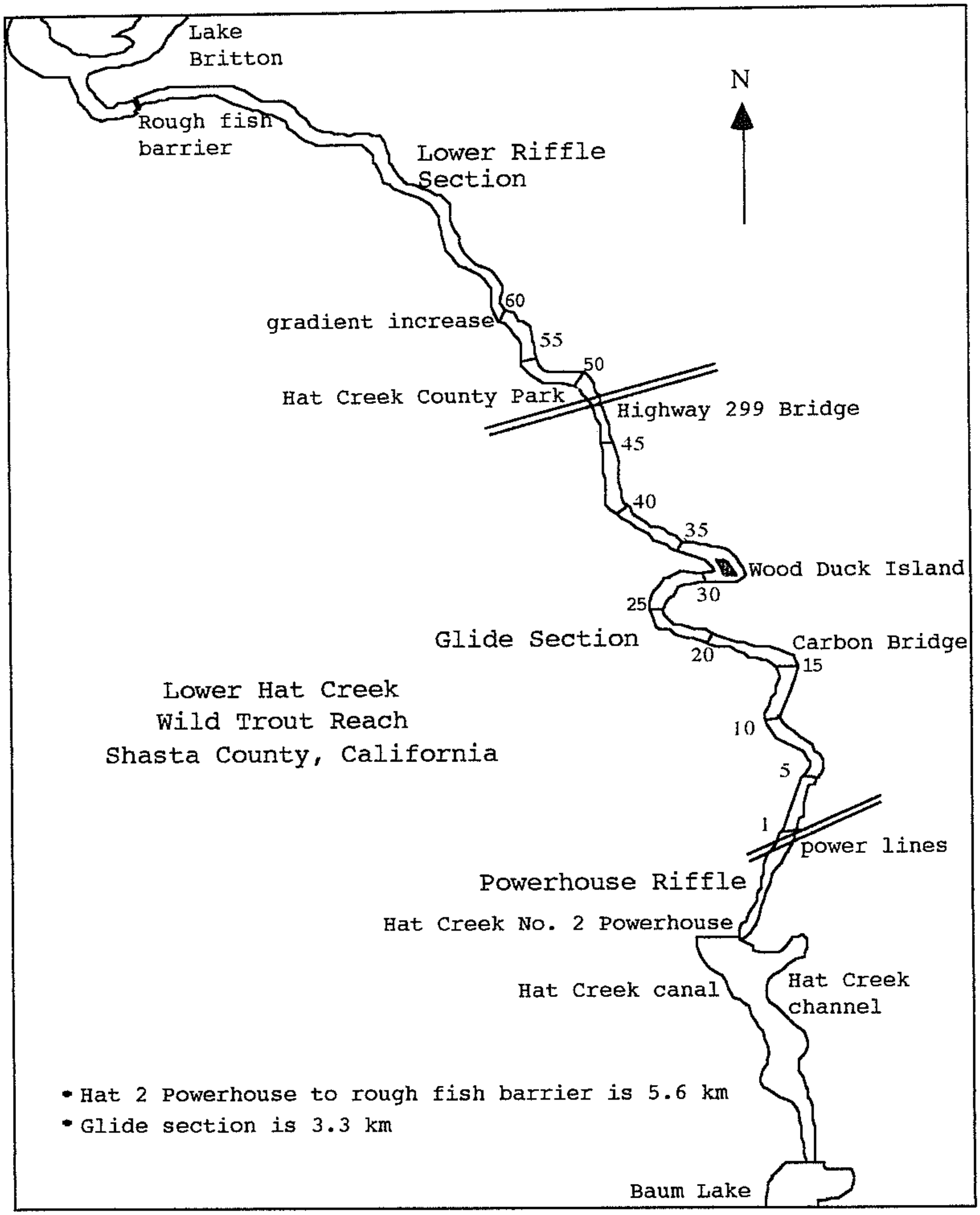


Figure 3. The glide reach of lower Hat Creek was divided into 50 m units, assigned from the left bank (facing downstream). Unit 1 began below the Powerhouse riffle, 25 m past the power lines. Unit 60 ended approximately 400 m past Hat Creek County Park.

tape. Riffle sections were not included because of the difficulty observing fish from the bank or observation towers.

Criteria used including units in random sampling were as follows: Ease of mapping the unit, clear unobstructed view of the entire unit, access to observation points at the unit, and prevention of possible damage to the habitat from concentrated foot traffic. Study units were randomly drawn from those 63 units meeting the above criteria.

The upstream transect of each 50 m unit was chosen as a representative measure of depth for that unit. Water depths were measured at 3 m intervals along the first transect of the 63 units, the last transect of unit 60, and midway through three additional units with deep holes or pools to account for all the depth variation within the creek. A one-way analysis of variance (ANOVA) was used to test for significant differences between transect depths recorded at the beginning of the 63 units. Simple random sampling (Scheaffer et al. 1990) based on depth was used to determine the study unit sample size. The sample size was calculated to account for 95 percent of the depth variability encountered in LHC.

The abundance of submersed macrophytes at each unit was treated as an equally important variable to account for the variability in habitat use and distribution of trout. The combined habitat characteristics of depth and the proportion of submersed macrophyte cover per unit were used in a more efficient post-stratified random sampling design (Scheaffer et al. 1990). Strata values were: 0–30 percent, 35–65 percent, and 70–100 percent macrophyte cover.

The weighted proportion of the three macrophyte strata were determined using Neyman allocation (Scheaffer et al. 1990) which considered the variability of percent cover in each stratum. The sample size based on depth was proportionally divided between the three weighted cover strata. The sample size was calculated to achieve a 95% confidence interval of the habitat variability encountered.

The glide section of LHC was surveyed to estimate the proportion of the total stream bed covered by submersed macrophytes per unit. The proportion of macrophyte cover per unit was estimated on June 27, 1994 when the creek was initially surveyed. Three people estimated the cover proportion independently; estimates were compared and a consensus was reached on the percent cover per unit. The species composition of submersed macrophytes was also recorded as a percent of total cover. Common submersed macrophytes found in LHC were: *Z. palustrus*, *M. exalbescens*, *E canadensis*, *P. crispus*, *R. aquatilis*, *Rhizoclonium* sp. and *Ceratophyllum demersum* were less common. These seven species accounted for approximately 99% of the submersed macrophyte cover observed in LHC.

