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Influence of Temperature on Microhabitat Choice by Fishes in a California Stream

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Abstract.—We used eight microhabitat variables to examine the assumption that the variables normally included in instream flow studies are adequate to discriminate among species' microhabitats. When eight variables were available in stepwise-discriminant analysis models to distinguish among the microhabitats of four fish species in a northern California stream, the variance explained ranged from 52 to 77%, and 59 to 86% of the observational records were correctly classified to species. The variables measured were temperature, total depth, focal point elevation (distance of fish from the bottom), focal point velocity (water velocity at fish's snout), mean water column velocity, surface velocity, substrate, and cover. When the number of variables available was reduced to the three normally used in instream flow studies (i.e., total depth, mean water column velocity, and substrate), the variance explained ranged from 0 to 20%, and 46 to 55% of the observational records were correctly classified to species. When all eight variables were available, two variables not normally measured in instream flow studies, temperature and focal point elevation, were important in discriminating among species. Focal point elevation explained between 32 and 43% of the variance in the five models in which it was available. Temperature was included in 14 of 15 models in which it was available and made significant contributions in 12. Total depth was included and significant in 12 of the 20 models in which it was available. When total depth was included in a model, it was always more important than temperature; however, temperature and focal point elevation were the only significant variables on two sampling dates. Mean water column velocity and substrate only made minor contributions in a few of the 20 models in which they were available.

The microhabitat of an individual stream fish is the place in the stream where it is located at any point in time. This place is presumably chosen by the fish in response to proximate factors to optimize its net energy gain (Fausch 1984) while avoiding predators and minimizing interactions with competitors. Because most similar-sized individuals of a species are likely to choose similar microhabitats, careful measurements of the characteristics of a number of individual locations should define the population response pattern to environmental variables.

The description of the microhabitats of stream fishes has assumed considerable importance in recent years because the information is used with stream hydraulic models to simulate the amount of habitat available to fishes in regulated streams under different flow regimes (Bovee and Cochnauer 1977; Bovee and Milhous 1978; Stalnaker 1979). The variables measured to define the microhabitats used in these simulations are generally those that can be measured easily both on transects and in association with the fishes (e.g., mean water column velocity, total depth, and substrate). The simulations generally assume that (1) the variables measured accurately represent the preferred microhabitat of the fishes, (2) the fishes studied have, in fact, chosen the optimal microhabitat for growth and survival, (3) the microhabitat descriptions can adequately discriminate among species to predict the quantity of suitable habitat area for each species in the assemblage, and (4) the microhabitat defined by these variables is a characteristic of the species, so that studies made in one stream are transferable to other streams containing the same species.

These assumptions are rarely tested adequately and can be questioned because recent studies have shown that the position of a fish in a stream can be influenced by many additional factors, such as proximity of a low-velocity area (for holding position) to a high-velocity area (for feeding), or the proximity of predators and competitors (Fausch and White 1981; Baltz et al. 1982; Power and Matthews 1983; Baltz and Moyle 1984; Moyle and Baltz 1985; Sheppard and Johnson 1985). Thus, a microhabitat description really only de-

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scribes the abiotic niche metrics of a population under existing environmental conditions and any implication of choice or preference must be qualified by resource availability and the presence or absence of interacting species. Temperature is one environmental factor that may not be given adequate consideration in simulation models even though it may cause seasonal shifts in microhabitat use (e.g., Smith and Li 1983), influence the outcome of competitive interactions (e.g., Baltz et al. 1982), or be an overriding factor in determining the longitudinal distribution of fishes in a stream (e.g., Moyle and Vondracek 1985).

The purpose of this paper is to examine microhabitat use by four species of native California fishes in a situation where a sharp temperature gradient in a cool river was created by the inflow of a cold tributary. In the river, a wide variety of depths, velocities, substrates, and temperatures was available. This allowed us to determine the importance of temperature in the choice of microhabitat by the fishes, as well as the relative importance of three other variables not commonly used in hydraulic stream modeling, namely, focal point elevation, focal point velocity, and surface velocity.

