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Habitat Selection and Movement Patterns of California Golden Trout in Degraded and Recovering Stream Sections in the Golden Trout Wilderness, California

KATHLEEN R. MATTHEWS

U.S. Forest Service, Pacific Southwest Research Station
Post Office Box 245, Berkeley, California 94701, USA

Abstract.—I used radio transmitters to determine habitat selection and movement patterns of California golden trout *Oncorhynchus mykiss aguabonita* in two areas defined by their different levels of habitat recovery in the Golden Trout Wilderness, California. Study areas were differentiated by the amount of streamside vegetation (low or high coverage of beaked sedge *Carex rostrata*). Lower amounts of streamside vegetation were typically associated with other signs of degradation caused by cattle, including widened streams, collapsed banks, and reduced bank undercutting. Twenty-nine California golden trout were monitored from 6 July to 14 July 1994 over 192 diel-tracking hours at six study sections in low- and high-sedge areas in Mulkey Meadow. In both low- and high-sedge areas, California golden trout were observed using nine habitat features (undercut bank, willows, collapsed bank, open channel, aquatic vegetation, sedge, boulder, grass, and detrital mats), but they more often selected undercut banks, aquatic vegetation, and sedge and avoided bare and collapsed banks. Home ranges were similar in high-sedge sections (17.3 m) and low-sedge sections (16.9 m). Most fish moved little and were found within 5 m of their previously recorded location at both low-sedge and high-sedge sites. Total movement over the tracking period was variable between individual fish, but mean cumulative distances differed and were greater in high-sedge areas than in low-sedge areas. This study documented that California golden trout in pools and runs used and selected habitat features typically damaged by grazing (undercut banks, aquatic vegetation, and sedge) and avoided habitat features (bare and collapsed banks) typically caused by cattle grazing. Grazing management that seeks to protect habitat features preferred by California golden trout must employ strategies that protect undercut banks, sedge, and aquatic vegetation, and that reduce bare and collapsed banks.

California golden trout *Oncorhynchus mykiss aguabonita* is the beautifully-colored California state fish with a native distribution restricted to high-elevation streams in the southern Sierra Nevada (Evermann 1906; Fisk 1983; Behnke 1992). Although most of its habitat lies within the Golden Trout Wilderness (GTW), habitat degradation nevertheless continues because of at least 100 years of livestock grazing. Despite the considerable interest in restoring degraded California golden trout habitat (Pister 1991), only recently has research focused on the basic ecology of California golden trout (Knapp and Dudley 1990; Stefferud 1993; Knapp and Vredenburg 1996; Matthews 1996). California golden trout are long lived, slow growing (Knapp and Dudley 1990), and exist in unusually high densities (up to 4,644 fish/km; Knapp and Matthews, in press).

Livestock have grazed the area since at least 1860; there are reports of 200,000 sheep present in 1 year between 1860 and 1890 and 10,000 cattle in the late 1800s (Felando 1982). Past overgrazing has resulted in widespread riparian degradation (Albert 1982; Felando 1982), and a few restoration efforts have been implemented by the U.S. Forest Service, Inyo National Forest, during the past 70 years. Moreover, because of a perceived threat to the viability of the population, California golden trout is a candidate species for listing under the Endangered Species Act (USFWS 1994). Although much attention has been directed to restoration methods (e.g., fences, check dams), virtually nothing is known about the effectiveness of these methods within the GTW. Little work has been done comparing the use of degraded and restored areas by California golden trout, and nothing is known about the response of these populations to restoration attempts.

The removal of livestock from streamside zones typically results in predictable changes (Platts 1991). Fencing portions of Mulkey Meadow in the GTW resulted in significant changes to physical characteristics of the stream, including increased streamside vegetation, stream narrowing and deepening, and increased bank stability (Knapp and Matthews, in press). Recent radio-tracking work

[1] Trade names and commercial enterprises are mentioned solely for information; no endorsement by the U.S. Forest Service is implied.

(Matthews 1996) documented that tagged California golden trout were most commonly associated with sedge and undercut banks, features typically damaged by grazing. In that study, however, the availability of habitat features was not measured, and no conclusions about habitat preferences could be drawn. If California golden trout prefer habitat features subject to damage by grazing (e.g., undercut banks), then grazing should be managed to minimize the degradation of these preferred habitat features.

Because the availability of suitable habitat often limits fish abundance, growth, and survival (Hicks et al. 1991; Griffith and Smith 1993, 1995), it is important to understand how habitat alteration influences habitat use. For example, in degraded streams where preferred habitats are in short supply, adult California golden trout may be confined to these habitats and compete more for them. Moreover, increased predation may result if cover is unavailable. As a consequence, reduced availability of preferred habitat features may translate into reduced growth, survival, and fitness. An assessment of habitat availability and preferences (available versus used) is crucial for determining California golden trout habitat requirements and recommending effective restoration.

In this study, I evaluated California golden trout habitat preferences in Mulkey Creek within the GTW, Inyo National Forest, where habitat restoration efforts (cattle exclosures) are underway. Using telemetry, I determined the habitat preferences of California golden trout in two areas that differed in the level of habitat degradation caused by cattle (designated as three sections with high coverage of sedge, primarily *Carex rostrata*, and three sections with low coverage). The objectives of this study were to determine (1) whether California golden trout habitat use and movement patterns differed in the two areas that differed in the level of habitat recovery, and (2) whether the fish used habitat features in different proportions to what was available, and (3) whether they selected or avoided habitat features typically influenced by grazing.