Study Unit Mapping

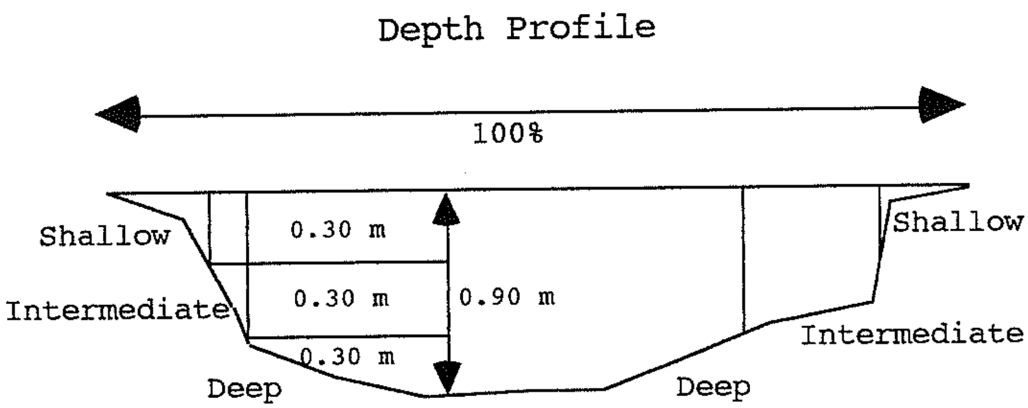
Each randomly selected study unit was mapped in reference to the wetted channel. The upstream left bank of the study unit was used as the reference and the beginning, or zero point, of the first transect. Reference tapes were stretched along the left and right banks perpendicular to the water flow but parallel to each other. The study unit was then divided into 11 transects at 5 m intervals along the reference tapes and marked with wooden stakes, which formed the study unit. All wooden stakes were painted with fluorescent marking paint and flagging tape was tied at the top. Units whose margin was a shear bank were mapped to that bank with the reference tape stretched over the water in front of the bank. These transects were marked with marking paint and/or flagging tape applied directly to the bank and/or riparian vegetation.

Study unit perimeter measurements were keyed into a computer graphics program and the maps produced were used as data sheets. A five-meter square gridded pattern was overlaid on the unit map which aided referencing the relative position of each trout observed in the study unit. A five-meter reference grid worked as effectively as a three-meter reference grid (pilot study) based on earlier observations. The five-meter gridded pattern required less time and effort to set up.

Microhabitat Use Variables

Because of the variability in microhabitat variables measured or observed across the creek channel, microhabitat variables were measured every three meters along each transect. Transects were five meters apart.

Water depth was measured along the first transect of each unit and all 11 transects within each study unit. Depth measurements were collected throughout the summer. Those depth measurements reflected the relative change in water level over the summer. Thus, focal point depths could not be compared equally, through time, between individuals without some bias. To rectify this problem, the range of water depth observed from the cross-section of each transect was expressed as three equal proportions of the measured maximum depth of the wetted channel (Figure 4). These proportions were reported as categories, 1) shallow, 2) intermediate, or 3) deep, determined for two different degrees of resolution, the depth range of both the entire study unit and the depth range of the transect associated with each trout. The depth range of transects associated with each trout better described the immediate water depth around each trout. The depth at which a trout held was then reported as one of these categories with the observed depth range for that cross-section and unit. The water depth at the focal point of each



	Cross Section Percent (%) of Wetted Channel
Shallow	21.9
Intermediate	24.1
Deep	54.0

Figure 4. Water depth was reported as a depth category whose cross-sectional length is a proportion of the wetted channel. Categories are shallow, intermediate, and deep based on equal proportional divisions of the range of the depth observed.

trout was estimated from isopleths derived from depth measurements recorded at three meter intervals along all 11 transects of each study unit.

Velocity was measured at three meter intervals along the first and last transect of each study unit at three levels in the water column: 2 cm above the substrate, 0.6 (60%) of the water column depth from the surface (mean depth), and 2 cm below the water surface. The water velocity at the focal point of each trout was extrapolated from isopleths formed from water velocity measurements recorded along the first and last transects of the study unit.

Substrate composition was based on the particle size observed along each transect of the study unit at three meter intervals. Substrate particle size was reported as categorical data; the composition formed by visual determination from a 0.5 m radius around each associated grid corner. Codes for particle size are reported (Table 2). The composition was recorded as dominant, 1st subdominant, and 2nd subdominant particle size. The substrate composition at trout focal points was estimated from the data collected from the corner of the reference grid that was associated with each trout.

Isopleths formed from the substrate types were unsuitable when rare substrate particle sizes (rocks or cobble) were not accounted for in the profile. To account for larger, rare substrate types observed at focal points,

Table 2. Substrate particle size and codes adapted from Bovee and Cochnauer (1977), based on a modified Wentworth scale. Types of instream cover (woody debris and submersed macrophytes) were also coded. Macrophytes were identified from Mason (1957).

Code	Substrate or Cover Type	Description or Size (mm)
1	Sod (SO)	rooted soil
2	Mud (M)	saturated, loose soil
3	Silt (SI)	suspendable mud
4	Sand (S)	<2 mm
5	Pebble (P)	2-20 mm
6	Gravel (G)	20-100 mm
7	Cobble (C)	100-200 mm
8	Rock (R)	200-300 mm
9	Small boulder (B)	300-500 mm
10	Diatomite bedrock (DEB)	solid surfaces
11	Small woody debris (SWD)	limbs, twigs
12	Large woody debris (LWD)	logs and stumps
13	*Zannichellia* (Z)	Grass Wrack
14	*Myriophyllum* (MYR)	Coontail or American Milfoil
15	*Elodea* (E)	Waterweed
16	*Potamogeton* (POT)	Pondweed
17	*Rununculus* (RUN)	Aquatic Buttercup
18	Other macrophytes (O)	less common macrophytes

but unaccounted for in the original unit substrate data, the substrate element used as velocity refuge by each trout was recorded. The velocity refuge element associated with the focal point of each trout was determined by snorkeling and/or tower observation. Velocity refuge elements were combined with the dominant and subdominant substrate recorded from the reference grid to describe the substrate composition of the focal point of each trout.

