Table 4. Descriptive statistics of water depths measured throughout ten study units. Values are reported in meters. The mean channel width is also reported per study unit.

Study Unit	Mean Depth (m), (CI)	Maximum Depth (m)	Standard Deviation	Stand Error	Mean Width (m)
2	0.96 (±0.03, *N*=230)	1.32	0.24	0.02	38.9
6	0.81 (±0.05, *N*=126)	1.22	0.31	0.03	34.0
15	0.94 (±0.05, *N*=136)	1.38	0.28	0.02	36.6
25	0.99 (±0.05, *N*=138)	1.60	0.28	0.03	34.0
29	0.85 (±0.05, *N*=134)	1.27	0.26	0.03	38.2
32	0.95 (±0.12, *N*=64)	1.71	0.49	0.06	16.7
36	1.03 (±0.04, *N*=191)	1.35	0.25	0.02	31.9
46	0.97 (±0.03, *N*=307)	1.61	0.25	0.01	34.2
50	0.87 (±0.04, *N*=122)	1.38	0.25	0.02	32.6
60	0.65 (±0.04, *N*=172)	1.50	0.24	0.02	40.6
Overall	0.91 (±0.02, *N*=1609)	1.71	0.30	0.01	33.8*

*Mean width without the influence of study unit 32, which was a side channel at the inside bend of Wood Duck Island was 35.7 m.

increase. With the slight deviation previously mentioned, all water velocities were nonetheless fairly homogeneous throughout the study units.

A water velocity profile of each study unit was also constructed using velocities at three-meter increments along the first and last transects of the study unit (Appendix F). Table 5 indicates the descriptive statistics of water velocity measured for each of the ten study units. The slightly lower velocities observed in study units reflected measurements taken when macrophytes were most dense.

Substrate composition was also determined along the first transect of each unit and the last transect of unit 60 (N=64) at the same time depth was measured. The particle-size composition of each transect is indicated in Appendix G. Substrate of the size suitable for larger-sized trout (cobble or rock) as water velocity refugia was in 76.6% of the transects. Diatomite bedrock was in 21.1% of the transects surveyed. Sand-sized particles (48.0%) were the dominant particle size, whereas silt (12.3%), pebbles (11.8%), mud (9.9%), gravel (7.3%), cobble (3.5%), rock (3.2%), diatomite bedrock (2.3%), sod (1.3%), and boulder (0.4%) represented the balance of the dominant substrate. Dominance of sand-sized particles was particularly evident where an intrusion of fine sediment (CDFG 1993) had moved around the bend, below the Carbon Bridge site and reached Wood Duck Island (Figure 2).

Table 5. Descriptive statistics of water velocity measured at three meter intervals along the first and last transects of 10 study units lower Hat Creek, 1994. Units 6 and 15 each had an additional transect measured mid-unit (transects 6 and 5 respectively). First=first transect, last=last transect.

	Water Velocity (m/sec)		
Study Unit	Surface first/last	Midcolumn first/last	Substrate first/last
Unit 2			
Mean	0.27/0.317	0.19/0.20	0.06*/0.06*
Std Deviation	0.16/0.12	0.14/0.07	0.07/0.04
Unit 6			
Mean	0.33/0.30/0.30	0.24/0.25/0.21	0.09/0.10/0.08*
Std Deviation	0.13/0.16/0.18	0.12/0.13/0.17	0.08/0.08/0.10
Unit 15			
Mean	0.32/0.36/0.46	0.24/0.27/0.38	0.10/0.15/0.07
Std Deviation	0.08/0.08/0.14	0.09/0.12/0.11	0.06/0.11/0.06
Unit 25			
Mean	0.31/0.38	0.25/0.29	0.11/0.14
Std Deviation	0.12/0.19	0.14/0.17	0.11/0.15
Unit 29			
Mean	0.34/0.31	0.27/0.28	0.12/0.10
Std Deviation	0.16/0.12	0.20/0.11	0.14/0.07
Unit 32			
Mean	0.44/0.29	0.41/0.29	0.26/0.17
Std Deviation	0.17/0.15	0.20/0.16	0.14/0.15
Unit 36			
Mean	0.35/0.36	0.25/0.27	0.03*/0.08*
Std Deviation	0.12/0.16	0.09/0.12	0.06/0.08
Unit 46			
Mean	0.33/0.37	0.26/0.25	0.04*/0.10
Std Deviation	0.18/0.11	0.17/0.17	0.05/0.12
Unit 50			
Mean	0.33/0.31	0.26/0.24	0.13/0.14
Std Deviation	0.32/0.14	0.25/0.14	0.20/0.10
Unit 60			
Mean	0.41/0.27	0.33/0.23	0.27/0.15
Std Deviation	0.27/0.24	0.25/0.20	0.13/0.12
Overall			
Mean	0.34	0.27	0.11
Std Deviation	0.17	0.16	0.11
N	256	257	255

*Indicates values which were highly influenced by the presence of submersed macrophytes.

Substrate composition profiles were formed for each study unit (Appendix H). Sand was the overall dominant (100% of the study units) particle size throughout each study unit, averaging 57% of the observed dominant classification (Table 6). Pebbles (70% of the study units) averaged 34% of the subdominant particle-size. Diatomite bedrock was in five of the study units (15, 25, 29, 32, and 50). Nine of the ten study units contained substrate which was large enough (cobble or rocks) to provide large-sized trout with cover from water velocity. Three study units (2, 25, and 29) contained LWD which trout also utilized as a water velocity refuge. Study unit 36 contained no large cobble or rock, diatomite bedrock, or LWD.

Trout Observations

Abundance estimates and size class distribution of trout were derived from tower observations tallied from the day that observation was optimal (Table 7). Data sheet maps for each study unit appear in Appendix I. The location of all trout observed are included.

Trout (*N*=917) were distributed unevenly over the 10 study units in a bimodal pattern (Figure 8) 200 mm trout (juvenile or age-1) were conspicuously missing from the distribution. YOY trout (<150 mm) represented 58.8% (*N*=512) of the trout observed, juvenile trout (150 mm-200 mm) represented only 8.8% (*N*=81) and adult trout (≥250 mm)

Table 6. Study unit substrate composition reported as the percent of the most common particle of each composition class (dominant (Dom.), first subdominant (1st SDom), second subdominant (2nd SDom), and large-sized rare particles LHC, 1994. Substrate particle size was coded: 1=sod, 2=mud, 3=silt, 4=sand, 5=pebbles, 6=gravel, 7=cobble, 8=rock, 9=boulder, 10=diatomite bedrock, 11=small woody debris, 12=large woody debris.

Study Unit	Dom. (%)/ Rare (%) (size code)	1st SDom (%)/ Rare (%) (size code)	2nd SDom (%)/ Rare (%) (size code)
2	4 (53.1)/ 6 (3.5)	5 (33.6)/ 6, 8, 11 (24.8)	6 (27.5)/ 7, 8, 12, 11 (41.1)
6	4 (54.8)/ 6, 7, 8, 12 (19.0)	5 (32.2)/ 6, 7, 8 (30.8)	4 (33.9)/ 6, 7, 8, 12 (51.6)
15	4 (64.4)/ 6, 7, 10 (23.7)	5 (36.8)/ 6, 7, 8, 10 (28.1)	6 (27.3)/ 7, 10 (31.8)
25	4 (64.0)/ 6, 8, 10 (18.4)	6 (31.3)/ 7, 8, 10, 12 (20.5)	5 (49.0)/ 6, 7, 8, 12 (38.8)
29	4 (77.4)/ (0.000)	5 (38.4)/ 6, 7, 8, 10, 12 (38.4)	7 (30.6)/ 6, 8 (44.4)
32	4 (60.7)/ 7, 10 (19.7)	4, 5 (23.3)/ 6, 8, 11 (30.0)	8 (57.1)/ 6 (28.6)
36	4 (68.9)/ 6 (5.0)	5 (63.6)/ 6, 7, 8 (19.5)	4 (56.0)/ 6, 11 (36.0)
46	4 (44.6)/ 6 (13.1)	5 (38.8)/ 6, 7, 11 (15.5)	6 (35.3)/ 7, 8, 10, 12 (21.6)
50	4 (38.0)/ 6, 7, 8, 10 (34.7)	4 (33.3)/ 6, 7, 8 (36.7)	4 (44.9)/ 6, 7, 8 (53.1)
60	4 (41.8)/ 6, 7, 8 (32.8)	4 (30.1)/ 6, 7, 8 (33.0)	4 (42.9)/ 6, 7, 8 (40.0)
Overall	4 (56.5, *N*=1216)/ 6,7,8,10,12(16.7)	5 (33.7, *N*=846)/ 6,7,8,10,12,11(30.5)	6 (29.2, *N*=383)/ 6,7,8,10,12,11(68.7)

Table 7. Size-class distribution of trout observed at ten study units, lower Hat Creek, 1994.

Study Unit	Date	Trout size-class <100 (mm)	150-200 (mm)	250-350 (mm)	>350 (mm)	Totals
2	7/30/94	16	3	0	0	19
6	7/31/94	79	33	98	7	217
15	8/5/94	110	6	112	46	274
25	8/3/94	40	8	2	0	50
29	8/6/94	33	8	1	0	42
32	8/9/94	52	6	33	5	96
36	8/13/94	13	3	0	0	16
46	8/13/94	64	5	9	0	78
50	8/17/94	78	9	11	0	98
60	8/16/94	27	0	0	0	27
Totals		512	81	266	58	917

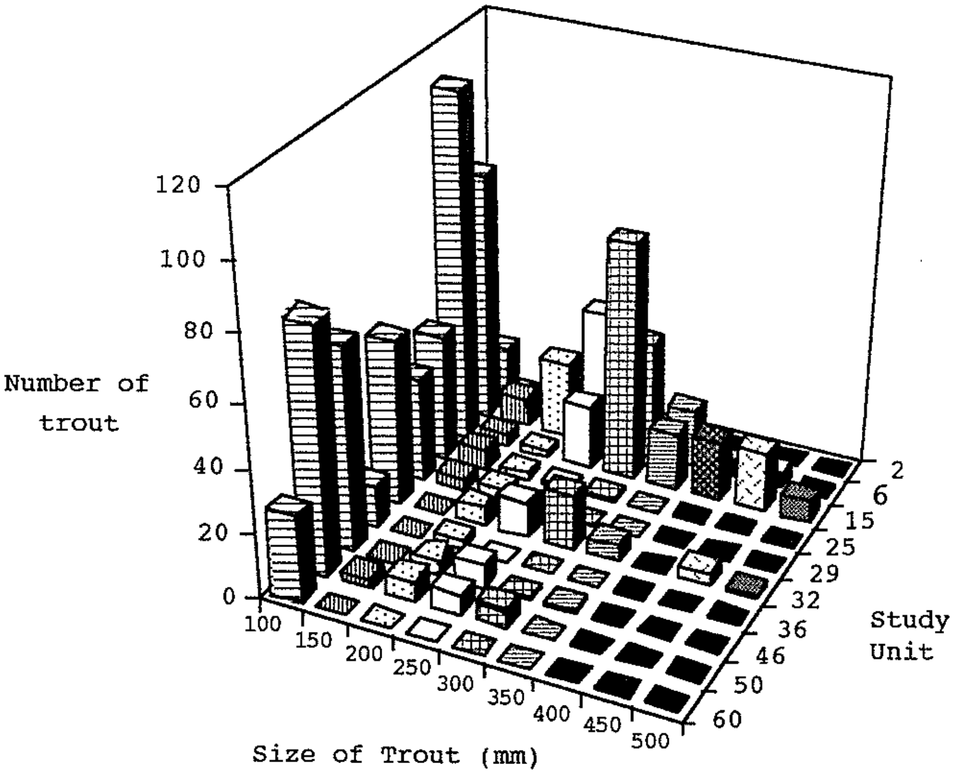

Figure 8. Abundances of trout by size (mm) are reported per study unit. The abundance and size of the trout were obtained by observations from the creek bank, lower Hat Creek, 1994.

accounted for 35.3% (N=324). Adult trout were sub-divided into two size-classes to distinguish between those trout of trophy size (≥350 mm), which represented 6.3% (N=58) of the trout observed. A large portion of trout, 54%, (N=491, of which 38.5% were YOY) were in the upper section of the glide reach in study units 6 and 15. These units were associated with two major gravel beds in LHC. Together they hosted 36.9% (N=189) of the YOY trout across the study units.