Study Site

I conducted the study at Mulkey Meadow (36°22'N, 118°15'W; elevation, 2,850 m) on the Kern Plateau in the GTW, Inyo National Forest. The GTW lies at the southern end of the Sierra Nevada in California; it encompasses 133,500 ha and was created in 1977, in part to protect the habitat of the California golden trout. This area was largely unaffected by the Pleistocene glaciation and is characterized by large subalpine meadows (up to approximately 7.5 km^2). These meadows lie primarily along the South Fork Kern River and a major tributary, Mulkey Creek. Meadows in the eastern GTW are vegetated predominately by the sagebrush species *Artemesia tridentata* and *A. rothrockii*, but streamside zones typically support communities of sedge *Carex* spp. and willow *Salix* spp. (Odion et al. 1988). Mulkey Meadow is currently grazed by approximately 235 cow–calf pairs each summer. The fish fauna in Mulkey Creek is restricted to the California golden trout.

Two study sites (high sedge and low sedge) in Mulkey Creek (Figure 1) were selected on the basis of coverage of streamside vegetation; each site consisted of three 100-m sections. All stream reaches were typical of those found in low-gradient meadows (Rosgen types C-4 and E-4; Rosgen 1994). The high-sedge area (sections 1–3) was characterized by dense streamside vegetation and was typical of those portions of Mulkey Meadow exclosed from grazing and undergoing recovery (narrowed sedge-lined stream with deeper water; Knapp and Matthews, in press). Sections 1 and 2 were separated by 49 m and were located downstream and outside of a cattle exclosure; sections 2 and 3 were 244 m apart. Section 3 was inside a cattle exclosure. Most of the area within sections 1–3 is either within an exclosure or lightly grazed. The low-sedge area (sections 4–6) were characterized by sparse streambank vegetation and was typical of the stream sections found in heavily grazed areas (widened and shallowed stream, lack of streamside vegetation; Knapp and Matthews, in press). In the management plan for the Inyo National Forest, bank trampling and chiseling levels are set so that signs of current grazing damage do not exceed 20% of sampled points (USFS 1988); however, 1994 trampling and chiseling estimates for this portion of Mulkey Meadow were 61%, far in excess of the recommended guidelines (D. Hubbs, Inyo National Forest, unpublished data). Sections 4–6 were 25 m apart and were located upstream and outside of a cattle exclosure.

An inherent problem for field studies is replication (Hurlbert 1984); in this study, replication would have required working in several different low- and high-sedge areas throughout the Kern Plateau. However, such an experimental design would have been extremely labor intensive. Moreover, most ungrazed areas are within exclosures established at different times on different streams (Mulkey Creek and South Fork Kern River). How-

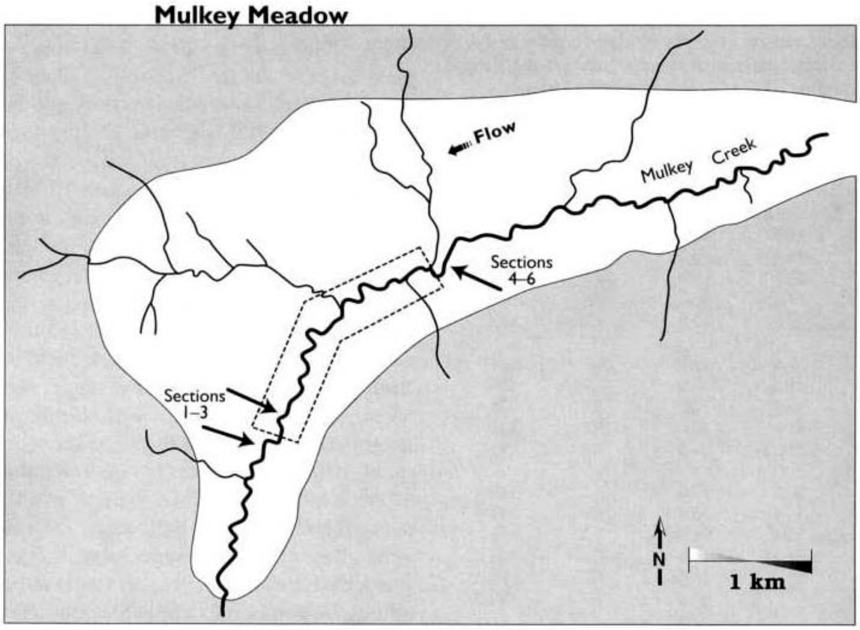

FIGURE 1.—Map of Mulkey Meadow; the exclosure is depicted by the dotted rectangle. Arrows show study sections 1–3 (high-sedge areas) and 4–6 (low-sedge areas). The creek flows from right to left. Stippled area is forest surrounding the meadow.

ever, the sites I used are very similar, except for bank morphology and streamside vegetation. Therefore, any differences in movement patterns and habitat use are probably the result of habitat differences, not intrinsic site differences.

Methods

Fish Tagging

I used radio-tracking to determine the position of each fish in the stream relative to time of day, location, and adjacent habitat characteristics. Adult California golden trout (>14 cm, 3–9 years old; Knapp and Dudley 1990) were captured by electrofishing and were immediately anesthetized with tricaine methanesulphonate (26 mg/L). Once a fish was anesthetized, a transmitter was implanted through an incision in the abdominal cavity just anterior to the pelvic girdle, and the incision was sutured with Supramid HS 23.[1] During surgery, fish were kept immobile on a padded V-shaped tray, and the gills were constantly bathed with anesthetic (6.5 mg/L) flowing from a battery-operated water pump. After surgery and prior to release, each trout was measured (total length) and allowed to recover for approximately 5 min in a water-filled cooler without anesthetic.