Study Area

The study was conducted in the Pit River just above the town of Big Bend (Shasta County), California. Observations were confined to a 150-m reach of the river near the mouth of Nelson Creek. The river above Nelson Creek had regulated flows during the summer of about 3 m^3/s and maximum temperatures of 14.4–25.0°C from July through September 1984. The discharge of Nelson Creek into Pit River was 0.5–1.0 m^3/s; the maximum daily temperatures of the creek ranged from 11.6 to 18.6°C during the same period. The cold waters of the creek formed a temperature plume and, consequently, a temperature gradient across the river. Temperatures taken along transects across the river showed that complete mixing of the colder water with the cool river water did not occur for several hundred meters downstream of the confluence. Substrates ranged from large boulders to fine sand and depths were up to 2 m. Minimum underwater visibility in the river was 2 m or better during our surveys and became greater where river water mixed with clear Nelson Creek water.

Methods

We made direct observations of fish use of microhabitats in the mixing zone (Baltz et al. 1982; Baltz and Moyle 1984; Moyle and Vondracek 1985). Fishes were located by observers snorkeling in an upstream direction through the zone where creek and river water mixed. Once a fish was located and identified to species, the following microhabitat data were recorded: (1) water velocity at the fish's snout (focal point velocity), (2) mean water column velocity, (3) surface water velocity, (4) distance of fish from the bottom (focal point elevation), (5) total depth of the water column, (6) cover type, (7) substrate composition, (8) temperature, and (9) the estimated length of the fish.

TABLE 1.—Cover codes used to describe microhabitat use and availability in the Pit River system (adapted from Bovee 1982).

Code	Cover description
1	No cover
2	Objects <150 mm in diameter
3	Objects 150–300 mm in diameter
4	Objects >300 mm in diameter
5	Overhanging vegetation
6	Root wads or undercut banks
7	Surface turbulence
8	Objects <150 mm plus overhanging vegetation
9	Objects <150 mm plus root wads or undercut banks
10	Objects <150 mm plus surface turbulence
11	Objects 150–300 mm plus overhanging vegetation
12	Objects 150–300 mm plus root wads and undercut banks
13	Objects 150–300 mm plus surface turbulence
14	Objects >300 mm plus overhanging vegetation
15	Objects >300 mm plus root wads or undercut banks
16	Objects >300 mm plus surface turbulence

Velocity measurements were made with a Marsh-McBirney model 201 electronic velocity meter mounted on a top-setting wading rod. When the water depth exceeded 0.75 m or when the water column was obstructed by boulders or logs, a weighted mean water column velocity was calculated from measurements taken at proportional depths of 0.2, 0.6, and 0.8 of the water column. Otherwise, only the velocity at the proportional depth of 0.6 was used (Bovee and Milhous 1978). Water column depths and focal point elevations were read directly on the wading rod. Lengths of fish were estimated by comparison with substrate elements, which in turn were measured with the wading rod or a reference bar carried by the snorkeler.

Substrate composition was coded on a modified Wentworth particle size scale: 1 for detritus; 2—silt; 3—mud; 4—sand; 5—gravel; 6—cobble; 7—

boulder; and 8—bedrock (Bovee and Cochnauer 1977). A two-digit substrate index was constructed from the dominant component (first digit) and the subdominant component (second digit); thus a substrate coded 45–76 was sand–gravel to boulder–cobble. Sixteen cover types were also defined (Table 1).

We used a randomization protocol to characterize resource availability each time we collected microhabitat-use data. These randomly collected data were used to describe total depth, mean water column velocity, surface velocity, substrate, cover, and temperature resources available for use by fishes in each sampling period. We tried to collect as many random observations of resource availability as we had obtained on microhabitat use to assure an adequate characterization of availability. We used a random number table to select a unique set of transect locations for each sampling date. The stream reach surveyed was stratified into 20-m intervals, and a random transect location was selected in each interval to avoid situations in which all transects were clustered together.