The distance between a trout and its nearest neighbor was determined from measuring distances from one another recorded on the reference data sheet. The distance from each trout and the nearest bank was also determined from the data sheets. YOY trout have "loose" focal points and do not establish home ranges until their first or second year as juveniles (Bachman 1984). The area where YOY trout were present was noted in relationship to cover elements, depth, distance from the edge water, and whether they were near spawning gravel.

Study Unit Setup

Trout were observed from 3.5 m portable, aluminum towers and high banks. A gridded pattern was set up at each study unit as a reference for trout locations. During the first summer field season, flat, orange painted rocks marked the corners of each quadrat. During the spring and second summer the abundance of macrophytes obscured the substrate and precluded painted rocks as grid markers. A five-meter grid pattern was suspended approximately 16 cm above the water surface during observation to accurately reference trout locations.

The suspended grid pattern was formed by commercial fishing ganyon line strung from bank to bank and anchored with rebar (Figure 5). Eleven transect lines were placed five meters apart. Each transect line was previously marked with flagging at five-meter increments. Contrasting colored flagging was used at five and ten meter intervals per transect line. Over spring 1994, flagging tape was tied to transect lines with the ends hung free. During observation it appeared that the flagging tape disturbed the trout as it spun in the breeze on the transect line. The flagging also slid along the line from its original reference position. Trout did not rise within the gridded study unit during the morning hatch, but, rose on either side of the study unit. The transect lines were then modified by knotting both ends of the flagging and the ganyon line together. After modification, the flagging did not flap or spin on the line, nor did it alter the behavior of the trout.

<u>Tower and Bankside Observation</u>

Water visibility for trout observation improved when the creek was viewed from a greater height. Therefore, observation, either from towers or high banks, provided an

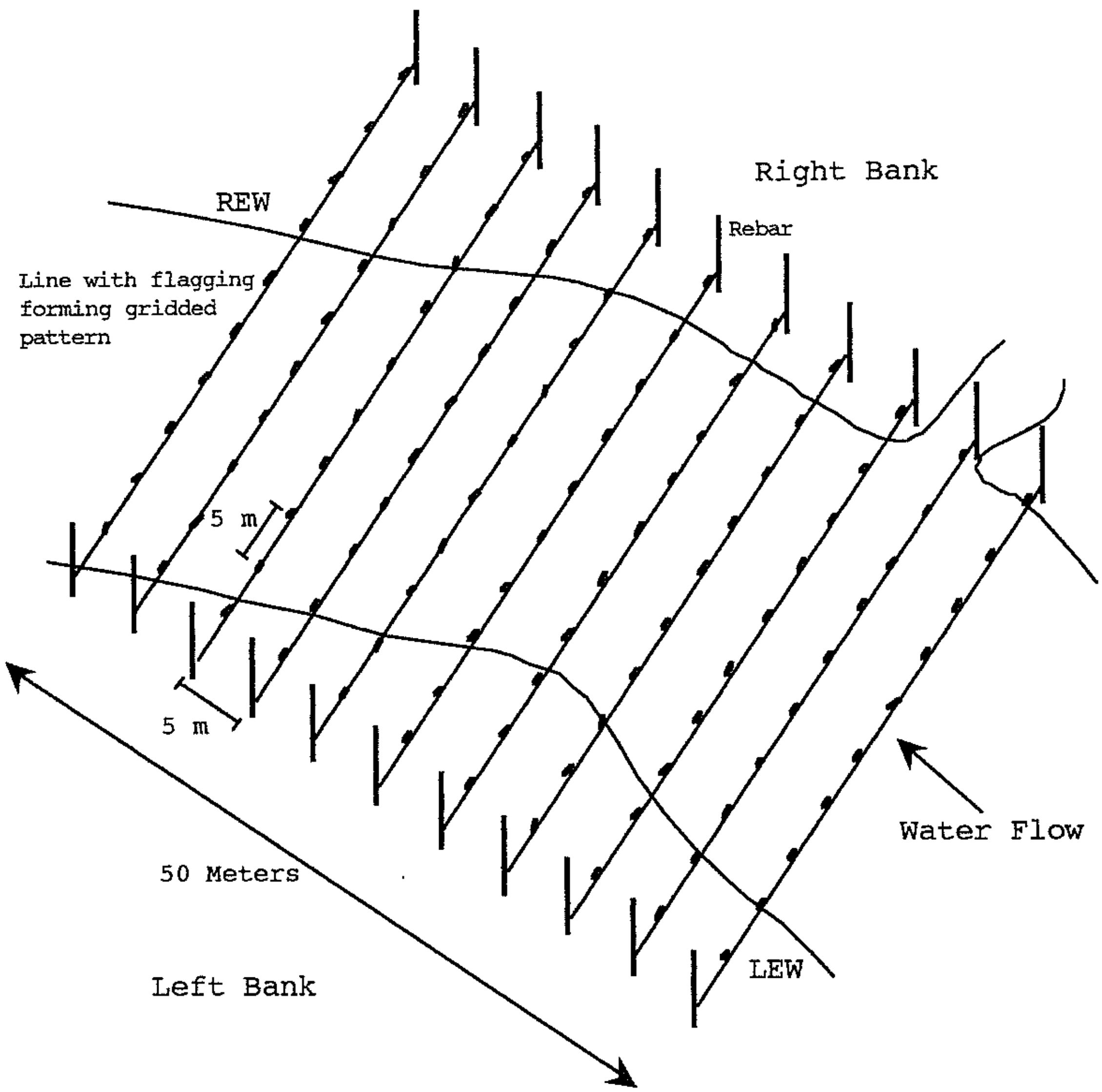


Figure 5. Gridded pattern suspended over study unit, lower Hat Creek, 1993-94. Each transect line was marked at 5 m increments with contrasting flagging for every other increment. REW=right edge water, L=Left.

adequate vantage point to locate trout and estimate abundance. Each study unit was surveyed from a tower and/or from a high bank using two observers, one on each bank. Polarized sunglasses and binoculars fitted with polarizing filters aided in locating trout. The entire unit was scanned with binoculars to locate all trout in the unit, then their location was referenced on the data sheet. The estimated resolution of the grid was one meter, that is, 0.5 meters in any direction from the trout.