Snorkel Surveys

Population estimates for the three replicate snorkel passes (Appendix J) were tested to determine if there was a significance difference between passes. A one-way ANOVA found no significant differences between passes by unit all P-values were >0.509 at α=0.05 for each study unit.

The range of visibility underwater was from 1.0- 2.0 meters, on rare occasions up to 2.5 meters. Though trout abundance estimated from a high position on the creek bank was more accurate than from two-person snorkel surveys, the two estimates were compared. The mean number of trout in each size-class, for each pass (Table 8) was compared with the population estimated from each study unit from bankside observations (Table 7). The estimates of size-class abundance from the two methods were tested for differences

Table 8. Estimated numbers and size-class distribution of trout obtained from snorkel surveys lower Hat Creek, 1994. Snorkel surveys consisted of three replicate passes over one day with a 30-minute rest between passes. Population estimates were calculated as the mean of the three passes (Ho: population estimates were equal for all passes, ANOVA *P*-value >0.460) with 95% confidence intervals.

Study Unit	Survey Date	Trout size-class <100 mm (C.I.)	150-200 mm (C.I.)	250-350 mm (C.I.)	>350 mm (C.I.)	Totals (C.I.)
2	7/30/94	30.7 (±5.4)	4.3 (±4.0)	1.3 (±0.7)	0.0	36.3 (±8.6)
6	7/31/94	87.0 (±45.2)	12.0 (±6.3)	60.3 (±23.4)	23.7 (±6.2)	183.0 (±77.1)
15	8/5/94	81.7 (±8.04)	32.7 (±1.7)	68.0 (±4.0)	30.0 (±0.0)	212.3 (±4.6)
25	8/3/94	20.3 (±11.5)	4.0 (±2.0)	1.3 (±0.7)	0.3 (±0.7)	26.0 (±10.5)
29	8/6/94	22.0 (±3.0)	0.7 (±0.7)	0.7 (±0.7)	0.0	23.3 (±2.6)
32	8/9/94	34.7 (±11.5)	8.0 (±2.3)	15.3 (±1.3)	11.3 (±1.3)	69.7 (±10.3)
36	8/13/94	16.3 (±5.8)	1.0 (±1.2)	0.0	0.0	17.3 (±4.7)
46	8/13/94	25.7 (±11.3)	2.0 (±1.2)	0.3 (±0.7)	0.0	28.0 (±13.1)
50	8/16/94	17.7 (±16.1)	0.7 (±0.7)	1.3 (±1.3)	0.0	19.7 (±15.1)
60	8/16/94	23.3 (±4.0)	0.0	0.0	0.0	23.3 (±4.0)
Totals		359.7 (±36.2)	65.3 (±7.5)	148.7 (±26.6)	65.3 (±7.5)	638.7 (±72.8)

with a multiple comparison, paired *t*-test, where *P*-values were adjusted based on Bonferroni-based procedure (Wright 1992).

The paired *t*-tests indicated there was no statistically significant difference, $P > 0.192$, $\alpha = 0.017$, between size-class estimates from the two methods. However, trout numbers estimated by snorkel count estimates were lower then counts from towers on eight of the ten study units. The exceptions were unit 2 and 36. The higher snorkel estimate from unit 2 could have been due to the addition of one snorkeler, who was inexperienced; double counting trout may have occurred. The snorkel estimate for unit 36 was only one fish greater than the bankside estimate.

The results of the snorkel survey were not used as the final estimate of trout abundance given the difficulty with underwater visibility, inadequate number of personnel to effectively cover the entire channel, and the lower estimated trout abundance observed in snorkel surveys. Trout focal points were also not determined from snorkel surveys.

Trout Focal Point Characteristics

Depth. Water depth was measured as a continuous variable. However, due to changes in depth during the summer these data could not be compared equally without some bias when averaged over time. All water depth measurements were not collected at one specific period in time. Most measurements were collected early in summer. Some measurements were also later in the summer. To "correct" for the temporal changes in depth, focal point depth was also compared using one of three depth categories. Focal point depth was determined by two methods. The first from isopleths formed from the entire study unit and secondly, as a depth range determined from the transect associated with each observed trout. Focal point depths derived from depth ranges, formed from individual transect lines, were thought to represent more precise local variation in depth. However, there was little difference in focal point depth determined from the two methods. The range of study unit depths per depth category was slightly different per study unit; overall ranges were: shallow (0.00–0.57 m), intermediate (0.41–1.14 m), and deep (0.82–1.71 m).

Water depth used by all size-classes of trout is reported by study unit in Table 9. Adult trout (N=324) held at a mean water depth of 1.15 m (s=0.13, s^2=0.02, SE=0.01). The majority of adult trout (unit(U)=89.8%, transect (T)=93.5%) held in the deepest portion of the channel when either the overall maximum unit depth was considered, or the maximum depth for the associated transect was considered. Only 10.2% (U), and 6.5% (T) of the adult trout held in water in the intermediate depth category and no adult trout held in the shallow water depth category.

Table 9. Focal point depth reported as the percent (%) use of three depth categories (shallow, intermediate, and deep) by trout size-classes. The range of category depth is included, obtained from the water depth range observed for each study unit. The percent of overall use is reported for both the depth range of each unit as well as transects associated with each trout (U=unit depth range, T=transect depth range).

Study Unit Category (Depth Range (m))	Depth Category Use (%) by Trout Size-class YOY (%)	 Juvenile (%)	 Adult (%)
Unit 2			
Shallow (0-0.44)	0.0	0.0	0.0
Intermediate (0.44-0.88)	31.3	0.0	0.0
Deep (0.88-1.32)	68.8	100	0.0
Unit 6			
Shallow (0-0.41)	7.6	0.0	0.0
Intermediate (0.41-0.82)	73.4	0.0	0.0
Deep (0.82-1.22)	19.0	100	100
Unit 15			
Shallow (0-0.46)	9.1	0.0	0.0
Intermediate (0.46-0.92)	54.5	0.0	2.5
Deep (0.92-1.38)	36.4	100	97.5
Unit 25			
Shallow (0-0.53)	5.0	0.0	0.0
Intermediate (0.53-1.09)	62.5	12.5	50.0
Deep (1.09-1.60)	32.5	87.5	50.0
Unit 29			
Shallow (0-0.42)	9.1	0.0	0.0
Intermediate (0.42-0.84)	51.5	0.0	0.0
Deep (0.84-1.27)	39.4	100	100
Unit 32			
Shallow (0-0.57)	0.0	0.0	0.0
Intermediate (0.57-1.14)	80.8	100	73.7
Deep (1.14-1.71)	19.2	0.0	26.3
Unit 36			
Shallow (0-0.45)	0.0	0.0	0.0
Intermediate (0.45-0.90)	0.0	0.0	0.0
Deep (0.90-1.35)	100	100	0.0
Unit 46			
Shallow (0-0.54)	0.0	0.0	0.0
Intermediate (0.54-1.08)	46.9	60.0	0.0
Deep (1.08-1.61)	53.1	40.0	100

Table 9. Focal point depth reported as the percent (%) use of three depth categories (shallow, intermediate, and deep) by trout size-classes. The range of category depth is included, obtained from the water depth range observed for each study unit. The percent of overall use is reported for both the depth range of each unit as well as transects associated with each trout. U=unit depth range, T=transect depth range (continued).

Study Unit Category (Depth Range (m))	Depth Category Use (%) by Trout Size-class YOY (%)	Juvenile (%)	Adult (%)
Unit 50			
Shallow (0-0.46)	9.0	0.0	0.0
Intermediate (0.46-0.92)	47.4	0.0	0.0
Deep (0.92-1.38)	43.6	100	100
Unit 60			
Shallow (0-0.50)	7.4	0.0	0.0
Intermediate (0.50-1.00)	92.6	0.0	0.0
Deep.(1.00-1.50)	0.0	0.0	0.0
Overall	U/T	U/T	U/T
Shallow (0-0.57)	5.9/5.1	0.0/0.0	0.0/0.0
Intermediate (0.41-1.14)	58.4/43.8	12.3/8.6	10.2/6.5
Deep (0.82-1.71)	35.7/51.1	87.7/91.4	89.8/93.5

Juvenile trout (*N*=81) held at a mean water depth of 1.11 m (*s*=0.17, s^2=0.03, SE=0.02). The majority of the juvenile trout (88.9% (U) and 91.4% (T)) held in the deepest portion of the channel, while 10.1% (U) and 8.6% (T) held at the intermediate depth.

YOY trout (*N*=512) held at a mean water depth of 0.87 m (*s*=0.25, s^2=0.06, SE=0.01). The majority of the YOY trout (58.4% (U), 43.8% (T)) held in the intermediate water depths, 35.7% (U) and 51.1%(T) held in the deep water, and 5.9% (U) and 5.1% (T) held in the shallow water.

Velocity. The surface water velocity associated with the location of each size-class of trout was similar: adult (mean=0.40 m/sec), juvenile (mean=0.40 m/sec), YOY (mean=0.35 m/sec). Adult trout association was less variable than juvenile or YOY trout (adult, s^2=0.02, juvenile, s^2=0.04, YOY, s^2=0.12). Mean velocity of the mid-water column associated with all trout was also similar (adult, mean=0.34 m/sec, s^2=0.02; juvenile, mean=0.31 m/sec, s^2=0.04; YOY, mean=0.30 m/sec, s^2=0.10). This same trend carried over to the velocities measured at the substrate (Table 10).

Velocities were measured at specific focal point locations behind cobble and rocks used by trout. Water velocities were essentially 0.0 m/sec 2 cm above the substrate behind both sizes of substrate. Current was only detected as the current meter sensor was raised above the

Table 10. Water velocity reported as a mean value of the observations for the focal point location of each size-class of trout per unit. Mean values were reported for three positions (surface, mid, and substrate) measured in the water column. Standard deviations were supplied to describe the distribution of the velocity measurements.

	Water Velocity Use by Trout Size-class					
Study Unit	YOY		Juvenile		Adult	
	Mean (m/sec)	Std. Dev.	Mean (m/sec)	Std. Dev.	Mean (m/sec)	Std. Dev.
Unit 2						
Surface	0.32	0.12	0.36	0.03		
mid	0.24	0.07	0.22	0.02		
substrate	0.09	0.07	0.08	0.05		
Unit 6						
Surface	0.15	0.12	0.44	0.04	0.44	0.03
mid	0.13	0.09	0.36	0.05	0.35	0.05
substrate	0.07	0.06	0.16	0.04	0.17	0.02
Unit 15						
Surface	0.41	0.14	0.37	0.10	0.36	0.06
mid	0.35	0.16	0.33	0.10	0.29	0.07
substrate	0.12	0.06	0.14	0.07	0.13	0.08
Unit 25						
Surface	0.17	0.10	0.18	0.08	0.31	0.11
mid	0.12	0.09	0.17	0.10	0.19	0.05
substrate	0.04	0.05	0.06	0.04	0.06	0.06
Unit 29						
Surface	0.38	0.08	0.33	0.03	0.33	0.00
mid	0.28	0.14	0.18	0.14	0.26	0.00
substrate	0.11	0.11	0.03	0.05	0.33	0.00
Unit 32						
Surface	0.52	0.07	0.44	0.01	0.45	0.02
mid	0.50	0.05	0.44	0.04	0.46	0.04
substrate	0.34	0.04	0.33	0.10	0.32	0.09
Unit 36						
Surface	0.40	0.09	0.45	0.06		
mid	0.31	0.10	0.31	0.06		
substrate	0.05	0.06	0.10	0.15		
Unit 46						
Surface	0.38	0.10	0.43	0.02	0.54	0.06
mid	0.27	0.16	0.34	0.03	0.49	0.08
substrate	0.06	0.10	0.04	0.06	0.07	0.03

Table 10. Water velocity reported as a mean value of the observations for the focal point location of each size-class of trout per unit. Mean values were reported for three positions (surface, mid, and substrate) measured in the water column. Standard deviations were supplied to describe the distribution of the velocity measurements (continued).