We collected data systematically on microhabitat use and resource availability in the mixing zone during four sampling periods: 23–24 August 1983; 17 September 1983; 20–21 July 1984; and 13–14 September 1984. A fifth data set was formed by combining all four sampling periods. We began collecting surface velocity data in 1984, and temperature availability data were not collected in September 1984. Because of time limitations, we concentrated our efforts on the four largest and most conspicuous species that were of immediate management interest: rainbow trout *Salmo gairdneri*, Sacramento sucker *Catostomus occidentalis*, hardhead *Mylopharodon conocephalus*, and Sacramento squawfish *Ptychocheilus grandis*. Other species present were Pit sculpin *Cottus pitensis*, speckled dace *Rhinichthys osculus*, California roach *Hesperoleucus symmetricus*, and tule perch *Hysterocarpus traski*.

Our microhabitat-use observations were used in a stepwise discriminant-analysis procedure (SAS 1982: Stepdisc) to determine which variables or sets of variables discriminated among species. Variables specified on a list were available for inclusion in a model. The variables specified were only included in the stepwise models if the significance level of an *F*-test from an analysis of covariance was less than 0.15; however, the significance level for variables included in the models was usually less than 0.05.

We also used a nonstepwise discriminant-analysis procedure (SAS 1982: Discrim) that first used all variables available in each of the four runs to discriminate by species and then calculated the percentage of observations correctly classified. The general model—species $= x_1 + x_2 + x_3 + \ldots + x_n + E$, where x_1 to x_n are microhabitat variables and E is the residual error term—evaluates all of the data available to construct a function that best discriminates among species. Then, without regard to information on species' indentifications, the procedure reassigns each observational record to species by means of the function. This constitutes an evaluation of the model (=function). Models which explain very little of the total variance or which have a low percentage of correct classifications are not of much value.

The variables available for inclusion in the model were changed with each run of the five samples. In run 1, all eight microhabitat variables were available; in the three subsequent runs, the number of variables was progressively reduced. In run 2, cover code (a categorical variable) was deleted to meet the statistical requirement for continuous data; focal point elevation and focal point velocity were also excluded, to leave only those five variables that occur independently of the presence of fishes. The data in run 2 were comparable, but not equivalent, to the availability data we collected. In run 3, surface water velocity was deleted, leaving only temperature and the three variables normally used in an instream flow study (i.e., total depth, mean water column velocity, and substrate). Finally, in run 4, the temperature variable was deleted.

Results

The number of observations and species size distributions (Figure 1) differed among sampling dates due in part to small differences in the location and length of stream surveyed; however, the rank order of abundance for the four species differed only slightly (Table 2). The Sacramento sucker was the most abundant species and samples included both juveniles and adults. Rainbow trout were generally small and were common on all sampling dates. Sacramento squawfish were primarily represented by juvenile fish and were common on two of the four sampling dates. The hardhead was the rarest species on three of the four sampling dates.

Because we have considered all size classes together, ignoring ontogenetic shifts within species, and because sample sizes differed substantially among species, microhabitat comparisons among

TABLE 2.—Microhabitat variable means (±SD) or ranges of categorical variables for fishes in Pit River near Nelson Creek, California.