The focal point of each trout was defined as the location where the trout was observed to spend the majority of its time when not foraging or engaged in interactions with other trout. The individual home ranges of selected trout were determined by recording movements over a 15 minute time period during four days of observation. Trout have been shown to display site fidelity (Edmundson et al. 1968, Everest and Chapman 1972, Bachman 1984), therefore I assumed that a trout of a given size, seen over four consecutive days at the same location, was the same individual.

Observation began July 28 and ran 24 consecutive days. One day was allowed between each four-day period to break down the units currently being studied and set up the next two units. Two study units were observed at a time. The order in which the two study units were observed was rotated each day. Each study unit was observed for four days to detect if there was movement of trout into and out from the unit. All days were not equal in their quality for observation because of weather conditions and time of day. Therefore, four replicate observation days also provided a range of observation conditions to choose among. The day that provided the best conditions for observation was determined from the four observation days; data collected on that day were used to obtain direct counts of trout per size-class, as well as focal point locations.

Visibility was best from 0900–1300 hours; windy conditions usually hindered observation in the afternoon. Reflection from the sun on the creek surface influenced visibility as well, thus the window of opportunity was compressed between poor visibility due to the angle of the sun and early afternoon wind. Cloud cover also influenced the quality of observations when the clouds were reflected on the water surface.

Trout were categorized into three size classes: ≤150 mm total length (TL) (4 in), 150–200 mm TL (6-8 in), and ≥250 mm TL (>10 in). It was assumed that these three size classes represented YOY, juvenile, and adult trout. Teleki (1972) and Demas (1973) used scales collected from LHC trout to back-calculate length at age. Their findings were incorporated into the size-class divisions used for this study. Those adult trout >350 mm TL (≥14 in), known as trophy trout, were not assigned a size-class of their own, but, were only mentioned as a division in the adult size-class. These size-class assignments were similar to those determined by Teleki (1972) and Demas (1973).

Known lengths of weighted PVC pipe were placed in the water to aid estimating trout length. The PVC pipes were also used while conducting snorkel surveys. We were not able to physically measure the length of trout during this study, therefore, standard lengths of all trout were estimated and recorded in 50 mm (2 in) increments. We believe we were able to estimate the length of a trout at plus or minus 25 mm (1 in) for the larger size classes. Most trout lengths were estimated relative to other trout close by, which maintained a consistency in estimation even if lengths were biased. YOY trout and most juveniles represented fairly uniform cohort length, so their lengths were more accurately estimated.

Snorkel Surveys

Snorkel surveys were used to survey trout habitat, aid species identification, observe trout not visible from the towers, and estimate the trout population per study unit. The entire glide section of the creek was snorkeled every two weeks to observe changes in physical characteristics such as macrophyte growth, movements or redistribution of trout, growth of YOY trout, sediment movement, and water clarity.

Due to the depth and water velocity of the glide reach, snorkeling upstream was not an option. Therefore, snorkel surveys were conducted while floating downstream. For this reason, coupled with low visibility, the trout were disturbed from their focal point by the snorkelers before that location could be established. Snorkeling was not used as a technique to locate trout focal points, but, more as a tool to survey relative abundance and physical focal point characteristics.

Three replicate snorkel surveys were conducted on one day at each study unit to estimate the number and size of trout. After each pass the study unit was allowed to 'rest' for 30 minutes. The trout seen and their lengths were recorded on wrist slates made of rigid plastic attached to the wrist with surgical tubing. The relative complexity of each study unit was also noted while snorkeling and recorded later on the unit maps. Non-study units that did not meet unit selection criteria, primarily units with overhanging trees, were snorkeled extensively to observe trout abundance and size, as well as microhabitat use. This type of habitat was underrepresented in the sampling design and snorkeling allowed general, descriptive impressions which could be evaluated. The number of trout and size distribution, as well as their use of velocity refugia were recorded on wrist slates for those units.

Cover Elements

Instream elements used as either concealment cover from predation or water velocity refuge were described and added to each study unit map. Instream cover elements in LHC included macrophytes, large and small woody debris, undercut banks, large substrate particle size, and depth. Riparian cover included overhanging trees and bushes, shading, and the Highway 299 Bridge. The type of cover element which provided an energy efficient location (velocity refuge) for the trout was recorded for each trout. The type of cover element, used as disturbance or fright cover, was determined and recorded by observing where the trout fled when disturbed.

Microhabitat Use Compared to Availability

Isopleth maps of water depth, water velocity, substrate type, and density of submersed macrophytes per study unit were created to evaluate the availability of selected microhabitat compared to the amount used. The isopleth(s) within the selected range of use for each microhabitat variable, were analyzed to quantify the proportion of the study unit that was suitable. The microhabitat variable maps were then superimposed over one another to determine the proportion of the unit where all microhabitat variables overlapped within the selected range of use. That proportion, defined as availability, was compared to the trout distribution maps of each study unit. Areas that held trout and exhibited suitable habitat were defined as occupied, or used.

Water depth isopleths were divided in 0.25 m increments and water velocity was reported in 0.10 m/sec (0.33 ft/sec) isopleths. Substrate maps consisted of categorical data that contained dominant, subdominant, and rare particle sizes such as cobble or rocks. The presence or absence of submersed macrophytes was indicated at each corner of the study unit grid.

Low Altitude Aerial Photography

The glide reach of LHC was photographed approximately every two weeks during summer as well as when each unit was set up with the grid. Each 50 m unit was photographed from a helicopter approximately 30 m off the ground. The helicopter and pilot were provided by PGE one morning each week throughout the summer.

A full compliment of transect lines was suspended over each study unit and photographed from the helicopter. The aerial photographs provided a fairly accurate way to estimate the percent of macrophyte cover per each quadrat in the grid pattern. The photographs also supplied documentation of the temporal variability in macrophyte density.