I used Advanced Telemetry Systems (ATS, Isanti, Minnesota) transmitters. Each transmitter (with an external, nylon-coated stainless-steel antenna) was 16 × 8 × 5 mm and weighed 0.9 g in air. The 20-cm external antenna trailed from the closed incision. California golden trout are small fish, and I was restricted to using the smallest transmitters available. Because of the small size, the life expectancy of the transmitter was 21 d. Therefore, I restricted my study to 10 consecutive days (including recovery time after tagging).

Fish apparently recovered quickly from surgery and tagging, and my previous observations indicated that tagged fish behaved similarly to untagged fish (Matthews 1996). Visual observations of tagged fish indicated no apparent adverse effects from the tag, and during the study I observed tagged fish swimming normally and feeding in a manner similar to untagged fish.

Each California golden trout was captured, tagged, and then released at its original capture site on 3 July 1994 (Table 1). Five fish were tagged and released into each of the six study sections. Each of the 30 transmitters had a different frequency. To locate tagged fish, I used two systems: (1) an ATS Challenger R4000 and a hand-held

TABLE 1.—California golden trout tagged on July 3, 1994, including section (1–3 are in high-sedge areas; 4–6 are in low-sedge areas), fish number, weight (g), length (cm), home range (m), and total distance moved.

Site and fish number	Weight (g)	Length (cm)	Home range (m)	Total distance (m)
		High-sedge areas		
Site 1				
1	35	16.0	27.8	460
2	38	16.0	50.2	513
3	28.2	15.0	20.9	230
4	29.8	16.0	30.8	264
5	31.8	15.0	9.7	143
Site 2				
6	39.8	17.0	24.1	229
7	32	16.0	21.9	106
8	31.5	14.0	7.3	58
9	41	16.0	25.7	322
10	25	14.5	3.1	70
Site 3				
11	26.8	14.0	5.1	118
12	34.7	15.0	25.9	302
13	32.4	16.0	1.2	28
14	37	16.0	2.1	48
15	33	15.0	4.1	84
Mean		15.4	17.3	198.3
		Low-sedge areas		
Site 4				
16	44.8	17.5	5.2	64
17	26	14.5	2.0	31
18	29	15.0	21.0	82
19	24	15.0	[a]	
20	34.3	16.0	1.9	37
Site 5				
21	47	17.5	31.9	
22	35.5	15.5	7.8	61.5
23	30	14.5	4.2	71
24	29	15.5	45.2	118
25	30	15.0	13.3	182
Site 6				
26	48	18.5	3.9	117
27	42	17.0	2.0	41
28	30	16.0	4.8	76
29	32.7	16.0	90.5	202
30	27.3	15.0	2.3	22
Mean		15.9	16.9	85.1

[a] Fish was found dead.

three-element collapsible Yagi antenna and (2) a Lotek SRX 400 telemetry receiver with an automated data-logging system. Using the ATS receiver and a hand-held antenna, trackers could detect tagged fish at distances up to 100 m. Prior to data collection, I verified that transmitter locations could be determined to within 2 m^2 by triangulation. Also, trackers could sometimes see tagged fish and were able to verify the location of transmitters to within a fairly small area.

After the transmitters were deployed, the following data were recorded approximately every hour by two teams of trackers using the ATS equipment. Teams were assigned to separate 12-h shifts (0800–2000 hours or 2000–0800 hours) for complete 24-h coverage. Sections 1–3 (high-sedge) were sampled continuously from 0800 hours on 6 July through 0800 hours on 10 July (96 tracking hours). Sections 4–6 (low-sedge) were sampled continuously from 2000 hours on 10 July through 2000 hours on 14 July (96 tracking hours). Thus, tagged California golden trout in low-sedge areas had four additional days of recovery before tracking began. The following information was recorded each time a fish was located: (1) fish location to the nearest meter (meter mark [MM] estimated from flagging placed at 25-m intervals and distance to MM measured with Sonin electronic rangefinders), (2) time, (3) macrohabitat type (pool, riffle, or run), and (4) microhabitat features of the 2-m^2 area in which the fish was found (undercut bank, willows, bare bank, collapsed bank, open channel, aquatic vegetation, sedge, boulder, grass, or detrital mat). Trackers were able to record precise locations and habitat associations of tagged fish at night because the fish were often in the open and away from streambanks. Moreover, when it was dark, California golden trout could be approached without causing them to flee.

The Lotek automated data-logging system used underwater antennas (9311 low-loss coaxial cable) that were placed every 28 m on the stream bottom and recorded (every 5 min) the transmitters within 28 m (14 m on each side of the antennas). The eight underwater antennas were fabricated by trailing equal lengths of coaxial cable from the receiver to equally spaced locations within the stream. At the terminal end of the cable (the end to be placed in the water), about 10 cm of cable was stripped and exposed, threaded through the eye of a 0.5-kg lead weight, soldered, and any exposed wires wrapped in electrical tape before being submerged on the stream bottom. The exposed coaxial cable antennas were calibrated to pick up signals within 14 m on either side (28 m total) and served as in-water antennas for transmitters. This automated system was set up on sections 1–3 and remained for the entire 8-d tracking study. Its primary purpose was to record any long-distance movements over short time periods that might be missed by the trackers who relocated transmitters once per hour. I used two receivers (total of 16 antennas) to collect the automated data. Each receiver was equipped with eight antennas, and together they covered a total area of 448 m. Each data-logging computer made a sequential run through all eight antennas and logged every transmitter signal encountered.