Variable	Aug 1983	Sep 1983	Jul 1984	Sep 1984
Rainbow trout				
Total depth (cm)	58.5±21.8	68.8±21.6	50.1±17.3	63.7±19.2
Focal point elevation (cm)	11.0±10.8	10.6±5.3	12.7±10.3	16.3±12.4
Mean water column velocity (cm/s)	26.1±17.6	24.0±14.8	12.4±8.8	18.1±13.6
Focal point velocity (cm/s)	16.7±19.8	17.1±13.8	10.0±8.0	15.0±14.5
Surface velocity (cm/s)	36.6±17.1	30.6±17.9	15.5±10.7	27.8±13.2
Temperature (°C)	16.7±0.9	16.0±0.6	18.2±1.5	16.4±1.3
Substrate[a]	45–76	46–76	50–76	56–76
Cover code[b]	1–16	1–16	1–16	1–16
Sample size	20	19	78	20
Hardheads				
Total depth (cm)	80.4±40.3	74.0±47.6	78.0±4.9	76.2±19.1
Focal point elevation (cm)	41.4±37.5	35.5±23.3	13.2±9.5	23.3±15.0
Mean water column velocity (cm/s)	18.7±7.9	31.7±18.7	21.6±9.8	10.8±10.4
Focal point velocity (cm/s)	12.8±7.8	31.1±15.6	18.9±11.4	15.6±21.0
Surface velocity (cm/s)	27.2±6.6	28.2±17.9	16.3±9.8	15.8±7.0
Temperature (°C)	16.6±1.0	16.9±0.8	20.2±0.6	17.2±1.8
Substrate[a]	56–76	75–76	75–76	75–76
Cover code[b]	1–5	1–4	1–7	1–16
Sample size	13	4	4	6
Sacramento squawfish				
Total depth (cm)	88.8±16.0	83.3±16.2	85.5±20.4	69.4±26.8
Focal point elevation (cm)	23.9±27.7	39.3±26.1	12.5±9.9	21.6±12.4
Mean water column velocity (cm/s)	19.4±10.0	10.1±8.3	18.5±10.4	12.5±11.0
Focal point velocity (cm/s)	14.5±11.2	10.9±14.4	12.2±10.6	12.7±10.9
Surface velocity (cm/s)	25.8±13.5	22.2±16.4	25.6±15.6	27.8±24.1
Temperature (°C)	16.8±1.5	17.6±0.9	20.1±1.7	17.1±1.9
Substrate[a]	54–76	70–76	56–76	65–76
Cover code[b]	1–16	4–4	1–16	1–16
Sample size	17	3	28	8
Sacramento suckers				
Total depth (cm)	78.2±21.9	85.6±36.1	54.2±26.3	71.0±28.6
Focal point elevation (cm)	1.6±3.8	5.1±19.9	1.7±5.2	2.8±5.2
Mean water column velocity (cm/s)	20.6±16.2	26.7±21.2	10.2±10.9	25.4±22.8
Focal point velocity (cm/s)	9.5±7.3	13.2±14.4	5.5±7.3	10.8±12.1
Surface velocity (cm/s)	32.6±29.3	33.7±22.0	12.3±13.4	26.0±17.9
Temperature (°C)	17.2±1.1	17.1±1.0	19.3±2.1	17.7±1.3
Substrate[a]	50–76	46–87	10–76	56–76
Cover code[b]	1–16	1–16	1–16	1–16
Sample size	44	22	159	31

[a] From a modified Wentworth code; the first and second digits of each number represent the dominant and subdominant substrates, respectively.

[b] See Table 1.

species and sampling dates are limited to comparisons of the most obvious patterns (Table 2). Rainbow trout consistently occurred in shallower water than did the other three species. Sacramento suckers had the lowest focal point elevations and rainbow trout were usually found at lower focal point elevations than were hardheads or Sacramento squawfish. There were no apparent patterns for mean water column velocity; however, Sacramento suckers generally had lower focal point velocities than the other species. Surface velocity means showed no apparent patterns. Temperature means were all highest during July 1984 and, among the four species, rainbow trout generally used the coolest water.

Comparisons of means showed no significant differences among dates for most measurements of random resource availability (Table 3). Total depths did not differ among dates (F-value, 1.61; df, 3, 222; $P > 0.18$). Mean water column velocities were statistically similar (F-value, 1.43; df, 3, 222; $P > 0.23$), and surface velocities were also similar for the two dates sampled in 1984 (F-value, 0.19; df, 1, 92; $P > 0.66$). Temperature availability data were only recorded on three sampling dates, one of which was significantly different