Study Unit	Water Velocity Use by Trout Size-class					
	YOY		Juvenile		Adult	
	Mean (m/sec)	Std. Dev.	Mean (m/sec)	Std. Dev.	Mean (m/sec)	Std. Dev.
Unit 50						
Surface	0.32	0.25	0.45	0.16	0.44	0.00
mid	0.29	0.11	0.28	0.10	0.33	0.00
substrate	0.14	0.13	0.14	0.06	0.17	0.00
Unit 60						
Surface	0.56	0.09				
mid	0.58	0.02				
substrate	0.24	0.06				
Overall						
Surface	0.35	0.19	0.40	0.10	0.40	0.06
mid	0.30	0.17	0.31	0.11	0.34	0.09
substrate	0.13	0.12	0.13	0.09	0.16	0.09

substrate element, usually 5 cm above the substrate. Therefore, the estimated substrate velocity used by trout was near zero. The means for the velocities at the substrate reported in Table 9 are more likely the substrate velocities adjacent to the trout.

Substrate. Substrate compositions associated with each trout size-class per study unit are shown in Table 11. Diatomite rubble (mode=10) was the dominant particle size at the focal point of adult trout. Diatomite bedrock was also composed or rubble of cobble and rock particle sizes, as well as, bedrock projections and irregularities. The most common subdominant element was gravel, followed by sand.

Juvenile trout were usually associated with a substrate composition dominated by sand, with gravel and cobble present to a lesser degree. Juvenile trout also always held behind some large substrate element. Dominant substrate of cobble size or larger was associated with 33.3% of the juveniles, while 25.7% (first subdominant) and 50.9% (second subdominant) of the subdominant substrate composition was cobble or larger particle sizes. YOY trout were predominantly associated with sand, though, approximately 17.6% were associated with substrate dominated by gravel size

Table 11. Substrate composition determined at the focal point of each trout was reported by size-class per study unit lower Hat Creek, 1994 as the mode and mean of those particle sizes observed. The proportion of the most common substrate particle per category was noted as the mode %. Substrate composition was recorded as dominant (DOM.), 1st subdominant (1st SDom.), and 2nd subdominant (2nd) particle size. Substrate particle size was coded: 1=sod, 2=mud, 3=silt, 4=sand, 5=pebbles, 6=gravel, 7=cobble, 8=rock, 9=boulder, 10=diatomite bedrock, 11=SWD, 12=LWD.

		Substrate Composition per Trout Size-class		
Study		YOY	Juvenile	Adult
Unit	Statistic.	Dom./1st SDom./2nd	Dom./1st SDom./2nd	Dom./1st SDom./2nd
2	Mode(*N*)	4(9)/5(7)/6(7)	4(3)/8(2)/12,7(1)	
	(mode %)	52.9/50.0/70.0	100/66.7/50.0	
	Mean	4.5/4.8/6.5	4.0/7.0/9.5	
6	Mode(*N*)	4(42)/6(32)/4(26)	5,8(9)/4(15)/7(16)	7(49)/5(51)/4(73)
	(mode %)	53.2/48.4/48.1	27.3/46.9/51.6	46.7/48.6/71.6
	Mean	4.7/5.4/5.4	6.3/4.9/5.7	6.5/5.4/4.8
15	Mode(*N*)	4(54)/6((52)/4(51)	10(5)/4,6,8(1)/6,7(1)	10(112)/10(27)/6(11)
	(mode %)	49.1/58.4/69.9	83.3/33.3/50.0	70.9/50.0/91.7
	Mean	4.7/5.8/4.9	9.0/6.0/6.5	8.2/8.4/6.1
25	Mode(*N*)	10(30)/8(15)/12(10)	4(5)/4,12(3)/7(2)	4,12(1)/2,4(1)/5,7(1)
	(mode %)	75.0/71.4/76.9	62.5/37.5/40.0	50.0/50.0/50.0
	Mean	8.5/7.4/10.0	5.4/7.0/8.0	7.5/3.0/6.0
29	Mode(*N*)	4(33)/5,8(7)/7(7)	4(8)/5(3)/6(2)	4(1)/6(1)
	(mode %)	100/31.8/100	100/50.0/50.0	100/100
	Mean	4.0/6.5/7.0	4.0/5.7/6.8	4.0/6.0
32	Mode(*N*)	4(37)/10(21)/10(8)	4(6)/1(1)	4(38)/6(16)/6(1)
	(mode %)	71.2/56.8/53.3	100/100	100/64.0/100
	Mean	3.7/7.4/9.1	4.0/1.0	4.0/5.7/6.0
36	Mode(*N*)	4(12)/5(8)	4(2)/5(2)/4(1)	
	(mode %)	92.3/100	66.7/66.7/100	
	Mean	4.2/5.0	4.7/6.0/4.0	
46	Mode(*N*)	5(36)/4(31)/4,6(12)	4(5)/5(5)/8(2)	5(8)/6(7)/7(7)
	(mode %)	56.3/56.4/40.0	100/100/66.7	88.9/77.8/87.5
	Mean	4.8/4.6/5.3	4.0/5.0/7.3	4.9/5.7/6.9
50	Mode(*N*)	4(64)/8(9)/4(9)	4(4)/7(4)/4(3)	4(7)/5(6)/7(8)
	(mode %)	82.1/36.0/75.0	44.4/50.0/75.0	63.6/54.5/80.0
	Mean	4.9/6.0/4.8	5.6/6.1/4.8	5.0/5.1/6.6

Table 11. Substrate composition determined at the focal point of each trout was reported by size-class per study unit lower Hat Creek, 1994 as the mode and mean of those particle sizes observed. The proportion of the most common substrate particle per category was noted as the mode %. Substrate composition was recorded as dominant (DOM.), 1st subdominant (1st SDom.), and 2nd subdominant (2nd) particle size. Substrate particle size was coded: 1=sod, 2=mud, 3=silt, 4=sand, 5=pebbles, 6=gravel, 7=cobble, 8=rock, 9=boulder, 10=diatomite bedrock, 11=SWD, 12=LWD (continued).

		Substrate Composition per Trout Size-class		
Study		YOY	Juvenile	Adult
Unit	Statistic	Dom./1st SDom./2nd	Dom./1st SDom./2nd	Dom./1st SDom./2nd
60	Mode(*N*)	4(23)/4(4)		
	(mode %)	85.2/66.7		
	Mean	4.0/4.3		
Overall				
	Mode(*N*)	4(293)/5(99)/4(126)	4(38)/4,5(22)/7(22)	10*(111)/5(65)/4(74)
	(mode %)	57.2/27.5/51.2	46.9/31.4/30.9	34.3/31.7/54.0
	Mean	4.8/5.8/6.1	5.6/5.5/6.1	6.9/6.2/5.2

*Other large substrate elements (cobble and rock) present with diatomite bedrock were not always noted, though diatomite bedrock projections and irregularities were implied.

or larger particles. The subdominant substrates associated with YOY trout were gravel or larger particle sizes in 44.4% (first) and 41.5% (second) of the observations.

The means of the substrate composition for all size-classes of trout were influenced by the modes of the coded substrate values, as evidenced by the standard deviations (adult, 2.6/2.0/1.4; juvenile, 1.9/2.9/2.6; YOY, 1.8/1.7/2.9). The means were provided to get some sense of data distribution.

Velocity Refugia. Eight elements were described as velocity refugia used by trout in LHC: (1)submersed macrophytes, (2)cobble, (3)rock, (4)large woody debris (LWD) and small woody debris (SWD), (5)sand dune, (6)overhanging tree or bush floating in the water, (7)creek margin, (8)diatomite bedrock. YOY trout utilized all types of available refugia.

Rocks and cobble were used by larger trout as velocity refuges almost exclusively (mode=rock). Smaller or less significant refugia did not provide adequate refugia for larger trout. LWD was always used in the presence of fast water velocity. Only two of the 324 adult trout sampled used submersed macrophytes as refuge from water velocity, though the macrophytes were sparse and scour had formed a small sand dune. YOY trout used the creek margin as a velocity refuge area most often, though sand dunes and macrophytes were also used. YOY trout also used LWD and SWD when available.

Units which were not randomly selected or used in the sampling design, yet contained dense overhanging trees or LWD, hosted large numbers (>30) of trout of all size-classes. Snorkeling revealed groups of trout holding behind logs or fallen trees. Submerged logs, perpendicular to the water flow and not contacting the substrate or elevated off the substrate by limbs, attracted trout. Those logs provided channel constrictions which increased water velocity. Logs, or trees on the creekbed, or along the bank, decreased the water velocity and tended to collect sediment. Those habitats held few or no trout.

Relative Location of Trout. Distances from shore and from the nearest neighbor were determined for each trout (Table 12). Relative distances of adult trout were greatly influenced by data from unit 15. Almost half the adult trout observed in this study unit were located 4 to 12 meters from the right bank. Both YOY and adult trout were more closely grouped near the creek margin, though the adults on average were farther from the shore and from each other. Juvenile trout were more widely distributed and more isolated from other trout.

Table 12. The relative location of three size-classes of trout was reported as the distance from the nearest shore and the distance from its nearest neighbor, lower Hat Creek, 1994.

Distance	YOY (*N*=512)		Juvenile (*N*=81)		Adult (*N*=324	
	Mean (m)	St.Dev.	Mean (m)	St.Dev.	Mean (m)	St.Dev.
To Bank	6.3	4.2	10.1	4.3	8.9	3.5
To Neighbor	0.7	1.4	1.8	2.1	0.8	0.8

Macrophyte Cover per Quadrat and Study Unit. YOY trout were associated with quadrats that averaged 26.0% (*s*=21.1) macrophyte cover. Juveniles were associated with quadrats whose mean proportion of macrophyte cover was 17.9% (*s*=20.2) and adults were associated with quadrats with a mean of 9.26% (*s*=8.5) cover (Appendix I and K). YOY were highly associated with macrophytes, juveniles to a lesser degree, and adults scarcely so. Distribution of submersed macrophytes within each study unit was determined in August, 1994, when observations were made (Appendix K). The distribution of submersed macrophytes is shown as contours of presence or absence.

Submersed Macrophyte Cover

From Photo Slides. Due to limited availability of flight time, LHC was photographed in early morning, usually 0730-0900 hours. Unfortunately, as the sun rose it cast shadows from the trees onto the creek which obscured a portion of the creekbed. Some photographs reflected this partial shading. Each photo slide encompassed approximately one to two units when photographed from 30 m above.

The variability in the density of macrophyte cover per unit, visually determined from the photo slides, ranged from 10%-100% (mean=39.4%, *s*=18.7, s^2=349.2, SE=1.2). A simple, random sample size was calculated using weighted proportions of macrophyte cover strata (0-30, 35-65, 70-100) seen in the photo slides (*N*=247). The sampling design resulted in the random selection of forty-six slides.

The two methods of estimation (the actual slide and a black and white wall tracing of the slide) and the visual quantification of macrophyte cover were tested with ANOVA. The ANOVA test failed to reject the null hypothesis of equal means ($P=0.872$, $\alpha=0.05$), which indicated that visual estimates of the proportion of macrophytes per slide appeared to be satisfactorily accurate. Visual estimates were then used for the remainder of the photo slides (Table 13).

The density and species composition of macrophytes were estimated over time for all 64 units throughout the length of the glide. Cover density and species composition estimates were made either from aerial photo slides, or estimates from the bankside when aerial photos were not available. Percent of cover per unit area determined per species of macrophyte was obtained from aerial photographs and bankside estimations from the June 27, 1994 survey (Figure 9).