Measurements of Macrohabitat and Microhabitat Features

On 4–5 July 1994, macrohabitats were measured and percent availability of microhabitat features was estimated in each study site. Within each 100-m section, I placed a 100-m tape along both bank edges and recorded macrohabitats and all microhabitat features encountered every 1 m for a total of 200 points (100 points along each bank). From the 200 points, I computed a percent availability of each macrohabitat and habitat feature. For example, if sedge was encountered in 90 of 200 points, then sedge would have a 45% cover within the 100-m section. With the exception of bare banks, the percent cover of each habitat feature was not mutually exclusive and often overlapped with other habitat features. For example, sedge and undercut banks often overlapped, and 100-m sections could have 80% and 75% coverage of sedge and undercut banks, respectively. Bare banks did not co-occur with any other habitat feature.

Data Analysis

I used *t*-tests (one-sided, $\alpha \leq 0.05$) to determine whether the percent availability of sedge and undercut banks was statistically different between the sites designated as high- and low-sedge. From sections 1–3 and 4–6, I computed the mean cover of either sedge or undercut banks from the 100-m sections. For example, the null hypotheses were H_0: mean percent cover of sedge in high-sedge areas $\leq$ mean percent cover of sedge in low-sedge areas; and H_0: mean percent cover of undercut banks in high-sedge areas $\leq$ mean percent cover of undercut banks in low-sedge areas. The alternative hypotheses were H_A: mean percent cover of sedge in high-sedge areas > mean percent cover of sedge in low-sedge areas; and H_A: mean percent cover of undercut banks in high-sedge areas > mean percent cover of undercut banks in low-sedge areas.

The number of observations of California golden trout in runs versus pools was compared to determine whether macrohabitat use differed over the 24-h period. I summarized the number of observations for individual fish within pools and within runs. Then, I compared the mean values using the individual fish rather than fish location as the unit of replication. These means of pool and run associations were compared with analysis of variance (ANOVA) and Student–Newman–Keuls' (SNK) pairwise multiple comparisons within high- and low-sedge areas. Although the variances were heterogeneous, the data were not transformed. Transformations made the data non-normal and more heterogeneous, and ANOVA is more robust to this problem if sample sizes are equal or nearly equal, as they were here (Zar 1984).

I also used *t*-tests to test whether California golden trout used habitat features in different proportions from what was available. I summarized the proportion of observations for individual fish occurring within each habitat feature. Then, I computed the mean proportion, using the individual fish as the unit of replication. These means of habitat feature associations were compared with the known proportion (constant) of the measured habitat feature within high- and low-sedge areas. Based on previous work (Matthews 1996), I suspected that sedge, aquatic vegetation, and undercut banks were preferred and would be used in higher proportion than what was available. Therefore, I tested whether the proportions observed were greater than the available proportions of these habitat features. Thus, the *t*-tests were one-sided and, as an example, a possible null hypothesis was H_0: mean proportion of California golden trout observed in sedge–pools $\leq$ measured proportion of sedge–pools (constant) (Zar 1984). I also suspected that the fish did not associate with collapsed and bare banks; therefore, I tested whether they used these habitats in lower proportion than what was available. For example, a possible null hypothesis was H_0: mean proportion of California golden trout observed in bare bank–pools $\geq$ measured proportion of bare bank–pools (constant). Comparisons between individual habitat features were performed on runs and pools (observations in riffles were too few) for day and night observations and between low- and high-sedge areas. I adjusted the significance level for these tests after grouping the tests into families of similar hypotheses. I separated runs–day, pool–day, runs–night, and pool–night into similar families for an adjusted $\alpha = 0.05/3 = 0.017$. For the tests involving undercut banks, I totaled all observations associated with undercut banks, including those with sedge and aquatic vegetation.

To determine whether California golden trout preferred or avoided particular habitat features, I computed electivity indices (Jacobs 1974; Strauss 1982; Moyle and Baltz 1985) for the microhabitat feature data. For these computations, electivity (D) is

$$D = \frac{r - p}{(r + p) - 2rp},$$

where r is the proportion of the habitat feature used by the fish (mean use of that habitat feature with individual fish as the unit of replication), and p is the proportion of the habitat feature available (Baltz 1990). Ranges for D fall between -1 (strong avoidance) and $+1$ (strong selection); -0.49 to -0.26 is moderate avoidance, and 0.26 to 0.49 is moderate selection. A neutral range (-0.25 to 0.25) would represent California golden trout using the habitat feature in proportion to its availability. I used only pools and runs for the analysis, because riffle use was uncommon and sample sizes were small.

Distances moved over the tracking period from one observation to the next were summarized into the following groups: 0–5 m, 6–25 m, 26–100 m, and more than 100 m for the diel periods, night (including the dawn and dusk period, 1930–0630 hours) and day (0630–1930 hours). For each diel period, I tested the hypothesis that there was no difference in movements of more than 5 m (log-likelihood ratio for contingency tables, G-test, $\alpha \leq 0.05$; Zar 1984).