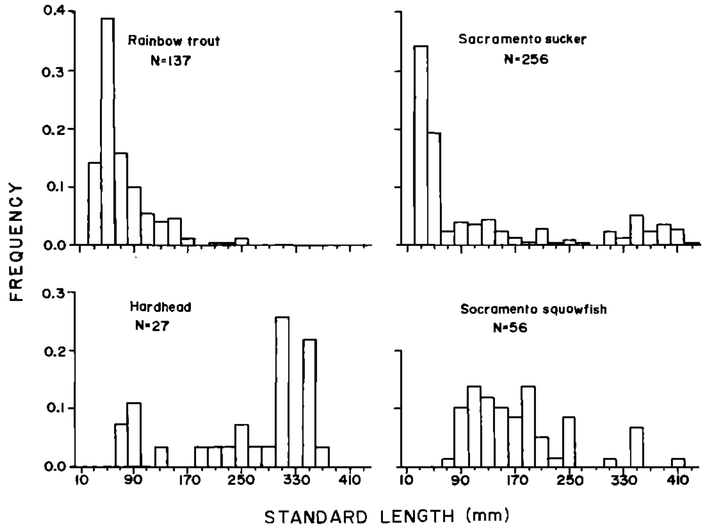

FIGURE 1.—Length–frequency distributions of four fish species for all sampling dates, Pit River, California, 1983–1984.

(F-value, 10.52; df, 2, 159; $P < 0.01$). Temperatures on 20–21 July 1984 were significantly higher (Duncan's multiple-range test; $P < 0.05$) than during earlier dates (August and September 1983). Substrates did not differ substantially among dates. Boulder and cobble were the dominant elements and substrates finer than sand were rare.

The variables used to describe microhabitat use were strongly correlated (Table 4), with the exceptions of temperature with total depth and temperature with mean water column velocity. The only significant negative correlations were with temperature, and the highest correlations were among the three velocity variables. Several of the randomized measurements used in the resource availability analyses were also correlated (Table 4); of these the strongest correlation was between mean water column velocity and surface velocity.

Although temperature was highly correlated with four of the other six noncategorical microhabitat variables, it appeared to be an important variable segregating the four largest species in the assemblage. All of the rainbow trout observed were at temperatures of 20.0°C or less on all four sampling dates (Figure 2). However, 11% of the hardheads, 21% of the Sacramento squawfish, and 16% of the Sacramento suckers were observed at temperatures greater than 20.0°C (Figure 2).

The relative importance of the variables included in each of the stepwise discriminant analysis models is reflected by the order in which the variables were selected and by the squared partial correlation coefficient for each variable (Table 5). The squared partial correlation coefficient is an estimate of the proportion of variance explained by each variable included in a model. When all eight microhabitat variables were available for inclusion in the models (Table 5, run 1), the percentage

TABLE 3.—Means (±SD) or ranges for measures of random resource availability on four sampling dates in the Pit River, California.

Variable	Aug 1983	Sep 1983	Jul 1984	Sep 1984
Total depth (cm)	63.6±32.66	56.4±29.72	61.3±26.67	52.2±29.03
Mean water column velocity (cm/s)	13.8±13.17	21.0±21.65	18.9±19.25	18.0±15.64
Surface velocity (cm/s)	no data	no data	21.4±16.16	23.3±16.85
Temperature (°C)	18.9±0.40[a]	17.7±1.29	19.0±1.86	no data
Substrate range[b]	45–76	10–76	37–76	31–76
Cover code[c]	1–16	1–16	1–16	1–16
Sample size	86	46	50	44

[a] Sample size for temperature measurements was 66.
[b] See text for description of substrate index.
[c] See Table 1.

of variance explained ranged from 52 to 77% (i.e., the sum of squared partial correlations for each model). Focal point elevation was the most important variable in four of the five models. Temperature was the most important variable in one model and was significant in three others. Total depth was the second most important variable in three models in which it occurred. Focal point velocity was included in three models but never ranked higher than third place. Cover code ranked third and fourth in its two occurrences, and surface velocity ranked fourth and sixth in its two occurrences. It is notable that substrate occurred in only one model and mean water column velocity was not included in any of the five models.