Estimated proportion of macrophyte cover and species composition were made from aerial photo slides taken on June 27, 1994 and from a bankside survey conducted the day previous (Figure 10). A paired *t*-test comparing the accuracy of estimating the percent cover from the creek bank and aerial photo slides found that the two methods were not

Table 13. The percentage of macrophyte cover was estimated visually per each study unit from aerial photographs lower Hat Creek, 1994 at approximately two week intervals. Where aerial photographs were not available, estimates from the bankside were substituted.

	Percent of Submersed Macrophyte Cover					
Unit	6/27/94	7/12/94	8/2/94	8/9/94	8/16/94	8/23/94
2	90	65	55	30	-	40
6	40	40	30	30	-	35
15	70	45	40	45	-	50
25	45	35	35	35	-	40
29	60	40	45	55	-	55
32	50*	30	35	30	-	40
36	90*	65	70	65	-	60
46	50*	50	45	60	60	60
50	15*	30	45	40	40	40
60	15*	40	45	40	40	40

*Indicates value estimated from the bankside.

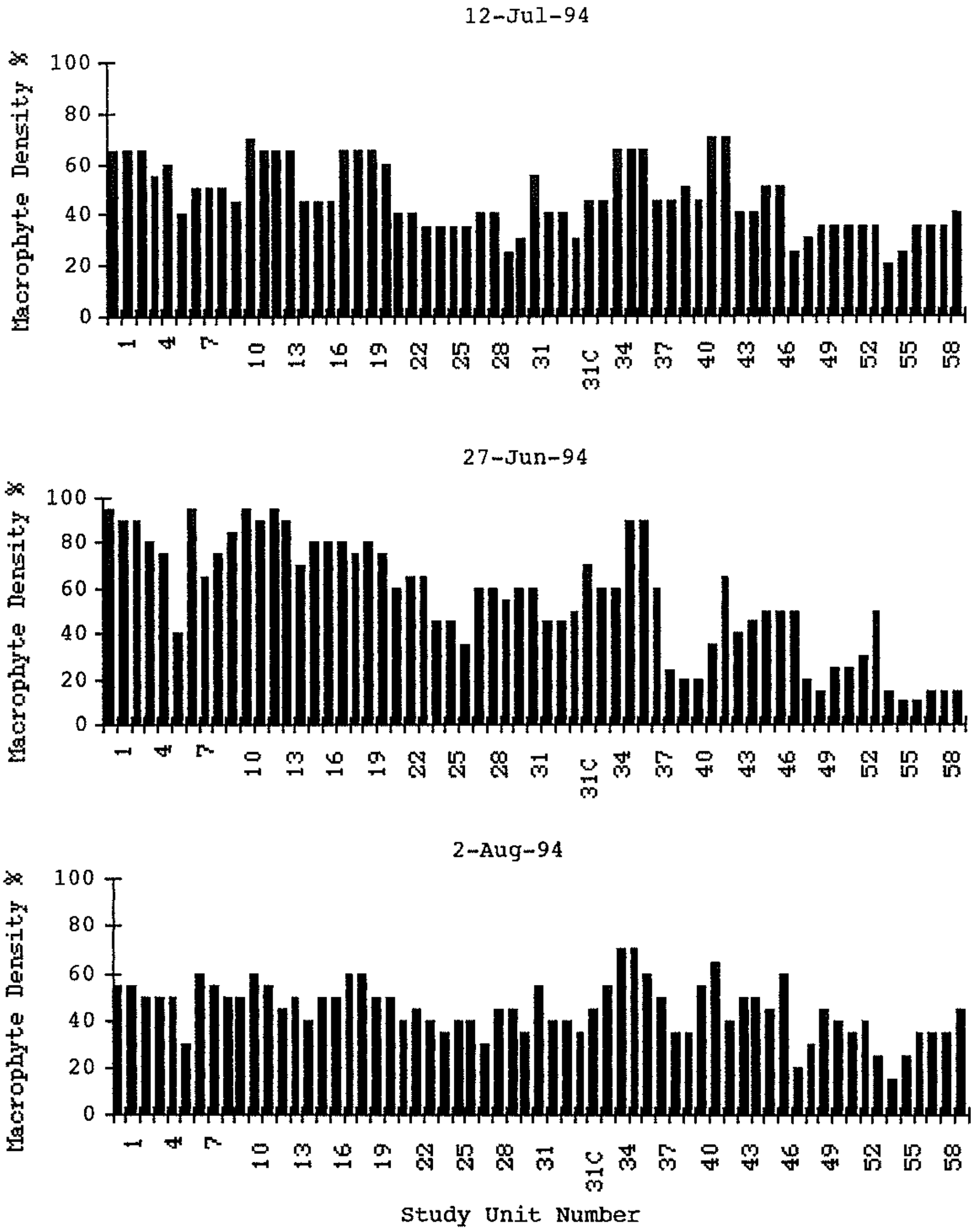

Figure 9. The density of macrophytes per unit (Figure 3) during the summer of 1994, lower Hat Creek. Density was estimated at approximately two week intervals using both aerial and bankside data.

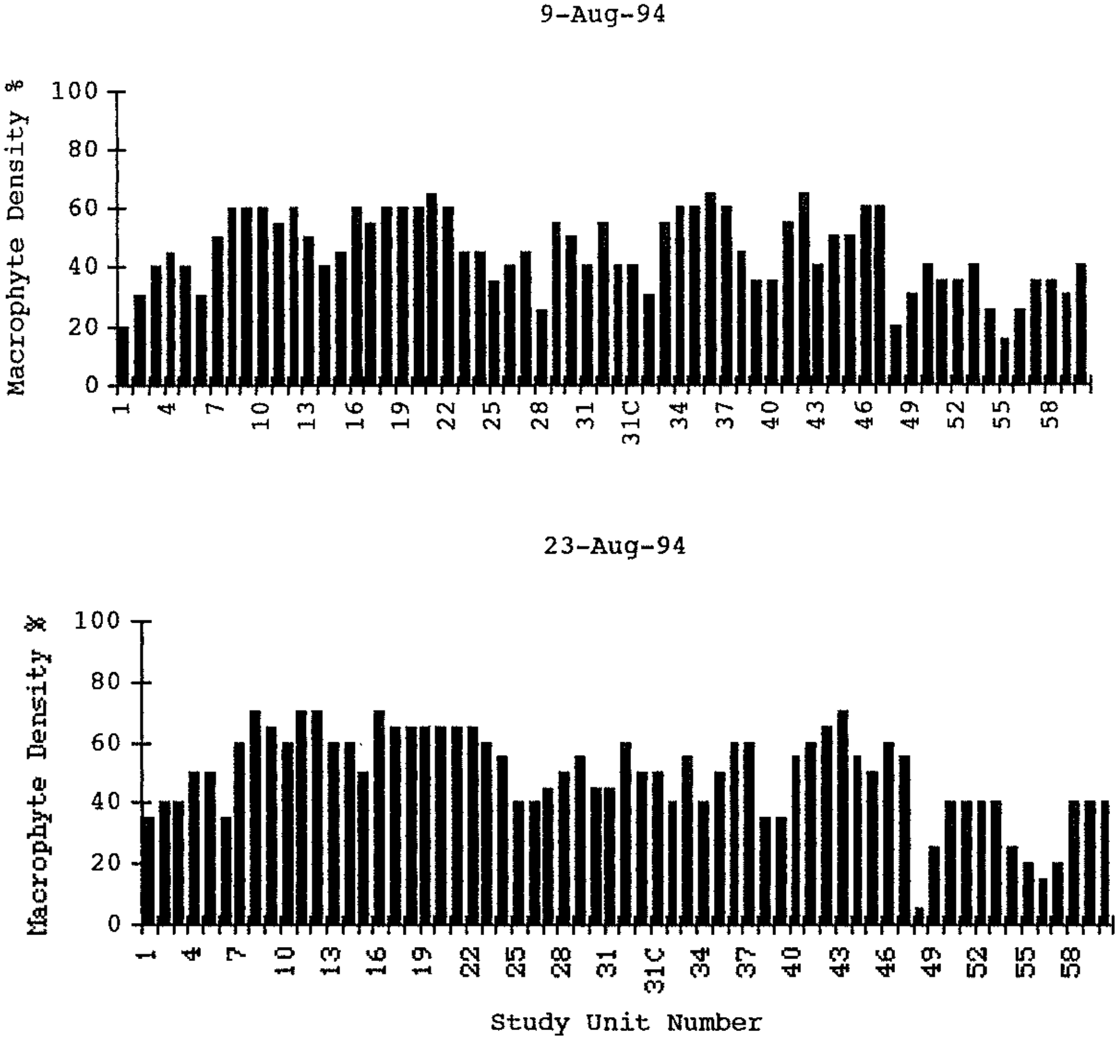

Figure 9. The density of macrophytes per unit (Figure 3) during the summer of 1994, lower Hat Creek. Density was estimated at approximately two week intervals using both aerial and bankside data (continued).

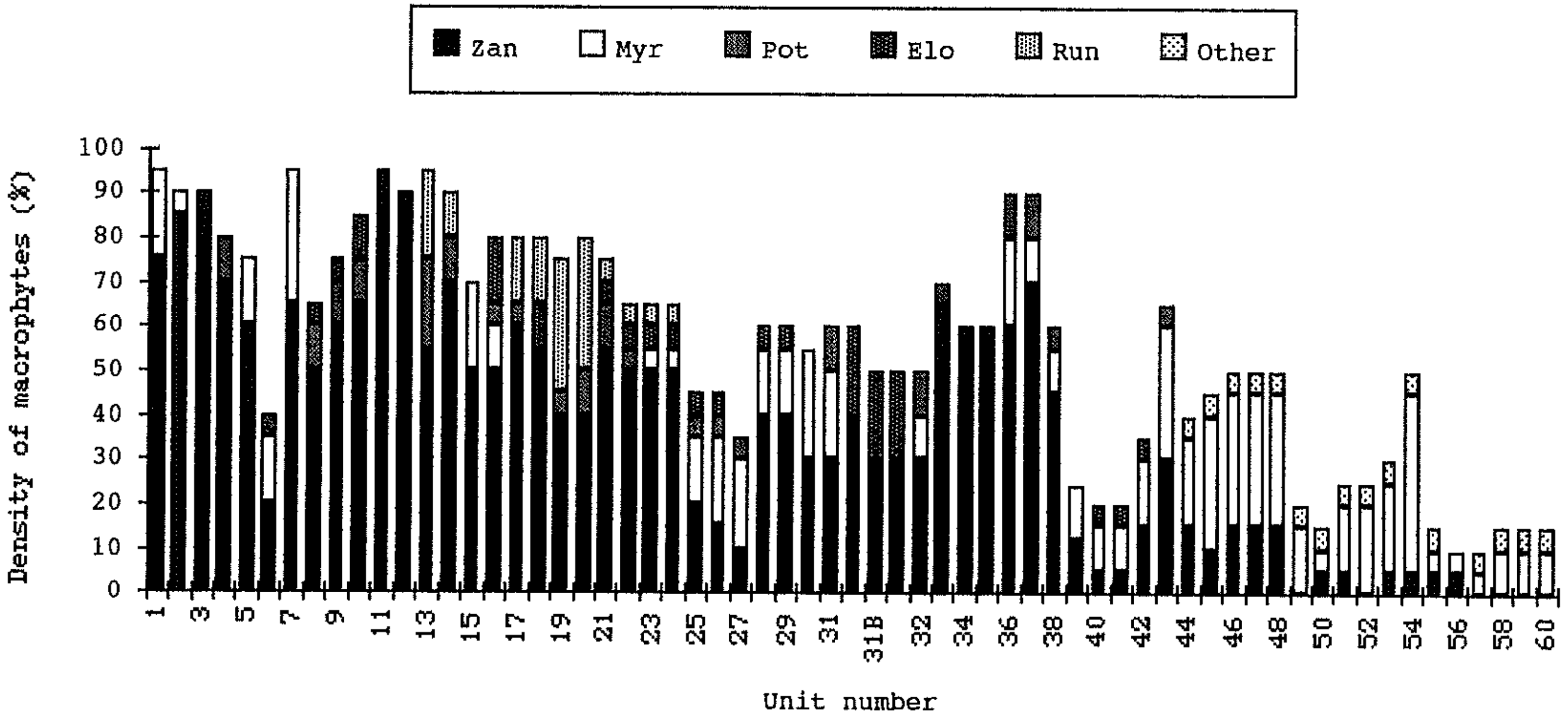

Figure 10. Species composition and density of macrophytes per unit, estimated on June 27, 1994. Percent coverestimates were obtained from aerial photographs and from bankside estimates. Zan=*Zannichellia*, Myr=*Myriophyllum*, Pot=*Potamogeton*, Elo=*Elodea*, Run=*Rununculus*, O=Other.

significantly different (P-value=0.219, α=0.05). Thus, when unit estimates of macrophyte cover were available from bankside estimation only, those estimates could be used with relative confidence.