I also totaled the movement for individual fish over the study period. For this summary, the cumulative distances moved per individual fish were summed and averaged for both low- and high-sedge sites. The means of the total distance moved over the study period were then compared (t-test, $\alpha \leq 0.05$) to determine whether the mean cumulative distance moved differed between low- and high-sedge areas.

To delineate home ranges, I used the "adaptive-kernel" method (Silverman 1986; Worton 1989), depicting 90% of all the location points recorded for individual fish. Thus, each home range represents the linear distance (m) along the stream where 90% of the 24-hour location data points were found for each fish; I used the MM position and did not collect depth information that would have yielded a two-dimensional home range (m^2). The home range estimates of fish in low- and high-sedge areas were compared, testing the null hypothesis that there was no difference in home range distance between low- and high-sedge areas.

Water Temperature and Dissolved Oxygen

Water temperatures and dissolved oxygen were measured in the low- and high-sedge areas during the tracking period. Dissolved oxygen (DO) and water temperature were measured and logged with a YSI 3800 water quality logger (DO accurate to ±0.03 mg/L and water temperature accurate to 0.4°C) that was calibrated prior to use. Readings were collected every half-hour from 5 July (0800 hours) through 10 July (1000 hours) at sections 1–3 and from 10 July (1200 hours) through 15 July (0800 hours) at sections 4–6.

Results

Fish Tagging

Thirty California golden trout (14.0–18.5 cm total length) were tagged: 15 in high-sedge areas (mean, 15.4 cm) and 15 in low-sedge areas (mean, 15.9 cm) (Table 1). In the low-sedge area (section 4), fish 19 was tracked for 1 day and subsequently found dead 144 m upstream. Apparently, it had been captured and carried upstream by an animal.

Low- and High-Sedge Area Measurement Comparisons

Habitat characteristics measured for high- and low-sedge areas demonstrated that the most commonly encountered habitat features were undercut bank, sedge, aquatic vegetation, bare bank, and collapsed bank. Average percent availability of sedge and undercut banks was higher (t-test, $P \leq 0.05$) in high-sedge areas (79% and 32%) than in low-sedge areas (25% and 3%). The mean availabilities of bare bank and collapsed bank were higher in low-sedge areas than in high-sedge areas (63% versus 6% for bare bank and 23% versus 0% for collapsed bank; t-test, $P \leq 0.05$). There was no difference ($P > 0.05$) in the availability of aquatic vegetation in high- and low-sedge areas (45% versus 50%).

Macrohabitat Use

California golden trout were most commonly found in runs and pools (Figure 2). Riffle associations constituted only 4.3% of all observations. In high-sedge areas, the mean number of observations in runs and pools averaged for individual fish did not significantly differ between day and night (Figure 3; ANOVA, $P > 0.05$). In contrast, in the low-sedge area, macrohabitat association apparently changed between day and night. Observations in runs increased significantly at night compared with day, and conversely, observations in pools decreased significantly from day to night (Figure 3; $P < 0.05$, ANOVA and SNK multiple comparisons).

Microhabitat Features

Throughout the study, California golden trout were found near nine microhabitat features: sedge,

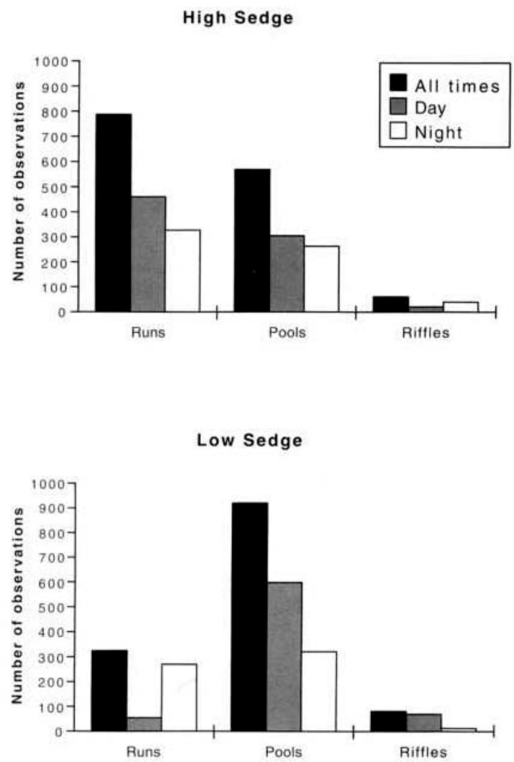

FIGURE 2.—Counts of California golden trout in runs, pools, and riffles summarized over the tracking period (6–14 July 1994) for all times, day (0630–1930 hours), and night (1930–0630 hours) in Mulkey Creek, Golden Trout Wilderness.