When cover code, focal point elevation, and focal point velocity were excluded from the models (Table 5, run 2), five variables that could be measured and modeled without regard to fishes were available for inclusion. These models explained 15 to 33% of the variance. Total depth was the first variable selected in three models and temperature was first in the other two. Temperature was important in all five models, while depth was important in three. Surface velocity and mean water column velocity were included in one model as the third and fourth variables entered, respectively.

In run 3, surface velocity was excluded, leaving only temperature and the three variables most commonly used in instream flow modeling (total depth, mean water column velocity, and substrate). The results of run 3 were very similar to run 2, again with 15–33% of the variance explained (Table 5).

In run 4, temperature was excluded, leaving only total depth, mean water column velocity, and substrate available for inclusion in the models. These models explained only 0–20% of the variance. Total depth was the first variable entered in three models, mean water column velocity was the first variable entered in one model, and no variables were able to discriminate among species with data collected 17 September 1983.

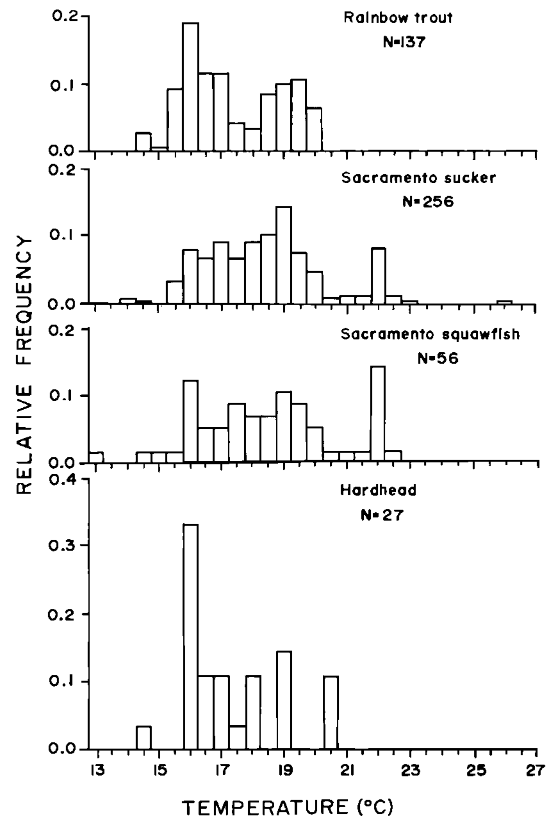

FIGURE 2.—Frequency-of-use temperature distributions for four fish species in the Pit River study area during all sampling dates, 1983–1984.

TABLE 4.—Total sample correlations for four sampling periods (1) among microhabitat-use observations on four native fishes and (2) among random resource-availability observations in the Pit River near Nelson Creek, California. Resource-availability correlations are above and use correlations are below the diagonal. Significance levels of the correlation coefficients are indicated by asterisks ($P < 0.05$*; $P < 0.01$**).

	Total depth (DTOT)	Focal point elevation (EFISH)	Mean water column velocity (VMEAN)	Focal point velocity (VFISH)	Surface velocity (VSURF)	Substrate (SUBST)	Temperature (TEMP)
DTOT	—		0.114		0.293**	0.195**	−0.017
EFISH	0.103*	—					
VMEAN	0.270**	0.117**	—		0.658**	0.117**	0.038
VFISH	0.165**	0.326**	0.665**	—			
VSURF	0.388**	0.162**	0.773**	0.490**	—	0.144	0.132
SUBST	0.194**	0.126**	0.211**	0.189**	0.158**	—	−0.025
TEMP	−0.028	−0.175**	−0.060	−0.127**	−0.120**	−0.214**	—

TABLE 5.—Microhabitat variables available and entered in stepwise discriminant analysis models used to discriminate among species. Values in parentheses are squared partial correlations which may be summed to estimate the variance explained by all variables entered in each model. The significance level for inclusion of variables in each model was $P < 0.05$, except for italicized variables ($0.14 > P > 0.05$).