Distribution. The upper portion of the glide section was dominated by the dense, long, filamentous macrophyte, *Z. palustrus*, or grass wrack. The lower section of the glide was more sparsely vegetated, primarily with *M. exalbescens*, or milfoil. The density of macrophytes varied over the summer throughout the study area. *Zannichellia palustrus* was very dense at the start of summer, then tapered off mid-summer, and increased in density once again by the end of August.

The nature of growth patterns of each species varied and appeared to determine trout distribution. *Zannichellia palustrus* was very dense, growing in large patches of multiple plants opposed to more singular small clumps. *Zannichellia palustrus* grew both in deep and shallower fast flowing water, filling the entire water column and covering the substrate. Its long foliage would form mats on the water surface which later sloughed off and floated downstream, caught up on woody debris and the creek margin. Trout did not hold within the dense growths of *Z. palustrus*, but used the outer perimeter of dense patches. *Myriophyllum exalbescens* grew in clumps in shallower water, both fast flowing and slower flowing water. Its foliage was more compact reaching the water surface only in shallow water. *Myriophyllum exalbescens* grew in swifter water than *Z. palustrus*, resulting in more scouring activity around the plant. The scouring in the sand formed dunes which provided trout with velocity refugia. There was scouring around *Z. palustrus*, but to a lesser degree. Both *E. canadensis* and *R. aquatilis* grew in dense patches in shallow, slower water either on the creek margin or on sand bars. Only YOY trout were associated with *E. canadensis* and *R. aquatilis*, and then to a lesser extent. *Potamogeton crispus* grew in sparser bunches along the substrate providing minor water velocity refuge.

Monitoring Physical-Chemical Variables

The water level of LHC was highest at the beginning of summer. LHC slightly overflowed its 'normal' edge water level and created temporary marshy areas. The water level dropped considerably during summer (Figure 11), though rate of decrease lessened toward the end of the summer. Total change in water level (difference from beginning of summer compared to end of summer) was not consistent throughout the creek. The overall drop in creek level was greatest in the upper section of the glide and least in the lower section, with the middle section levels intermediate (Hat Creek No. 2 Powerhouse Δ=365 mm; Carbon Bridge Δ=172 mm; Highway 299

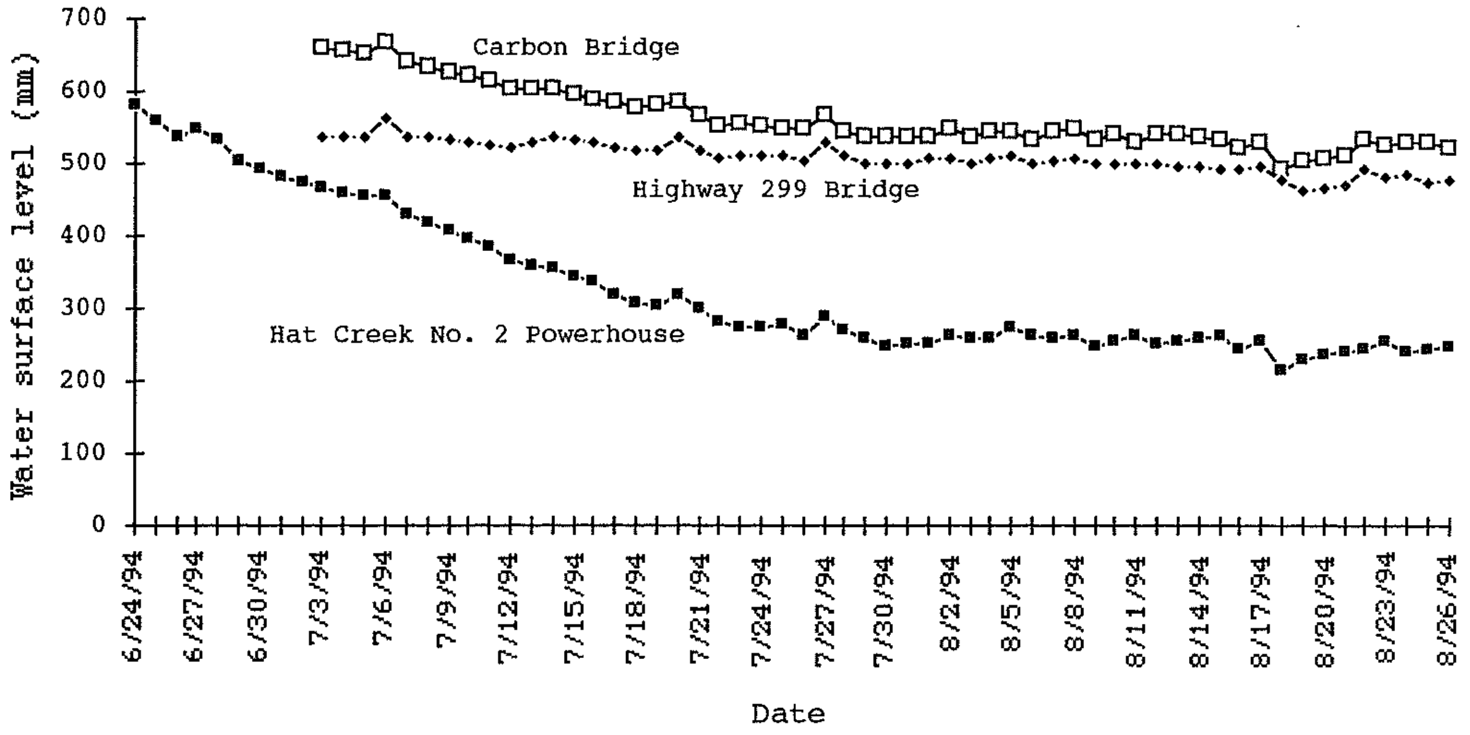

Figure 11. Water level measured daily throughout summer 1994 at three gauging stations located approximately equidistant along the glide reach of lower Hat Creek. Data reflect relative changes in the water surface level, not measures of true depth. Missing data points (24%) were estimated by extrapolation.

Bridge Δ=100 mm). The abundance of different plant species and abundance in submersed macrophytes caused water levels to change in different sections of LHC. Major fluctuations in water level coincided with irrigation fluctuations above LHC. These events are indicated in Figure 10 as small peaks occurring at relatively regular intervals.

Water discharge through Hat Creek No. 2 Powerhouse was relatively consistent over both 1992-1993 and 1993-1994 water years, primarily ranging from 6.6 cms to just over 13 cms with a few exceptions. The range of discharge was slightly greater during water year 1992-1993, attaining a maximum of 13.3 cms, while the high for water year 1993-1994 was 11.95 cms. Mean summer time discharge was also higher in 1993 than 1994 (Figure 12). Discharge was presented to further describe the conditions the trout were exposed to during this study.

Water temperatures were measured at gauging stations, usually in the afternoon. Water temperatures during the summer 1994 ranged from 13.5°C-19°C (mean=16.9°C, SE=0.094). The water temperature was usually 1-1.5°C higher in the lower section at Hat Creek County Park than at unit one in the upper section. Water temperature was measured only twice during the spring, 3/26 and 4/23/94, 10°C and 11°C respectively. During 1993 water temperatures ranged from

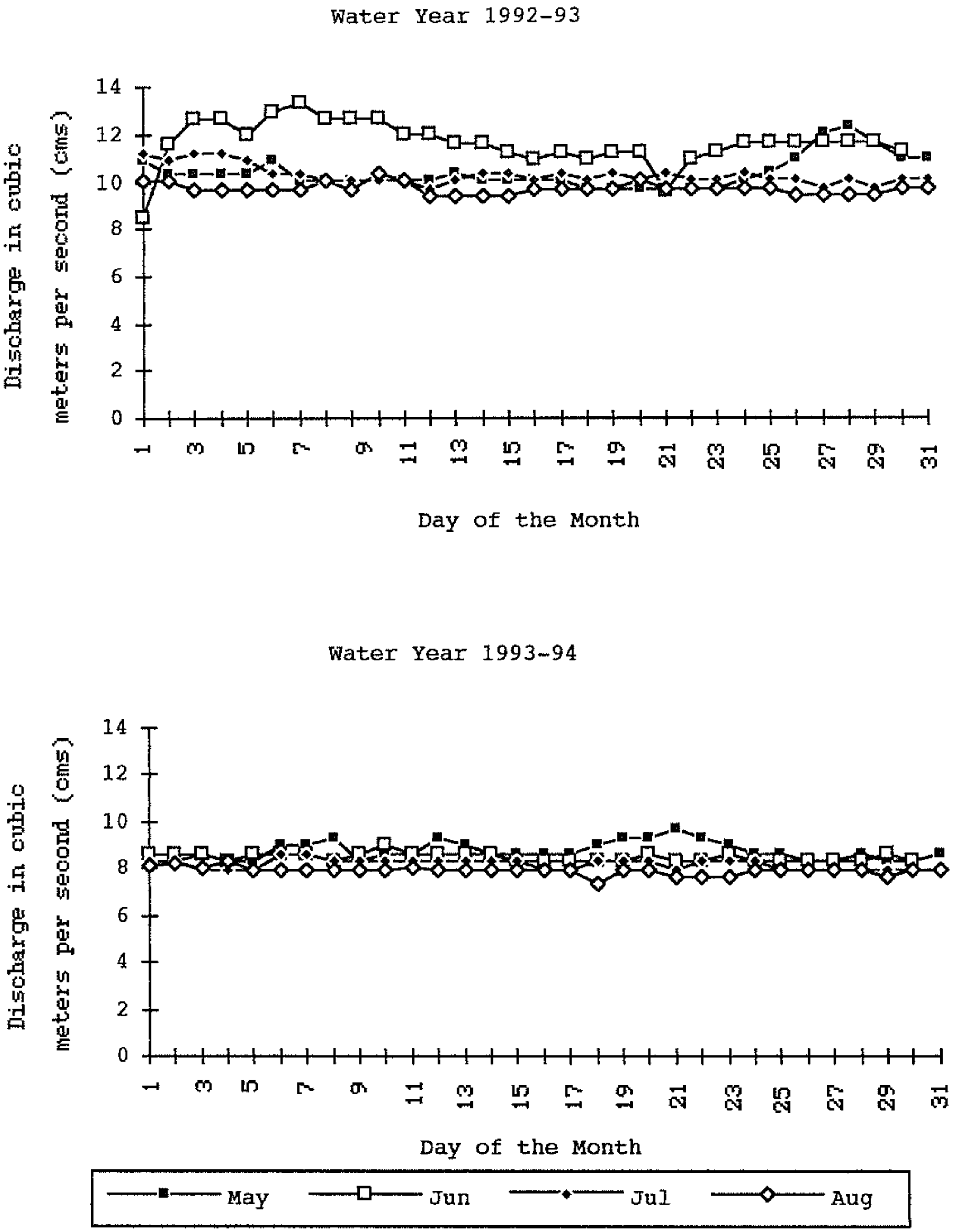

Figure 12. Summer water discharge (cms) through Hat Creek No. 2 Powerhouse for water years 1992-1993 and 1993-1994, courtesy of Pacific Gas and Electric, Burney, California.

spring (2/6-7, 2/13-14, 3/4-7, and 4/24/93) temperatures of 5.7°C-16°C (mean=12.6°C, SE=0.505) to summer (6/8-8/27/93) temperatures of 12°C-16°C (mean=14.0°C, SE=0.181).