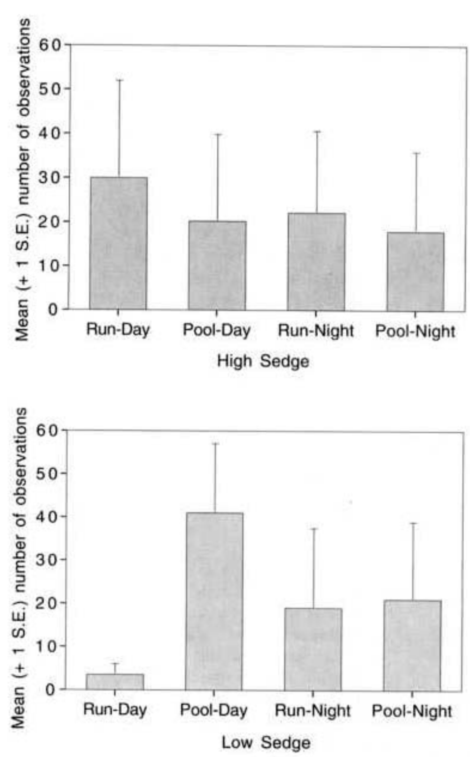

FIGURE 3.—Comparisons of the mean number of observations (+1 SE) in runs and pools during the day (0630–1930 hours) and night (1930–0630 hours). Riffles were not used for the analysis because of the low sample sizes. Treatment comparisons were significantly different only in low-sedge areas (analysis of variance, $P < 0.05$); significantly different pairwise comparisons are listed (Student–Newman–Keuls', $P < 0.05$) as follows: (1) pool–day > run–day, (2) pool–day < run–night, (3) pool–day > pool–night, (4) pool–night > run–day, and (5) run–night > run–day.

undercut bank, willow, collapsed bank, open channel, aquatic vegetation, boulder, grass, and detrital mats, but they were never found near bare banks. The most commonly used microhabitat features in 1,418 observations in high-sedge areas were aquatic vegetation (82.9%), sedge (80.4%), and undercut banks (78.6%). In high-sedge areas, California golden trout were found in open channels only at night (55 observations at night and 0 during the day). In low-sedge areas, they were most commonly found near aquatic vegetation (94.4% of 1,325 observations), sedge (62.5%), undercut banks (53.1%), and collapsed banks (13.6%).

Habitat Use—High-Sedge Areas

For high-sedge areas, *t*-tests and electivity indices of use versus availability indicated California golden trout disproportionately used and strongly selected undercut banks and aquatic vegetation, avoided collapsed and bare banks, and used sedge relative to its availability.

Undercut banks.—In three of four *t*-test comparisons (during the day and night in pools, and in runs during the day), fish were found near undercut banks in higher proportions than expected, compared with their availability (Table 2). Similarly, they strongly selected ($D > 0.5$) undercut banks in runs and pools during the day and in pools at night. The mean proportion of observations for undercut banks in runs at night was not significantly different than undercut bank availability; however, for the same night period, the electivity index indicated that California golden trout did moderately select ($D = 0.28$) undercut banks.

Sedge.—Overall, California golden trout used sedge in similar proportions to what was available (Table 2). For runs and pools during the day and

TABLE 2.—Summaries of null hypotheses, t-tests (α = 0.017 with Bonferroni adjustment 0.05/3), P-values and degrees of freedom, and results of electivity indices (D) in the study to determine whether California golden trout used habitat features in greater proportion to what was available. "Available" represents measured habitat proportions from the three sections and "used" represents mean measured association of habitat features averaged over the individually tagged California golden trout.

Comparison	Null hypothesis (H_0)	t-test	P, (df)	Available	Used	Electivity indices
		High-sedge areas				
Run (day)	Undercut bank use ≤ available	Reject	<0.0005 (423)	0.30	0.73	Strong selection
	Sedge use ≤ available	Do not reject	0.02 (441)	0.86	0.78	Moderate avoidance
	Aquatic vegetation use ≤ available	Reject	<0.0005 (426)	0.58	0.93	Strong selection
Pool (day)	Undercut bank use ≤ available	Reject	<0.0005 (284)	0.40	0.8	Strong selection
	Sedge use ≤ available	Do not reject	0.07 (268)	0.64	0.77	Moderate selection
	Aquatic vegetation use ≤ available	Reject	<0.0005 (275)	0.42	0.9	Strong selection
Run (night)	Undercut bank use ≤ available	Do not reject	0.07 (145)	0.30	0.44	Moderate selection
	Sedge use ≤ available	Do not reject	0.17 (252)	0.86	0.77	Moderate avoidance
	Aquatic vegetation use ≤ available	Do not reject	0.018 (263)	0.58	0.83	Strong selection
Pool (night)	Undercut bank use ≤ available	Reject	0.0007 (204)	0.40	0.72	Strong selection
	Sedge use ≤ available	Do not reject	0.5 (161)	0.64	0.63	Neutral
	Aquatic vegetation use ≤ available	Reject	0.0025 (178)	0.42	0.71	Strong selection
All	Bare bank	Reject		0.06	0.0	Strong avoidance
		Low-sedge areas				
Run (day)	Undercut bank use ≤ available	Reject	0.00075 (29)	0.03	0.44	Strong selection
	Sedge use ≤ available	Do not reject	0.1 (22)	0.27	0.40	Moderate selection
	Aquatic vegetation use ≤ available	Reject	<0.0005 (40)	0.51	0.81	Strong selection
Pool (day)	Undercut bank use ≤ available	Reject	0.002 (253)	0.10	0.37	Strong selection
	Sedge use ≤ available	Do not reject	0.025 (316)	0.35	0.54	Moderate selection
	Aquatic vegetation use ≤ available	Reject	0.001 (581)	0.48	0.79	Strong selection
Run (night)	Undercut bank use ≤ available	Reject	<0.0005 (174)	0.03	0.57	Strong selection
	Sedge use ≤ available	Do not reject	0.01 (202)	0.27	0.54	Strong selection
	Aquatic vegetation use ≤ available	Reject	<0.0005 (236)	0.51	0.88	Strong selection
Pool (night)	Undercut bank use ≤ available	Reject	<0.0005 (174)	0.10	0.58	Strong selection
	Sedge use ≤ available	Do not reject	0.07 (217)	0.35	0.51	Moderate selection
	Aquatic vegetation use ≤ available	Reject	0.002 (297)	0.48	0.92	Strong selection
All	Collapsed bank ≥ available	Do not reject	0.05 (126)	0.21	0.09	Moderate avoidance
All	Bare bank use ≥ available	Reject		0.63	0.0	Strong avoidance

for runs at night, the mean proportion of fish observations in sedge did not significantly differ from the sedge availability. The electivity index indicated that they moderately avoided sedge. For pools at night, California golden trout use of sedge also did not significantly differ from sedge available, and sedge selection was neutral.