			Order of variables[a] entered
			Run 1
Available: DTOT, EFISH, VMEAN, VFISH, VSURF, COVCOD, SUBST, TEMP			
Entered:	23–24 Aug	1983	EFISH (0.36), DTOT (0.18), *VFISH* (0.08)
	17 Sep	1983	TEMP (0.33), EFISH (0.32)
	20–21 Jul	1984	EFISH (0.34), DTOT (0.17), COVCOD (0.06), VFISH (0.06), TEMP (0.05), VSURF (0.03)
	13–14 Sep	1984	EFISH (0.43), TEMP (0.14), *SUBST* (0.10), *VSURF* (0.10)
	All dates		EFISH (0.32), DTOT (0.09), TEMP (0.06), COVCOD (0.03), VFISH (0.02)
			Run 2
Available: DTOT, VMEAN, VSURF, SUBST, TEMP			
Entered:	23–24 Aug	1983	DTOT (0.15), *TEMP* (0.06)
	17 Sep	1983	TEMP (0.33)
	20–21 Jul	1984	DTOT (0.17), TEMP (0.08), VSURF (0.05), VMEAN (0.03)
	13–14 Sep	1984	TEMP (0.15)
	All dates		DTOT (0.10), TEMP (0.08)
			Run 3
Available: DTOT, VMEAN, SUBST, TEMP			
Entered:	23–24 Aug	1983	DTOT (0.15), *TEMP* (0.06)
	17 Sep	1983	TEMP (0.33)
	20–21 Jul	1984	DTOT (0.17), TEMP (0.08), VMEAN (0.04)
	13–14 Sep	1984	TEMP (0.15)
	All dates		DTOT (0.10), TEMP (0.08)
			Run 4
Available: DTOT, VMEAN, SUBST			
Entered:	23–24 Aug	1983	DTOT (0.15)
	17 Sep	1983	None
	20–21 Jul	1984	DTOT (0.17), VMEAN (0.03)
	13–14 Sep	1984	*VMEAN* (0.09), *SUBST* (0.11)
	All dates		DTOT (0.10), SUBST (0.02)

[a] DTOT (total depth), EFISH (focal point elevation), VMEAN (mean water column velocity), VFISH (focal point velocity), VSURF (surface velocity), COVCOD (cover code), SUBST (substrate), and TEMP (temperature).

The number of observations correctly classified to species by the nonstepwise procedure varied considerably among sampling periods, but the percentage generally increased as the number of variables was increased (Figure 3). Only the July 1984 sampling period, which also had significantly higher temperatures, did not show an increasing trend. A minimum of 46% of the observations were correctly classified when the three variables available in run 4 were used, and a maximum of 86% were correctly classified when the eight variables available in run 1 were used. In a comparison which parallels the results of runs 3 and 4, the percentage of observations correctly classified increased substantially for three of four sampling periods when temperature was added to total depth, mean water column velocity, and substrate.

Discussion

In a situation where stream fishes were able to select temperature as well as other environmental features, temperature proved to be a better predictor of where each species was found than were two of the other three variables (i.e., mean water column velocity and substrate) most commonly used in instream flow models. In the first three modeling runs, all of which included temperature and the three variables, temperature was important in 14 of the 15 models. In contrast, total depth was important in nine, mean water column velocity in two, and substrate in only one model. In the eight models which included both total depth and temperature, the partial correlation for total depth was higher in each instance. In the absence of temperature (run 4, Table 5), total depth seemed to be the best predictor; however, total depth was significantly correlated with all other continuous variables except temperature (Table 4). Mean water column velocity, in contrast, had relatively poor predictive power (i.e., the squared partial correlations were very low) and was included in only four of 20 models. The poor predictive power of mean water column velocity is curious because, in situations where fishes do not have a wide range of temperatures from which to choose, it is important (e.g., Smith and Li 1983; Moyle and Vondracek 1985). Presumably, at our study site, temperature was the controlling factor (Magnuson et al. 1979) and interacted with total depth to limit the influence of velocity on microhabitat selection.