Water quality was tested at unit 2 which resulted in a pH of 7.6, dissolved oxygen (DO) of 7 mg/l, CO_2 of 15 mg/l, and water hardness of 85.5 ppm.

Analyses

Variable Reduction. Principal components analysis variables (microhabitat use variables) were: (1)size-class of trout, (2)number of trout per associated quadrat, (3)distance of trout to the creek margin, (4)distance to nearest neighbor, (5)depth, (6)depth code, (7)dominant substrate, (8)1st subdominant substrate, (9)2nd subdominant substrate, (10)water velocity refuge, (11)surface water velocity, (12)mean water velocity, (13)water velocity at substrate, (14)proportion of macrophyte cover on June 6, 1994, (15)proportion of macrophyte cover during observation, and (16)proportion of macrophyte cover per associated quadrat. The principal components analysis found significant Eigen values (≥1) in the first five factors, or principal components (Table 14).

The first seven PCs composed of specific microhabitat variables accounted for the majority of the microhabitat use variation, 82.49%, observed among the different size-classes of trout. These variables were held for further analysis.

Table 14. Habitat use variables were combined into factors,or principal components (PC) dependent on the proportion of variation in microhabitat use by the three size-classes of trout they explained. The variables that form the PCs are listed as: %SM=proportion of submersed macrophytes, vel.=water velocity, %SM/quadrat=proportion of submersed macrophytes within the associated quadrat, trout/quadrat=number of trout within the associated quadrat.

	Principal Components				
	#1	#2	#3	#4	#5
Variables	Depth Size-class 1st subdominant substrate Depth code Dominant substrate 2nd subdominant substrate %SM (6/27/95) Trout/quadrat	Surface vel. Mean vel. Distance to shore Vel. at substrate	%SM (6/27/95) Vel. at substrate %SM/quadrat Vel. refuge	Trout/quadrat Distance to neighbor	Distance to neighbor %SM (6/27/95)
Eigen Value	3.95	2.89	2.34 1.32	1.24	
% of Variation	24.71	18.09	14.60 8.26	7.75	

PC six (distance from nearest neighbor, 5.02% of the variation) and PC seven (water velocity refuge, 4.07% of the variation) contained single variables used in other PCs. All 16 variables analyzed with PC analysis were retained for further analysis as all were components of significant PCs. The continuous variable, 'depth', was dropped from further analysis because it was a redundant variable of 'depth code' (r=0.812). The variable 'depth code', though more general, was thought to have less temporal bias than the variable 'depth'.

Logistic Regression Model. Logistic regression was used to compare habitat use between size-classes of trout (Afifi and Clark 1990; Hintze 1992). A large percentage of correctly classified individual trout in each model indicated that habitat use was different among the size-classes analyzed (Table 15). The logistic model allowed testing among only two groups simultaneously. Therefore, pairwise groupings of size-classes resulted in 89.5% correct size-class classification of YOY and juvenile trout, or, 89.5% of the YOY and juvenile trout could be correctly classified to size-class by using habitat use variables in the model. The YOY and adult model correctly classified 87.8% of those size-classes. A third model compared juveniles to adults at 83.7% correct classification to size-class. Variable chi-squares of less than 2 were dropped from each analysis.

Table 15. Habitat use among the three size-classes of trout compared with logistic regression analysis lower Hat Creek 1994. Variables are presented in the order that they loaded in a step-up procedure. Variable chi-squares of <2 were dropped from the analysis. %SM(6/27/94) and %SM(8/94) are the proportion of submersed macrophyte cover per unit estimated on that date, %SM/quadrat=the proportion of submersed macrophyte cover of associated quadrat, neighbor=distance to nearest neighbor, shore=distance to nearest shore.

	YOY/Juvenile			YOY/Adult			Juvenile/Adult		
Step	Variable	Chi-square Beta=0	*P*-value Beta=0	Variable	Chi-square Beta=0	*P*-value Beta=0	Variable	Chi-square Beta=0	*P*-Value Beta=0
1	depth code	26.64	0.0000	depth code	55.36	0.0000	neighbor	6.31	0.0120
2	%SM/quadrat	4.64	0.0313	%SM/quadrat	87.29	0.0000	%SM (6/27/94)	13.97	0.0002
3	shore	30.65	0.0000	velocity refuge	34.01	0.0000	%SM/quadrat	8.58	0.0034
4	neighbor	8.79	0.0030	mean velocity	19.63	0.0003	mean velocity	10.74	0.0010
5	%SM (8/94)	20.66	0.0000	%SM (6/27/94)	76.13	0.0000	1st subdom. sub.	3.89	0.0486
6	%SM (6/27/94)	8.26	0.0041	%SM (8/94)	42.08	0.0000	velocity refuge	2.70	0.1003
7	mean velocity	3.87	0.0492	shore	20.74	0.0000			
8	dominant substrate	2.40	0.1215	dominant substrate	8.24	0.0041			
9				velocity at substrate	4.41	0.0358			
10				neighbor	4.03	0.0447			
Intercept		28.59	0.0000		23.46	0.0000		1.90	0.1681
Model	r^2=0.2287	173.14	0.0000	r^2=0.4477	668.65	0.0000	r^2=0.1928	95.04	0.0000
Correctly classified		89.54%			87.80%			83.70%	

Habitat use was different between the three size-classes of trout. Variables which distinguished size-classes from one another were different between trout size-classes (Table 15). The habitat use variable that described the most variation between the two groups was added to the model first. Variables added thereafter described a decreasing amount of variation. Depth and the proportion of submersed macrophyte cover per quadrat were the best discriminators when YOY habitat use was compared to either juvenile or adult trout habitat use. The variables that explained the majority of difference between adult and juvenile habitat use were the distance of each trout to its nearest neighbor, and the proportion of submersed macrophyte cover for both unit and quadrat.

<u>Habitat Use/Availability</u>. The availability of clear patches of substrate in dense submersed macrophyte growth was the dominant variable determining the presence of YOY and larger trout. Geomorphic and hydraulic features were the second set of variables used to predict residence. An energy efficient focal point consisted of a combination of large substrate elements located where water velocity was great enough to transport sufficient amounts of drift. Focal points characterized by high mean water velocity and large substrate elements were selected more often in the presence of deep water. Therefore, suitable microhabitats combined

several variables. While each habitat use variable had an optimal range for use, trade-offs in the optimal range of any one variable were necessary when suitable habitat was limited. Use of less optimal ranges of habitat use variables maximized the availability of suitable habitat.

To quantify the amount of habitat available, the proportion of the study unit that displayed the range of each variable used by all size-classes of trout was overlapped in a combined fashion (Table 16). These areas of overlapping variable use ranges were then determined to be the amount of suitable area available to trout. The size of trout home-ranges were extremely variable due to high trout densities, particularly in study units 6 and 15 It was not practical to quantify home-range sizes. Therefore, an area or patch deemed suitable, but absent of trout, was determined available though not used. This happened rarely except in unit 60. However, I still concluded that, most suitable areas observed within the study units were utilized by trout. Additionally, due to the concentrated groupings of larger trout I also determined that suitable habitat was limited.

Correlation of Trout to Submersed Macrophytes.

Spearman's rank correlation was used to test whether focal points were associated with substrate patches free of submersed macrophytes. Avoidance of dense submersed macrophytes in favor of clear substrate patches would

Table 16. The proportion of each study unit that contained the range of the microhabitat variables used was estimated from the unit profiles of microhabitat variables. The selected ranges of each microhabitat variable used by YOY trout and larger trout were determined by study unit. The proportion of the study unit that had suitable microhabitat available was estimated where all selected ranges of variables overlapped.

Habitat Variable	Proportion of Study Unit Within Selected Range									
	2	6	15	25	29	32	36	46	50	60
Macrophyte-free substrate*	0.34	0.53	0.44	0.63	0.39	0.58	0.19	0.48	0.62	0.59
Water Depth										
YOY trout	0.93	1.00	1.00	1.00	1.00	0.80	0.87	0.91	1.00	0.75
Larger trout	0.87	0.71	0.81	0.94	0.73	0.80	0.87	0.91	0.73	0.35
Water Velocity										
YOY trout	0.72	0.89	0.59	0.75	0.72	0.55	0.42	0.55	0.61	0.31
Larger trout	0.72	0.34	0.59	0.96	0.88	0.55	0.42	0.36	0.48	0.31
Substrate										
YOY trout	0.37	0.43	0.39	0.36	0.26	0.51	0.86	0.27	0.31	0.45
Larger trout	0.17	0.20	0.22	0.15	0.18	0.33	0.17	0.08	0.12	0.22
Suitable Habitat Available										
YOY trout	0.25	0.50	0.42	0.50	0.42	0.60	0.22	0.55	0.60	0.17
Larger trout	0.13	0.20	0.18	0.07	0.14	0.33	0.08	0.08	0.06	0.05

*The proportion of submersed macrophyte cover, though temporal in its density, was determined when the study unit was observed (7/28-8/18/95).

be indicative of the influence that patch dynamics had on trout when selecting microhabitats. The null hypothesis that the ranks of all size-classes of trout abundances were uncorrelated to macrophyte cover was rejected. All correlations were highly significant with *P*-value <0.001 for each size-class. Trout abundance and the proportion of submersed macrophyte cover per quadrat (*N*=730) were negatively correlated (adult r_s=-0.130, juvenile r_s=-0.127, and YOY r_s=-0.145). This suggests that all size-classes of trout held over substrate patches avoiding areas of high macrophyte density. Power analysis, using NCSS (Hintze 1992), yielded high power values of ß=0.83, 0.75, 0.91 respectively (adult, juvenile, and YOY trout) for detecting a true negative correlation when there was a negative correlation.

Two Phase Sampling Analysis. The proportion of macrophyte cover per unit was used as auxiliary information (AI) to obtain a population estimate of trout abundance in LHC (Scheaffer et al. 1990). The AI estimate was then compared to the snorkeling population survey by CDFG in 1993 (Table 17). The 1993 CDFG electrofishing estimate did not consider YOY abundances, therefore, it could not be compared to the AI population estimate, but the number of trout estimated in the larger size-classes was informative. Both

Table 17. Population estimates of trout in lower Hat Creek from electrofishing and snorkeling (CDF&G 1993) and from auxiliary information (AI) that was the proportion of macrophyte cover per unit, 1994. The regression coefficients for the AI data were calculated for separate trout size-classes and all size-classes combined; data from August 2, 1994.

	YOY	Juvenile	Adult	Total (CI)
CDF&G 1993				
Electrofish				
Rainbow		1689(200-300mm)	763(≥300mm)	2497±446*
Brown		246(200-300mm)	87(≥300mm)	333±85*
Snorkel (both species combined)				
1st survey		5284(<350mm)	332(>350mm)	5616
2nd survey	3840(<150mm)	2375(150-300mm)	407(>350mm)	6631
AI 1994 (both species combined)				
Weighted Regression	2234(<150mm)		1493(>150mm)	3727
Weighted Average				4520±2885

*Indicates that this total value represents only those trout ≥200 mm, thus did not consider the abundance of YOY trout.

CDFG estimates considered only the area from Hat Creek No. 2 Powerhouse riffle to the Highway 299 bridge, equivalent to 50 units from my 1994 study.