Submersed Macrophyte Cover

Aerial Photographs. Compton (1962, 1985) indicated that estimating percent composition was something of an art and required practice as well as some scaled visual example of density (see pages 332-333 and 366-367 respectively). Therefore, the accuracy of visual estimates of macrophyte cover and composition was investigated. The proportion of macrophyte cover was estimated by bankside observations and aerial photographs of each unit. A sample size of aerial photographs, based on the variability of macrophyte cover observed in the slides, was calculated using a simple random sample design (Scheaffer et al. 1990). Each slide usually represented one or two 50 m units. The randomly selected slides were projected on a screen to trace the creek channel and area of macrophyte cover. The tracing from the slide was then overlaid with an area dot grid. The proportion of macrophyte area per slide was then calculated from the proportion of dots that encompassed the macrophytes. This method easily and accurately quantified the proportion of macrophyte cover per 50-meter unit. That value was then compared to a visual estimate previously made directly from the same slide and a visual estimate from the tracing; a visual estimate from the black and white tracing was perhaps more easily determined than from the color slide. A one-way

ANOVA compared the two estimated values of macrophytes and the quantified value measured from each slide testing the hypothesis of equal means.

Monitoring Physical-chemical Variables

Water level gauges were placed at three locations in LHC: (1) below the Powerhouse riffle at the start of unit 1 on the left bank, (2) 30 meters upstream of the old Carbon Bridge pilings on the right bank, and (3) on the right bank below the Highway 299 bridge (Figure 2). These gauges were placed at easily accessible, approximately equidistant locations. The three locations enabled detection of local water level variation brought on by changes in macrophyte mass that affected channel roughness or other constrictions (Dave Bowers, pers. comm.). The gauges were made with a meter stick attached to either rebar or a metal fence post placed in protected areas along the bank. Water discharge was monitored daily through Hat Creek No. 2 Powerhouse by PGE.

Water temperatures were recorded at approximately the same time, three or more times a week, throughout the summer at the three water level gauging locations on LHC. Water quality was tested mid-summer. Acidity, alkalinity, carbon dioxide, water hardness, dissolved oxygen, and pH were tested with a Hach water ecology test kit.

Analyses

Variable Reduction. Measurements of microhabitat characteristics extrapolated to the focal point of each trout determined, by association, which habitat variables and their magnitude best described microhabitat used by three size-classes of trout. A variable reduction method, principal components analysis (PCA), was first used to decrease the dimensionality of the data (Ludwig and Reynolds 1988; Afifi and Clark 1990). PCA uses orthogonal, multidimensional principal components (PC), which were composed of the original microhabitat variables. These PCs account for the variation seen within factors, in this case microhabitat use by trout size-classes; the first PC accounts for the majority of the variation, with each subsequent PC explaining a diminishing amount.

Logistic Regression. Due to the categorical nature of the microhabitat and home range variables measured, logistic regression was employed to test size-class differences in microhabitat use (Afifi and Clark 1990; Hintze 1992). Logistic regression uses independent variables to build a model which tests the strength of those independent variables (habitat use variables) to classify, or distinguish between members of two known groups. Distinction between groups, or size-classes infers differences in habitat use or character among size-classes of trout. The model allows testing of only two groups simultaneously, therefore, pairwise groupings of size-classes were tested, YOY with juveniles, YOY with adults, and juveniles to adults.

The independent variables were first analyzed with a step-up variable loading procedure to explore which of the variables added were most useful. In this way the best subset of independent variables were selected to build the model. The variable adding the most discriminating power to the model was added first. The model inferred which variables accounted for the majority of the source of variation in microhabitat used between trout size-classes. Variables were thus examined to determine if an optimal set of variable combinations described microhabitat use between trout size-classes, or if single variables could account for the variability in use.

The model tested $\beta=0$ against the alternative $\beta\neq0$ using the chi-square statistic, where β is the regression coefficient. The Newton-Raphson method was used to solve the nonlinear equations of the maximum likelihood estimation of the logistic model in the statistical software NCSS (Hintze 1992).

Spearman's Rank Correlation. The nonparametric Spearman's rank correlation (Ludwig and Reynolds 1988) was used to test whether each size-class of trout avoided dense macrophytes in favor of the clear patchy microhabitats. A nonparametric correlation test was used due to the abundances of zeros in the data, (either zero trout or zero macrophyte cover in the quadrat). So many zeros lend themselves to a non-normal distribution. Tied ranks of trout density and the proportion of macrophyte cover per quadrat were corrected prior to running the correlation analysis (Zar 1984). The null hypothesis was tested that trout 'ranked' abundances were uncorrelated, or Ho: $p_s=0$. The influence of patch dynamics could be inferred from avoidance of particular habitat variables by trout, in this case quadrats of dense macrophytes. Trout density and the proportion of submersed macrophyte cover were calculated per quadrat, represented by the gridded pattern overlaid at each study unit. Percent cover was then used to test avoidance of macrophytes by trout.

Though quadrats were treated as if they were discrete natural entities, the size of such quadrats was considered biologically based in that trout home ranges did not appear to exceed a five meter square area. Pielou (1969) stated "sampling individuals that are scattered through a continuum necessitates taking arbitrarily delimited bits of the continuum as sample units". Most often quadrats are used to study spatial patterns. Pielou (1969) further stated that a grid of contiguous quadrats can lead to confounding of the two effects of quadrat spacing and quadrat size. Such grids however, may be legitimate "when the objective was to study the spatial pattern formed of two superimposed one-species patterns" of a population of small area, in this case 50 lineal meters.

Two Phase Sampling Analysis. Two approaches were investigated to estimate the trout population of the glide section of LHC. The first method used two phase sampling analysis, based on weighted regression (Scheaffer et al. 1990), to investigate the ability of submersed macrophyte density per study unit to efficiently predict trout abundance. Macrophyte cover was used as the more easily obtained auxiliary information (AI) to determine if the association to trout abundance was high enough to obtain an estimate of the trout population of the glide section of LHC. The second approach used only the weighted averages of the auxiliary information and the estimate of variance to obtain an estimate of the trout population in LHC (Scheaffer et al. 1990).

The proportion of submersed macrophyte cover per unit was estimated for all 63, 50 m units from aerial photographs and weighted. The regression coefficients calculated from using trout abundance as the dependent variable and macrophyte cover as the independent variable, were then extrapolated to all 63 units, as well as the upper 50 units. Trout abundance was calculated both with regard to size-class

(YOY and juvenile/adult), and as overall trout abundance without regard to size-class, to compare equally to the CDFG abundance estimates from 1993.