Aquatic vegetation.—The proportional use of aquatic vegetation was significantly greater than its availability, and California golden trout strongly selected aquatic vegetation in all comparisons except for runs at night (Table 2).

Bare banks.—California golden trout were never found near bare banks in high-sedge areas (0% use versus 6% availability) and the electivity index indicated bare banks were strongly avoided (D = −1).

Habitat Use—Low-Sedge Areas

In low-sedge areas, tests and electivity indices of use versus availability indicated that fish disproportionately used and strongly selected undercut banks and aquatic vegetation, moderately selected sedge, but avoided collapsed and bare banks.

Undercut banks.—The fish used undercut banks in significantly higher proportion to that available and strongly selected them in runs and pools, both day and night (Table 2).

Sedge.—According to the t-tests and electivity indices, California golden trout use of sedge was equivocal: proportional sedge use was not significantly different from the percentage of sedge available in any t-test comparison (Table 2). However, electivity indices indicated that they selected sedge in runs and pools during the day and night.

Aquatic vegetation.—Use patterns of aquatic vegetation in low-sedge areas were similar to use patterns in high-sedge areas. California golden trout used aquatic vegetation in significantly higher proportions than the percentage of available aquatic vegetation, and strongly selected aquatic vegetation in runs and pools, both day and night, in low-sedge areas.

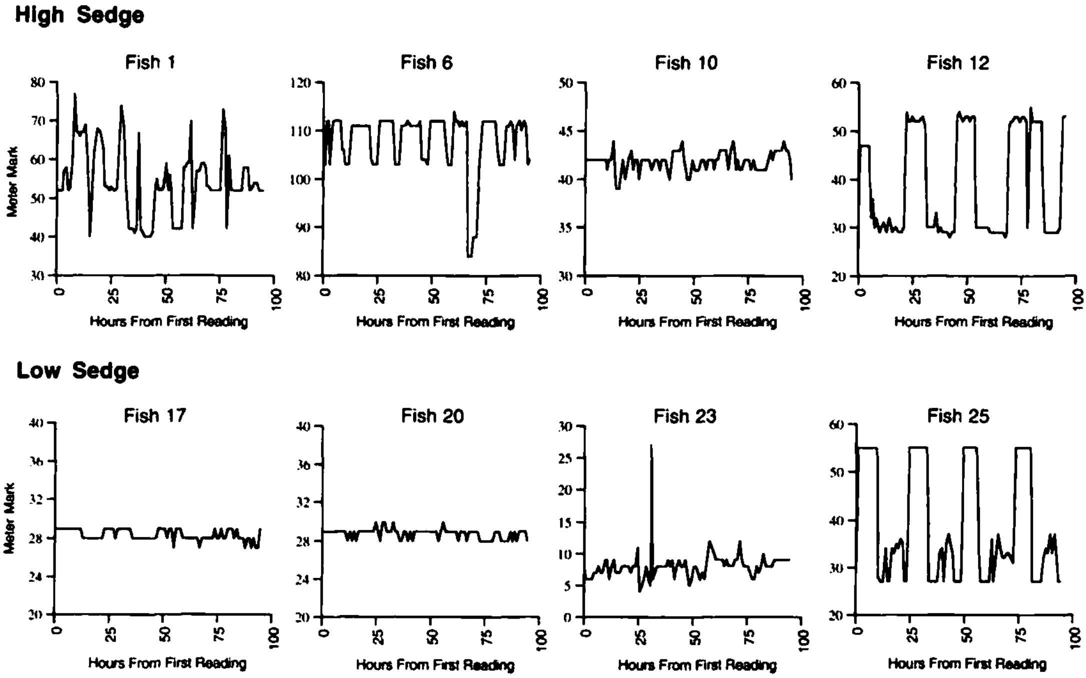

FIGURE 4.—Total movement along meter marks for the 96 tracking hours for fishes 1, 6, 10, and 12 in high-sedge areas and fises 17, 20, 23, and 25 in low-sedge areas.

Collapsed and bare banks.—In low-sedge areas, California golden trout were found near collapsed and bare banks in significantly lower proportions than collapsed and bare banks availability for the combined day–night data from all macrohabitats. The fish moderately avoided collapsed banks and strongly avoided bare banks.

Movement Patterns

Most tagged California golden trout exhibited little movement from one observation to the next in both low- and high-sedge sites. Most observations (89.7% of 1,405 observations in high-sedge areas and 96.3% of 1,309 observations in low-sedge areas) found the fish within 0–5 m of previous locations. No fish moved more than 100 m from one observation to the next. Movements of 26–100 m occurred, although these movements were rare and constituted less than 1% (18 of 2,714) of all observations. When the number of movements greater than 5 m were evaluated, there was no difference in movement between day and night (G-test, $P > 0.05$).