The strength of the association between the number of trout per study unit and the proportion of submersed macrophyte cover changed over time, due to the temporal growth of the macrophytes. Trout and submersed macrophyte abundance correlations were highest when macrophytes were least dense (r=-0.56) on August 2, 1994. They were lowest when macrophytes were most dense (r=-0.18) on June 27, 1994. Regression analysis was used to correlate trout density per unit (dependent variable) with the proportion of macrophyte cover per unit (independent variable), as well as obtain regression coefficients. Even though only 31.5% (r^2=0.315 trout size-classes combined; r^2=0.353 YOY, r^2=0.258 large trout) of the observed variation in trout abundance was explained by the regression when macrophytes were least dense, the correlation declined when macrophyte abundance increased.

Despite low correlations, (YOY, r=0.594; larger size-classes, r=0.508), the macrophyte density data from August 2 from the ten study units were used in size-class separated, weighted regressions that resulted in regression equations for YOY trout and larger trout size-classes:

Number of YOY trout per unit = 123.84 + (-1.632) x % macrophyte cover per unit.

Number of larger trout per unit = 159.01 + (-2.663) x % macrophyte cover per unit.

The regression coefficients were then expanded to all 63 units, the density of trout calculated for each unit, and then summed. The trout population estimate of the 63 units yielded *N*=5579 (YOY=3151, trout >150 mm=2428). To compare with the 1993 population estimates from CDFG, the regression equation was applied to 50 units from the Powerhouse riffle to Highway 299 bridge yielding an *N*=3727: YOY=2234, trout >150 mm=1493) (Table 17). There were no statistical differences between the two methods, (paired *t*-test *P*=0.0694, α=0.05), though the AI underestimated the trout population indicated from 1993 CDFG snorkel estimates. A power analysis, or the ability to find a difference when a true difference exists, indicated that the t-test was weak due to a small sample size

The second approach to exploring the use of the proportion of macrophyte cover to estimate the trout population incorporated two phase sampling for stratified estimates of variances (Scheaffer et al. 1990). This approach resulted in a trout population estimate of *N*=5695 for all 63 units and *N*=4520 for 50 units (mean=90.4

trout/unit, bound on error of estimation was ±57.7, $s=28.9$, $s^2=833.3$). This was a higher mean estimate than the weighted regression approach, but smaller that the 1993 CDFG estimate.

DISCUSSION

Impacts to the Habitat

The combined effect of past and present land use practices, as well as other factors, has decreased preferred trout habitat in LHC. Historical reductions in total habitat complexity, due to livestock grazing and more recently, heavy angler use has resulted in trampled banks, collapsed undercut banks, and loss of riparian vegetation, particularly bulrush marshes. The loss of streamside vegetation leads to erosion of the banks, less cover, and the loss of an important source of terrestrial invertebrate food supply (Murphy et al. 1981, Hawkins et al. 1982). Other factors include the degradation of bank integrity and complexity due to the activities of muskrat and beaver.

Damming LHC in 1921 (Markwart 1921) has also indirectly channelized the creek by maintaining steady water flows which negate a natural seasonal hydrograph. Chapman and Knudsen (1980) examined the impacts of channelization and livestock on salmonid habitat, concluding that when overhead cover, sinuosity, wetted area, and woody bank cover were reduced, total trout habitat decreased.

Additionally, snorkeling surveys conducted during this study indicated that fine sediment has filled in channel complexity in the upper glide section, further limiting suitable trout habitat (pers. observation and CDFG 1993).

Trout Size-class Frequency Distribution

Hankin and Reeves (1988) and Hillman et al. (1992) demonstrated that snorkeling was an effective method to survey fish populations. However, poor underwater visibility in LHC biased population estimates. Trout focal positions were also unreliably determined from snorkel surveys because trout detected snorkelers and fled their holding locations before the snorkelers observed them. However, snorkel surveys provided a useful tool to view the relative complexity of the creek and to monitor changes in macrophyte growth.

The data collected during this study suggest that YOY survival was poor in 1993, resulting in low recruitment into the juvenile size-class in 1994 (Table 6). The size-class frequency distribution of trout in 1994 was bimodal. The upper modal group was YOY trout (N=512) and the lower modal group was adult trout (N=324); the frequency of juvenile trout was conspicuously low, N=81 (Figure 7).

The size-class frequency distribution of trout in LHC appears to be most affected by the submersed macrophyte density. The density of submersed macrophytes within LHC benefits trout differentially during successive life history stages. An inverse relationship exists with larger trout abundance and the density of submersed macrophytes. While an increase in favorable habitat reflected greater YOY survival when submersed macrophytes were dense. Submersed macrophyte density influences these cycles of available, favorable and less favorable habitat, which in turn, affect the size-class frequency distribution of LHC trout. Some asymptotic value of macrophyte density likely maximizes the survival of LHC trout, sustaining an equilibrium in the trout population.

Microhabitat use

The logistic regression models were accurate in classifying 84-90% of the trout (*N*=917) by incorporating microhabitat use variables. The models indicated that microhabitat use was different between trout size-classes. The occurrences of trout misclassified to size-class in the model (10-16%) were assumed to indicate overlaps in microhabitat use between those size-classes of trout.

The depth of water and the proportion of submersed macrophyte cover per quadrat described most differences in microhabitat use between YOY and larger trout (Table 15). The difference in microhabitat use between juveniles and adults could also be explained by the proportion of submersed macrophyte cover per unit as well as quadrat, but the distance from a trout to its nearest neighbor was the best discriminator between those size-classes, where juveniles held at greater distances away from other trout (Table 12).

All size-classes of LHC trout tended to avoid or not use sampling quadrats that had dense submersed macrophytes. Yet, further analysis revealed that YOY trout were more closely associated with quadrats that exhibited denser macrophyte growth, mean cover density=26.0%. YOY selected temporary microhabitats closer to concealment cover than the larger size-classes of trout. The close proximity of dense submersed macrophytes eased the trade-offs for YOY trout between refuge from predation and foraging behavior (Chapman 1966; Fraser and Cerri 1982; Abrams 1991; Tabor and Wurtsbaugh 1991; Walters and Juanes 1993). Adults and juveniles held in areas with sparser macrophytes (mean cover density=9.3% and 17.9% respectively). During snorkel surveys, YOY trout hid from predators (snorkelers) in submersed macrophyte cover, while larger size-classes of trout usually fled up- or downstream to put distance between themselves and the predator.

Fausch (1993) stated that holding an optimal foraging position, or focal point is constrained by the dominance hierarchy and trade-offs associated with predation risk. Schlosser (1987, 1988) observed that several species of juvenile fish shifted to shallower refuge habitats in the presence of adult fish. Fraser and Cerri (1982) also found small fish avoided portions of the stream channel where predators were present, but such behavior was reduced when more cover was available. This was the case in study units 2, 36, 46, 50, and 60 where sand dunes and submersed macrophytes provided concealment and velocity cover.

The spatial differences in trout distribution among study units could be explained primarily by geomorphic and hydraulic variables. Focal points selected by trout not only provided a clear view of the drift, but, also provided an energy efficient location. Relatively large substrate elements were of particular importance to trout because they provided refuge from water velocity (Table 11). Bedrock outcroppings and sand dunes provided the same type of refuge allowing trout to take advantage of higher water velocities that carried drift. The water velocity associated with all trout was relatively homogeneous among all trout size-classes, although velocity associated with adults was less variable (Table 10). Deep water also attracted trout, though, again there was more variability in the depths used by juveniles and YOY (Table 9). Deeper water supplied trout with concealment cover (Cunjak and Powers 1987a) and protected them from predators.

Specific examples of these microhabitat criteria were found in several study units and throughout LHC. In particular, the interface between diatomite bedrock and moving, fine-grained sediment, in the presence of high water velocity (usually at a bend in the creek channel, notably study units 15 and 32), created areas that were deep, free of macrophytes, and contained diatomite rubble, projections and irregularities for trout to hold behind.

Adult trout were always associated with some type of large substrate component whether, cobble, rock, LWD, sand dunes, or bedrock projections and irregularities, though large substrate elements were rare and scattered (Table 6). Unit 36 contained negligible amounts of large substrate elements and no larger trout. Additionally, substrate composed of bedrock or gravel and cobble discouraged colonization and growth of submersed macrophytes.

Unit 15 contained 158 adult trout, 49% of the adult population observed, which influenced the data on substrate type associated with adult focal points (Table 11). The entire right bank of unit 15 was composed of diatomite bedrock; the width of the bedrock expanse was 10-12 meters. All of these trout held behind rock or cobble-sized particles, or bedrock irregularities. Unit 6 also held a large number of trout, YOY=79 and juvenile and adult trout=138. The habitat in unit 6 was complex, containing an abundance of gravel, cobble, rock and diatomite bedrock. It is apparent from these two units, that as habitat complexity increases, the abundance of trout increases.

As the size of trout decreased, the size of the substrate particle associated with trout decreased. Smaller particles probably afforded sufficient refuge from velocity due to smaller body size. Submersed macrophytes grew well in sand and formed dunes from scour activity. YOY trout used the dunes as velocity refugia and the macrophytes as both concealment cover and velocity refugia. Two large groups of YOY trout, (*N*=79 and 110) representing 36.9% of the YOY sampled, were associated with gravel spawning beds located along the shallower creek margin of unit 6 and 15 respectively. Bozek and Rahel (1991) observed the same association, where densities of YOY trout increased in shallower water depth and spawning gravel. These two substrate types, sand/dunes/macrophytes and spawning gravel, characterized the majority of microhabitats used by YOY trout.

Heggenes and Saltveit (1990) and Hayes and Jowett (1994) found that differences in mean water velocity and mean depth described most of the variability observed in trout position, or selected habitat. Hayes and Jowett (1994) and Heggenes et al. (1993) determined that large substrate components were also important variables determining trout position. All these spatial variables in combination determined the microhabitat selected by trout in LHC, but the temporal and spatial shape and density of the submersed vegetative matrix within the creek determined location.

Submersed Macrophytes

The temporal and spatial growth of submersed macrophytes influenced the availability of premium focal points for trout from late summer 1993 through winter 1994/95. *Zannichellia palustrus* dominated the upper two thirds of the glide section, covering some areas of the creek completely (Figure 10). Conversely, in the first fall through spring (1992-93) of this study, macrophyte density was reduced, in particular *Z. palustrus* was almost absent. For at least two years previous to the start of this study, submersed macrophytes were very reduced (Dave Bowers, pers. comm.).

Submersed macrophytes provided YOY and larger trout with protection from aquatic predators such as adult trout, river otter *Lutra canadensis,* and avian predators, particularly osprey (*Pandion haliaetus*), great blue heron (*Ardea herodias*), belted kingfisher (*Ceryle alcyon*), and bald eagle (*Haliaeetus leucocephalus*). Dense macrophyte growth positively benefited LHC YOY trout by providing concealment cover adjacent to foraging sites with a clear view of the drift. Walters and Juanes (1993) and Abrams (1991) suggest that the time that juveniles spend foraging is an act of natural selection, where the optimal balance between growth and predation risk is determined by the need to reach larger size for later survival and reproduction. Walters and Juanes (1993) viewed the trade-off between predation risk and foraging as recruitment limitations. Abrams (1991) focused on the adaptive control of foraging effort as it related to life history. In years of sparse submersed macrophyte growth in LHC, suitable microhabitat is decreased to the level that YOY are restricted to limited cover positions along the creek margins and forced to forage in risky areas. Such adaptive control is under less constraint during years when the density of macrophytes is increased in LHC.

Macrophyte beds not associated with the channel margins allowed YOY trout to venture farther into the creek channel, thus, increasing suitable YOY trout microhabitats. Limited cover types in a stream decrease the fish carrying capacity of that stream (Fausch 1993). Cover is necessary to the survival of all size-classes of trout, yet there may be some asymptotic value to the benefits that trout derive from increasing cover density, particularly where macrophytes constitute most cover. Too much cover may have a negative effect upon drift-feeding trout density, limiting not only the total clear surface area but also, and more importantly, obscuring areas that possess important microhabitat features. Demas (1973) reported that rainbow trout in LHC fed primarily on drifting aquatic invertebrates. Teleki (1972) reported that brown trout in LHC also fed primarily on drifting aquatic invertebrates, but benthic invertebrates were also important. Drift-feeding requires an unobstructed view of the water overhead, which is negated when submersed macrophytes fill the entire water column. The data indicate that trout production in LHC may currently be limited by the number of submersed macrophyte-free 'patches' of substrate.