I assumed that either the CDFG electrofishing (*N*=2830, ≥8 in (200 mm), or the two consecutive snorkeling estimates (*N*=5616, *N*=6631) were the true trout population count (CDFG 1993). Intuitively, population abundances exhibit temporal variation. The use of the population estimate obtained by CDFG from the year previous did not imply that the trout population did not change during this study's estimate in 1994, only that those estimates were used as a point of comparison. Tower and bankside observations of trout abundance were then used as the 'true' value, or the more unbiased approach in estimating trout abundance, opposed to two-person snorkel estimates, to compare the correlative power of the auxiliary variable.

RESULTS

Pilot Study—1993

Visibility was poor in LHC, especially while snorkeling, due to fine, suspended particles. Because of the limited visibility we could not consistently distinguish between brown and rainbow trout at all times. Both trout species were therefore pooled as a general trout category. The CDFG 1993 electrofishing data indicated an approximate 7.5:1 ratio in favor of rainbow trout (CDFG 1993).

The focal point of each trout was difficult to determine while snorkeling because trout were disturbed by the snorkeler and always moved from their focal points before their location could be determined. Because of the limited visibility and fright-responses of the trout, I made observations from high banks and towers. A three-meter square reference grid formed by orange, painted rocks placed on the creek bed was used to more accurately reference trout locations. Maps of the study site worked well as data sheets (Figure 6), corresponding easily to the gridded pattern on the creek bed. After the pilot study, a five-meter gridded pattern was determined to provide an adequate scale to reference trout location, which decreased the time and supplies needed to set up a study unit.

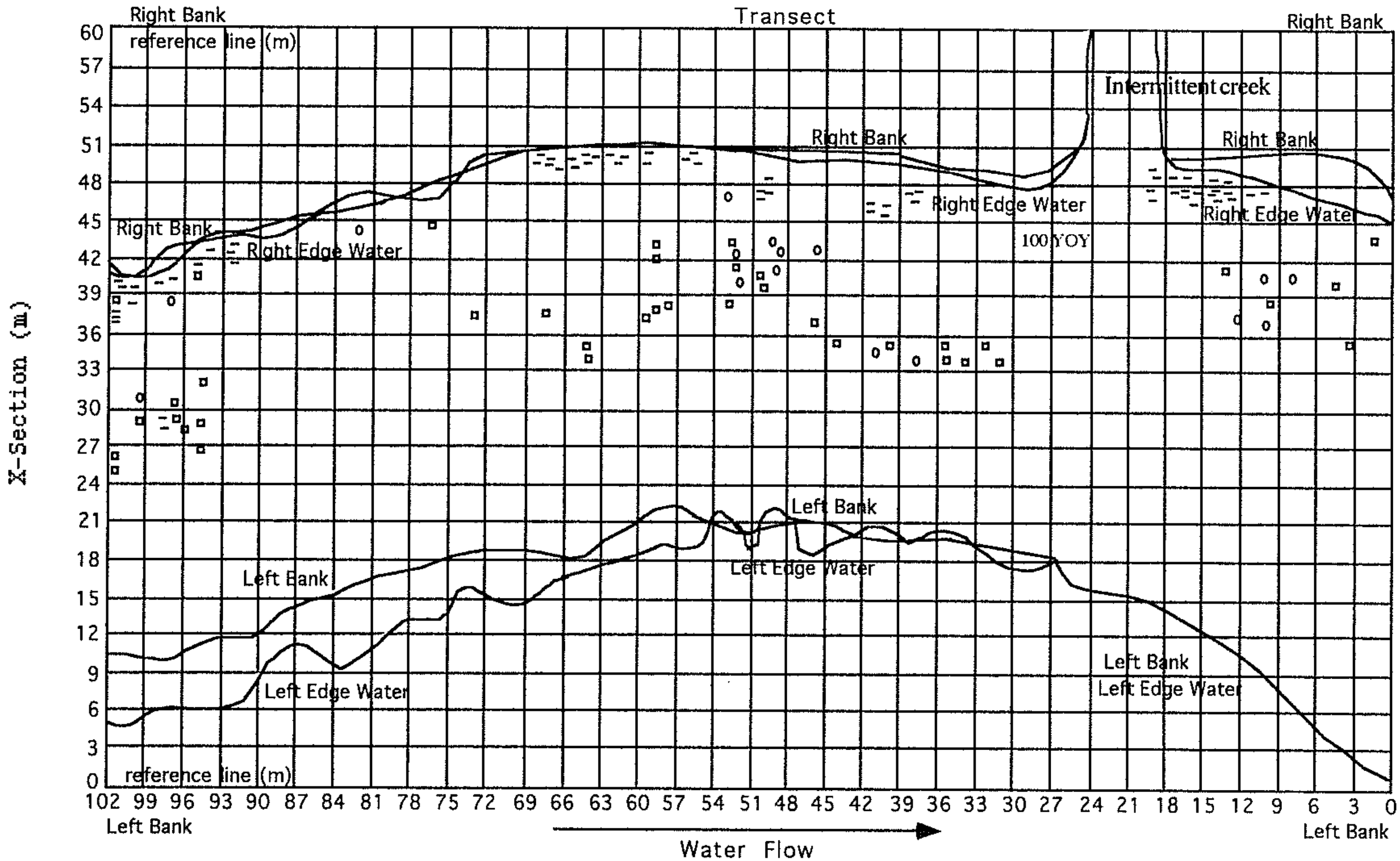


Figure 6. Reference grid of the first study unit from the 1993 pilot study. The study unit was located approximately at the beginning of 1994 unit six and ended approximately at the beginning of unit eight (102 m). YOY locations are represented by dashes, juveniles by circles, and adults by squares.

Snorkeling was used to survey creek complexity and substrate composition. Snorkeling was also effective at 'scaring up' fish that may not have been observed from bankside observations, which provided a way to evaluate the efficiency of bankside observation. Macrophytes completely covered the second pilot study unit which made observation of fish difficult, if not impossible. This unit was eventually eliminated as a study site. The first study site did not exhibit the extreme abundance of macrophytes.