Although temperature seemed to be one of the most important of the easily measurable variables in determining microhabitat choice, when all eight variables we measured were used to discriminate among species (run 1, Table 5), focal point elevation turned out to be the most important. It ranked first in four of the five models in run 1 and explained between 32 and 43% of the variance in each model. This is not surprising, because focal point elevation, along with focal point velocity, reflects most closely the conditions in the exact location where each fish is found. Unfortunately, use of these two focal point variables in hydraulic simulation has its practical limitations in assemblages of two or more species because of the large amount of time required to make the necessary measurements for all species and life stages (Baltz et al. 1982; Baltz and Moyle 1984; Moyle and Baltz 1985). It is also difficult to collect suitable availability data. A further limitation in the use of focal point elevations and velocities for instream flow modeling is that the hydraulic simulation cannot be extrapolated beyond the range of the calibration flows used to develop the simulation model (Bovee 1982).

The difficulty in using focal point elevation and focal point velocity in instream flow determinations, despite the desirability of doing so, means that the more indirect (i.e., nonfocal-point) measurements of fish microhabitat will continue to be used. Fortunately, all types of velocity measurements were correlated (Table 2). Mean water column velocity in particular showed an extremely high correlation with focal point velocity. Thus, the indirect measurements can be used to represent the microhabitats of the fishes, provided the influence of temperature is taken into account. The

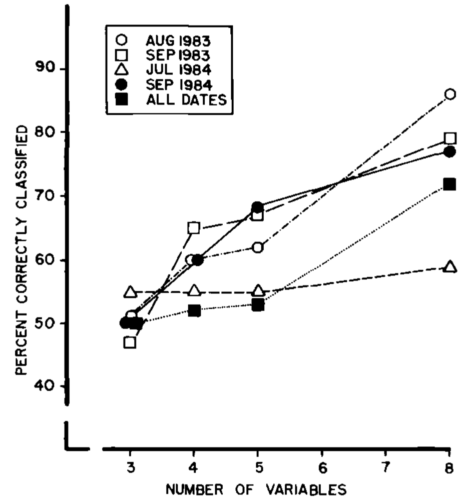

FIGURE 3.—The percentage of observational records correctly classified to species by discriminant analysis models. The variables 8, 5, 4, and 3 correspond to those available in runs 1 through 4, respectively (Table 5).

importance of temperature in the choice of microhabitat conditions by Pit River fishes suggests that fishes optimize their positions on a temperature gradient for growth, as indicated by laboratory (Jobling 1981; Knight 1985) and field studies (Stauffer 1980).

The addition of temperature as the fourth variable in the nonstepwise procedure, along with total depth, mean water column velocity, and substrate, resulted in a substantial increase in the ability of models to classify observations correctly by species (Figure 3). Together with other considerations on the importance of temperature, this suggests that instream flow studies should consider carefully the effects of temperature modifications on fish assemblages. Microhabitat data sets which do not distinguish adequately among species cannot be used to predict changes in fish assemblage structure. Relatively small changes in a stream's temperature regime may enhance nongame species at the expense of game species, in spite of the predictions from instream flow models based on simulations of depths, velocities, and substrates.

Because stream fishes can change their microhabitat preferences as temperature changes (Bjornn et al. 1977; Smith and Li 1983; Sheppard and Johnson 1985), microhabitat descriptions developed under summer conditions may not be adequate for other seasons or under changing temperature regimes. If temperature is to be incorporated adequately into hydraulic simulation models, seasonal microhabitat descriptions that reflect temperature-related shifts in microhabitat use should be developed and related to long-term temperature records or temperature modeling for each stream. Seasonal descriptions could offer important advantages to both fisheries and water managers because the most appropriate flows could be selected on a seasonal basis to optimize temperature regimes and other variables simultaneously.

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