Disturbance and Patch Dynamics

There were two subsequent disturbance events that coincided during this study. These two disturbances, sedimentation and changes in submersed macrophyte density, created a situation that reduced the availability of suitable trout habitat, creating patchy, limited areas of use. Because larger trout utilized areas of patchy substrate exclusively, it was possible to predict the distribution of larger trout in LHC by first, locating patches of clear substrate within the macrophyte matrix and then, determining whether large substrate elements were present to provide refuge from water velocity.

A disturbance as defined by White and Pickett (1985) is any relatively discrete event in time that disrupts the ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment. The growth of submersed macrophytes in LHC may be considered as a disturbance where in some years macrophytes were very abundant and dense, followed by a year, or years where they are less abundant and sparse. When macrophytes were dense, suitable microhabitats for larger trout were limited to spatially discrete substrate patches in LHC. Pickett and Thompson (1978) stated that most disturbances produce heterogeneous and patchy effects; these effects may themselves depend on the state of the community prior to the disturbance.

The 1993 pilot study indicated that when submersed macrophyte density was low prior to midsummer, larger trout were more widely distributed. Units 6 and 7 together hosted only 39 adult and 16 juvenile trout. When macrophyte density was high during midsummer 1993-fall 1994, larger trout were forced into fewer suitable microhabitats that concentrated their population into large aggregations (unit 6, *N*=138; unit 15, *N*=164). This redistribution of trout suggested that suitable, larger trout microhabitats were limited during that time. These large aggregations were observed within three or four, five-meter square substrate patches. Partitioning the drift among dense aggregations of trout probably decreased the amount of food the trout needed to compete and/or survive. Competitive interactions during the morning hatch were not obvious, though postural behavior would have been difficult to detect due to poor visibility.

Fausch (1993) suggested that trout survival was closely related to summer growth which is dependent on the acquisition of optimal foraging positions so that trout meet seasonal energy requirements. Acclimatization to changing environmental conditions during early winter is stressful, even in a stable spring-fed creek (Cunjak 1988; Cunjak and Powers 1987a). Cunjak et al. (1987) suggested that trout energy budgets in early winter may not maintain acclimatization and reproductive requirements. Such deficits limit survival.

When adequate cover for YOY trout, or premium focal points for larger trout are limited in LHC, survival may be compromised during the winter. I suggest that the dense submersed macrophyte growth impacted the survival of adult trout during winter 1994. Available foraging locations were crowded and the drift was partitioned among large aggregates of trout. The sparse submersed macrophyte growth in 1992/93 failed to provide adequate cover for YOY trout who probably limited their foraging runs from the cover available. Few 1993 YOY trout survived to recruit into the juvenile size-class in 1994.

No trout aggregations of the size observed in 1994 were seen in the creek during 1993 when macrophytes were less dense, despite extensive surveys. Additionally, the aggregation of larger trout observed at unit 15 (N=164) had almost completely dispersed in spring and early summer 1995, leaving only two juveniles and an uncounted number of YOY. In winter 1995 most of the submersed macrophytes, particularly *Z. palustrus*, died back without reappearing by spring or early summer. Study unit 15 was thus almost free of macrophyte growth. These observations lend further support to the hypothesis that availability of suitable habitat limited the number of larger-sized trout during 1994.

A sediment intrusion that appeared in LHC about 1987 was a second disturbance event which had a negative impact on trout (CDFG 1993). As the fine sediment plume moved down the creek it reduced depth and substrate complexity (CDFG 1993). Pickett and Thompson (1978) stated that the consequences of a given disturbance are strongly dependent on a variety of biotic and physical factors such as regional climatic gradients, topographic gradients, and substrate types. Damming LHC, with its low gradient in the glide section, created a condition where the creek was unable to transport the fine sediment through the system quickly. As creekbed complexity decreased the distribution and abundance of suitable trout habitat decreased. Snorkel surveys conducted during this study indicated that the sediment had now moved through the upper glide section. The leading edge of the plume was in the middle section of the glide, located past the old Carbon Bridge site immediately upstream from Wood Duck Island (Figure 3, unit 30).

Comparatively few bulrush marshes remain in LHC most marshes were turbid with organic sediment and shallow with no undercuts due to angler impacts and muskrat activities. McMahon and Hartman (1989), Griffith and Smith (1993), and Smith and Griffith (1994) documented the fact that undercut banks improved survival of juvenile salmonids. The lack of quality marshes and undercut banks may have elevated the importance of submersed macrophytes to YOY trout as concealment cover.

Limited suitable habitat affects the trout carrying capacity of the creek, which can lead to a poor or small year class. Griffith and Smith (1995) found that as the density of submersed macrophytes declined in an Idaho stream during winter, the density of age-0 trout declined, resulting in zero survival in their study area. Based on my study, the same relationship between YOY survival and submersed macrophytes existed in LHC. One cause of decreased numbers of trout in LHC was probably the result of periods of sparse submersed macrophyte cover.

The relationship between the sediment intrusion, reduced density of macrophytes, and decreased suitable microhabitats, contributed to the distribution and abundance of trout in LHC. The 1984, 1988, and 1991 CDFG trout population studies indicated a decline in trout abundance in the upper portion of the glide section (Powerhouse Riffle to Carbon Bridge). These same studies also indicated that the trout population mid-way through the glide section (Carbon Bridge to Wood Duck Island) increased (Figure 3). The 1993 CDFG trout population study (CDFG 1993) suggested that sediment influx influenced trout distribution, indicating that fewer trout held in the middle reach in 1993 compared to 1983, prior to the sediment entering the system. These spatial decreases and increases in trout abundance coincided with the sediment intrusion as it passed into the Powerhouse riffle and upper glide reach, then continued into the mid-reach between the Carbon Bridge site and Wood Duck Island. Hobbs and Huenneke (1992) stated that most ecosystems experience multiple disturbances and are shaped by multiple factors, where the results are not merely additive, but, act synergistically.

Trout Population Estimate

Assuming the 1993 CDFG trout population estimate was the baseline for the glide reach in LHC, the two phase sampling analysis (AI) using the weighted regression approach (Scheaffer et al. 1990), underestimated the trout population in LHC. The AI estimate failed to provide sufficient information to accurately estimate the trout population in LHC. The lower estimates derived from the AI method when compared to the CDFG snorkel estimate, were probably the result of the low correlation coefficient between submersed macrophyte cover per study unit and trout density per study unit. The regression coefficients obtained in the AI method were unable to efficiently describe the population. Correlation coefficients became worse with the higher densities of submersed macrophyte cover estimated early in the summer. The two phase sampling for stratified estimate of variances approach also underestimated the trout population. Confidence intervals of the mean of the AI estimate did encompass the CDFG estimate, but the standard error was large compared to the mean estimate. This disparity largely resulted from a standard deviation that reflected a small sample size, as well as a large variation between trout abundance per unit.

The trout population estimates were compared from data collected from two different years, CDFG 1993 and AI 1994. One might expect the estimate of the smaller size-classes to change annually if the creek was experiencing environmental or habitat changes that influence survival. However, if the two methods were equally effective at estimating trout abundance, the number of adult trout should be similar because survivorship increases with age and the adult population was formed by several cohorts. Therefore, if the 1993 CDFG snorkel population estimate was used as a baseline, the use of macrophyte cover as auxiliary information was not sufficient to estimate the trout population in LHC. Submersed macrophyte density was of value as a predictive tool to understand trends in population abundance, based on the differential relationship that submersed macrophyte density had to abundances in trout size-class (Table 7 and Table 13, also see Appendixes I and K).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The size distribution of trout observed in 1994 indicated that YOY trout had low survival in 1993, probably due to an extreme decrease in cover. Habitat change caused by pronounced fluctuations in seasonal and annual submersed macrophyte density (disturbance) was double-edged in the benefits that trout derived, where increased densities benefited YOY trout and decreased densities benefited larger trout.

House (1995) reported that temporal variation in abundance occurred naturally in an isolated population of cutthroat trout unimpacted by fishing or land use practices. There were natural, temporal variations in environmental conditions in LHC which directly affected trout abundance, most conspicuously, changes in submersed macrophyte density. Submersed macrophytes have always been present in LHC in varying densities (Dave Bowers, pers. com.). The variation in trout abundance in LHC is probably of natural occurrence, but during years of lower abundance, the trout population is further compromised by manmade influences.

Natural disturbances influence trout access to suitable habitat and thus impact trout survival and ultimately their abundance. Extreme or prolonged population declines occur when the impacts of manmade habitat degradation are compounded with natural fluctuations in population abundances; these cumulative effects negatively affected the abundance of trout in LHC.

The large aggregations of trout seen in units 6, 15, and elsewhere in the creek suggest that microhabitats suitable for larger trout were limited during summer 1994, but that YOY habitat was not limited due to dense submersed macrophyte growth. Data from this study and CDFG (1993) also indicate that the number of trout in LHC had increased (mean=6124 snorkeling, or N=2830±531 electrofishing, CDFG 1993) from the low numbers seen in 1991 (N=1665).

The variation in the distribution of trout observed in LHC could not be accounted for by distribution of submersed macrophytes alone, despite its temporal and spatial components. The spatial variation in geomorphic variables present in LHC such as channel morphology and substrate composition, also greatly influenced trout distribution. Greater instream complexity should return to LHC when the influx of sediment ultimately passes through the system, uncovering large substrate components that will result in increased trout abundance.

The trout population estimate in 1983 (Table 1, CDFG 1993) reflects a population prior to the influx of fine sediment into the creek in 1987. This could also be said for the 1984 (CDFG 1993) estimate (Table 1), however other environmental or manmade factors decreased the population the next year by one third, from *N*=6154 (1983) to *N*=4092 (1984) trout. The size distribution (Figure 1) in 1983 reflects a more idealized occurrence, though YOY numbers are lower, than subsequent years sampled. Therefore, given the condition of the creek and the affect of environmental factors, a potential carrying capacity of at least the 1983 population can be met, though may not be sustained. Carrying capacity in LHC is probably variable given disturbance events. A carrying capacity range might better describe the true potential of the creek, where the 1983 numbers (Table 1) are included within the range.

Recommendations

The banks of LHC should be protected to preserve shallow water habitat complexity, including formation of undercuts and marshes. Maintaining bank integrity insures that important nursery and rearing areas are provided for YOY trout. Bulrush marsh habitat is important to YOY trout, it provides concealment cover for YOY, particularly when submersed macrophyte density is low. Signs should be posted at all marsh sites to explain the sensitive nature of those areas. If marsh degradation continues, angler casting platforms could protect the marshes. Marshes could be further protected by enclosing them along their inner bank margin to exclude angler access. The number of non-native muskrat should be brought under control to curtail the damage done to the banks and bulrush marshes from their burrowing.

Until the sediment travels out of the system, suitable trout habitat will decrease in LHC. Protecting the creek banks also decreases the amount of sediment added to the system. Large structures may need to be added throughout the glide section to increase habitat complexity. LWD suspended from the bank, or even large cobble or rocks distributed in suitable locations, where macrophytes are sparse, would provide additional habitat for trout in years when submersed macrophyte growth is dense.

The density of submersed macrophytes needs to be monitored and quantified seasonally and annually. Monitoring submersed macrophyte could help predict when low trout survival might occur. When used as a predictive tool for population abundance, submersed macrophyte density could supply information to help manage the creek. Lessening the impact on the population during years of low trout survival might be achieved by decreasing the access anglers have to the trout by selectively shortening fishing seasons and decreasing take.

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