Trout held in the same location each day over a two week period of observation in the summer (Figure 6). Adult (N=39) and juvenile trout (N=16) were distributed throughout the study unit, though centered more midchannel. The except to that distribution was where deeper water afforded cover along the right bank. Most of the area monitored along the left bank was shallow and the substrate was composed of deep mud. Adult trout held behind cobble and rocks, or large woody debris.

The east margin of the first study site (right bank) was a major spawning area, one of two such sites in the glide where an abundance of gravel supplied suitable spawning substrate. YOY trout (N=165) were found throughout the study site. YOY trout held along the creek margin and ventured toward midstream when macrophytes or large woody debris were available as cover. There were also approximately 100 YOY trout concentrated at the upstream end of the unit. They held over the spawning gravel that had been recruited from the intermittent creek located on the east, or right bank.

Study Unit Selection—1994

Fourteen units that featured heavy, overhanging riparian vegetation could not easily be mapped and a portion of those units were obscured by overhanging trees as well. These units were not included in the random selection of study units. Also, three additional units were not included in sample selection because bulrush (*Scripus* sp.) marshes lined one, or both banks. There was some difficulty in observation when the unit was viewed over these marshes. In addition, the damage to the marsh habitat which would have been caused by concentrated use, precluded their use. One additional unit was also deleted from sample selection because of deep water along an inaccessible high cut bank. A total of 18 of the 63 units (29%) were not available for random sample selection (Scheaffer et al. 1990) resulting in 45 available units (Table 3).

In order to determine how many transects were needed to describe the variability in water depth, a coefficient of variation (CV=0.519, 52%) was calculated and combined with a percent sampling error (PE) of no more than 10% to maintain a 95% confidence interval for water depth measured along unit transects. A sample size of eight transects, or study units

Table 3. Lower Hat Creek units which could be selected for intensive study. All determinations took place on 6/27/94. Abbreviations are as follows: Mac=submersed macrophyte, DS=downstream, US=upstream, LB=left bank, RB=right bank, BRM=bulrush marsh, OHT=overhanging tree, CB=Carbon Bridge, WDI=Wood Duck Island, DE=diatomite, and DER=diatomite rock, SCB=shear cut bank.

Study Unit	Mac %	Mac Density Strata	Easily Mapped	Reason Excluded from Use	Comments
1	85	3	yes		Begins below Hat 2 riffle DS of powerlines on LB, where rock shoring ends.
2	70	3	yes		
3	85	3	yes		
4	90	3	yes	BRM	
5	80	3	no	BRM	
6	70	3	yes		Begins US from small creek on RB.
7	90	3	no		
8	85	3	no	BRM	
9	75	3	yes		
10	75	3	yes		
11	85	3	yes		
12	85	3	no	SCB	
13	85	3	no	OHT	
14	85	3	no		
15	70	2	no		
16	70	3	yes		Begins across from CB power pole on RB.
17	70	3	yes		
18	75	3	yes		
19	75	3	yes		
20	75	3	yes		
21	55	2	yes		
22	55	2	yes		
23	55	2	yes		
24	40	2	yes		
25	30	1	yes		
26	40	2	no		
27	60	2	yes		
28	60	2	yes		
29	50	2	yes		
30	40	2	yes		
31	60	2	yes		
31A	60	2	yes	BRM, OHT	Begins at upstream tip of WDI.
31B	50	2	yes	OHT WDI.	Begins outside bend of
31C	50	2	yes	OHT	Begins outside bend of WDI.
32	50	2	yes		Begins at top 1/3 of WDI.

Table 3. Lower Hat Creek units which could be selected for intensive study. All determinations took place on 6/27/94. Abbreviations are as follows: Mac=submersed macrophyte, DS=downstream, US=upstream, LB=left bank, RB=right bank, BRM=bulrush marsh, OHT=overhanging tree, CB=Carbon Bridge, WDI=Wood Duck Island, DE=diatomite, and DER=diatomite rock, SCB=shear cut bank (continued).

Study Unit	Mac %	Mac Density Strata	Easily Mapped	Reason Excluded from Use	Comments
33	70	3	yes		
34	60	2	yes		
35	60	2	no	OHT	
36	90	3	yes		
37	90	3	yes		
38	60	2	no	OHT	
39	24	1	no	OHT	
40	20	1	no	OHT	
41	20	1	no	OHT	
42	35	2	yes		
43	65	2	yes		
44	40	2	yes		
45	45	2	yes		
46	50	2	yes		
47	50	2	yes		
48	50	2	yes	BR	Begins at upstream side of Highway 299 bridge.
49	20	1	yes		
50	15	1	yes		
51	25	1	no		Begins approximately at wild trout legend at County park.
52	25	1	no		
53	30	1	yes	BRM	
54	50	2	no		
55	15	1	no	OHT	
56	10	1	no	OHT	
57	10	1	yes	OHT	
58	15	1	yes		
59	15	1	yes		
60	15	1	yes		

was calculated as required based on simple random sampling design to account for the variability in depth observed in the glide section of LHC. The habitat characteristics of depth (N=903, mean=0.775 m, s=0.402 SE=0.013), post stratified by macrophyte cover percent (N=63, mean=54.0%, s=24.3, SE=3.1, maximum=90%, minimum=10%) were combined as a post stratified, random sampling design (Scheaffer et al. 1990).

Three ranges of macrophyte cover formed submersed macrophyte density strata: 0–30 percent (1), 35–65 percent (2), and 70–100 percent (3). The number of units and the weighted value determined per stratum were: 15 units (s_1=6.51, w_1=0.20), 26 units (s_2=8.40, w_2=0.45), and 22 (s_3=7.56, w_3=0.35) units respectively (Table 2).

Since weighted proportions were not whole numbers (n_1=1.62, n_2=3.62, n_3=2.76), rounding up resulted in nine study units, or sampling units, selected from the three strata, two from strata 1, four from strata 2, and three from strata 3. This distribution maintained the weighted proportional requirement within each stratum. Unit 6 was not randomly selected, yet, this unit included half the site used for the pilot study. A comparison with the second year was desired so unit 6 was added resulting in ten study units (Figure 7). A description of the 10 study unit locations and their channel morphology is in Appendix B.