California golden trout in high-sedge areas moved significantly greater mean cumulative distances than in low-sedge areas (t-test, $P < 0.05$; Table 1). Cumulative distances ranged from 28 to 513 m in high-sedge areas and from 22 to 202 m in low-sedge areas.

Most fish moved little and confined their activities to one central area (Figure 4). A few (e.g., fish 12) moved between two or more locations. In a high-sedge section, fish 12 typically spent daylight hours around MM 50 and nighttime hours around MM 30; both sites had sedge, undercut banks, and aquatic vegetation. Similarly, in a low-sedge section, fish 25 made 20-m nightly moves into a backwater spring where the water temperature was about 8°C cooler than stream water temperatures. Mean home ranges were 17.3 m (range, 1.2–50.2 m) in high-sedge areas and 16.9 m (range, 1.9–90.5 m) in low-sedge areas; the difference was not significant (t-test, $P > 0.05$).

The automated logging system collected over 1,000 data points per tagged fish in the high-sedge sections. Most were found within the receiving range of two to three antennas (total maximum distance of 84 m). Each antenna covered a 28-m section, and only one transmitter (fish 9) was located by more than four adjacent antennas throughout the study. Thus, no movements over 112 m were recorded. Because the antennas covered a 448-m area, longer distance movements would have been recorded had they occurred. The lack of movement greater than 100 m agrees with the manually collected data.

Water Temperatures and Dissolved Oxygen

During the study period, diel water temperatures ranged from 7.0 to 22.5°C in the high-sedge areas and 9 to 24°C in the low-sedge areas. Dissolved oxygen diel measures ranged from 6.5 to 8.5 mg/L in high-sedge areas and from 4.8 to 8.0 mg/L in low-sedge areas.

Discussion

Adult California golden trout disproportionately used and selected undercut banks and aquatic vegetation, avoided bare and collapsed banks, and used sedge relative to its abundance. Habitat features most often used by California golden trout are typically subject to damage and reduction by cattle grazing (undercut banks, aquatic vegetation, and sedge) in Mulkey Creek, GTW. Surveys and streamside mapping in the sections of Mulkey Meadow most degraded by cattle also documented less undercutting than in sections inside the cattle exclosure (Knapp and Matthews, in press; A. Dennis, U.S. Forest Service, Pacific Southwest Research Station, unpublished data; L. Collins, University of California, Berkeley, unpublished data). Overhead cover (undercut banks), vertical structure, and vegetation are important components of trout habitat and often influence growth, biomass, and survival (Boussu 1954; Lewis 1969; Bustard and Narver 1975; Fausch et al. 1988; Marcus et al. 1990; Bjornn and Reiser 1991; Griffith and Smith 1993, 1995). Our ability to provide adequate preferred habitat for California golden trout may be jeopardized by grazing.

Conversely, California golden trout avoided bare and collapsed banks. In low-sedge areas, the majority (63%) of measured streambank is bare bank, which apparently is unsuitable for California golden trout because they avoid it. Whether this avoidance of relatively abundant features (collapsed and bare banks) and the tendency to associate with and select less available habitat features (undercut banks, sedge, aquatic vegetation) could result in adverse conditions for California golden trout (e.g., reduced growth or increased predation) is unknown but warrants further study. By inhabiting preferred areas (recovering sites), fish could have more access to food and cover which could later influence such factors as adult winter survival (Cunjak and Power 1987) or spawning success. Future research should determine whether growth or condition differs in degraded and recovering areas.

Although predation is generally considered an important determinant of fish habitat use (Power 1984, 1987; Harvey 1991; Harvey and Stewart 1991), its influence on California golden trout is unclear. California golden trout predators are rare on the Kern Plateau and should not be an important factor in habitat use. No other fish are found in Mulkey Creek, and piscivorous birds are currently rare on the Kern Plateau (personal observation); whether birds were more common when the meadows were pristine is unknown. Nevertheless, at the more degraded sites California golden trout were found in runs more often at night than during the day, suggesting that predation may be a factor in some habitat use. Because of the lack of cover in runs (undercut banks constituted only 3% of streambank in low-sedge areas), fish may avoid runs during the day when they are more vulnerable to predation.

During this study, California golden trout moved little; home ranges were small and similar in size to the home ranges I have noted in earlier research (Matthews 1996). While resident trout are considered somewhat immobile (Northcote 1992), recent studies have described movements of over 30 km for brown trout *Salmo trutta*, cutthroat trout *Oncorhynchus clarki*, and Colorado River cutthroat trout *O. c. pleuriticus* (Young 1995a, 1995b). The short duration of this study may account for the lack of movement, but Young (1995a, 1995b) described movements up to 1.1 km over a 24-h period for brown trout and Colorado River cutthroat trout. Whether California golden trout move more during other seasons is a subject for future research.

Grazed and ungrazed areas within the GTW result in a dichotomous availability of habitat features and different habitat use by California golden trout. Whether the high-sedge areas are more reflective of the natural condition of Mulkey Meadow in the absence of grazing is unclear because little is known about conditions on the Kern Plateau before grazing began in the 1800s. Nevertheless, California golden trout habitat is primarily within a federally designated "wilderness" where human impacts are expected to be minimal. Grazing management can be adjusted to maintain a predominately natural environment as directed by the Wilderness Act of 1964 (Kloepfer et al. 1994). If the values of wilderness are to be upheld, restoration efforts and grazing management should be directed towards protecting undercut banks, sedge, and aquatic vegetation and preventing bare and collapsed banks.

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