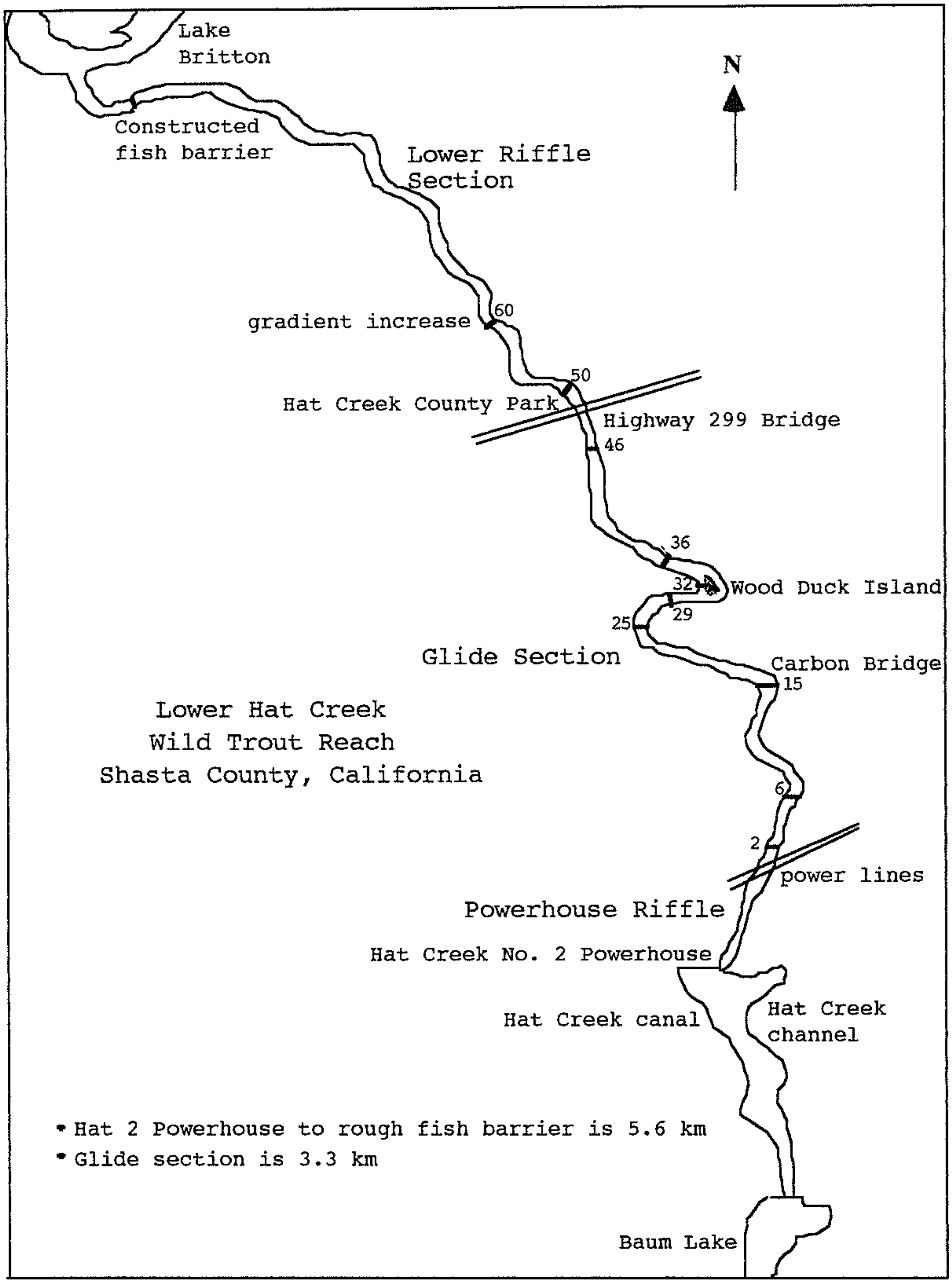


Figure 7. Locations of ten randomly selected study units in lower Hat Creek, 1994.

Study Unit Characteristics

The 10 study units had a mean channel width of 33.7 m, s=6.64. Study unit 32 was a side channel located on the inside bend of Wood Duck Island. This channel was narrow, with a mean width of 16.7 m. The mean creek channel width of the study units, excluding unit 32, was 35.7 m, s=3.03. The channel morphology of the study units could be divided into two categories, either bends or straight sections. There were 4 bends and 6 straight sections represented in the sample units.

Water depth was measured at three-meter increments along the first transect of all units (N=63) and the last transect of unit 60 (Appendix C). A one-way ANOVA found no significant differences between transect depths recorded along the 64 transects (P=0.828, α=0.05, df=886). The mean water depth of the glide was 0.86 m, s=0.34, s^2=0.12, SE=0.01. The maximum depth recorded was 2.2 m at non-study unit 11. Depth measurements were not collected on the same day and thus, the mean value did not reflect the small temporal changes in the water surface level observed over summer. Temporal changes in water level were greatest in the upper section which included study units 2 and 6. The remainder of the glide was affected to a lesser degree due to a decrease in channel roughness brought on by less dense macrophyte growth.

Depth profiles of the study units appear in Appendix D. Descriptive statistics of water depth for all 10 study units are shown in Table 4. The study units were fairly homogeneous in their depth distribution, though study unit 25 and 32 had deep undercut banks at one of their margins. The mean depth of the 10 study units was 0.91 m ±0.02, s=0.30, N=1609.

Water velocities were measured along the first transect of 33 units (Appendix E). Measuring water velocity was time intensive. I thought a representative sample of 33 units could be used to approximate the variability of water velocity observed within the glide section. Three positions in the water column were measured: Surface, mid, and substrate. Water velocities were relatively homogeneous over all units with a mean surface velocity of 0.34 m/sec (1.07 ft/sec), s=0.17, mid-column velocity of 0.25 m/sec (0.83 ft/sec), s=0.16, and substrate velocity of 0.11 m/sec (0.35 ft/sec), s=0.11. Low mean velocity readings measured mid-channel indicated the dampening effect abundant macrophyte growth had on water velocities.

The slightly higher velocities measured in study units 15, 25, and 32 indicated the unique channel morphology of those units, which consisted of diatomite bedrock and a bend in the creek, while study unit 60 reflected a gradient