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Distribution and Abundance of California Giant Salamander (*Dicamptodon ensatus*) and Signal Crayfish (*Pacifastacus leniusculus*) in the Upper Redwood Creek Watershed, Marin County, California

Open-File Report 2006–1066

U.S. Department of the Interior
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Cover. Photograph of California giant salamander larvae (*Dicamptodon ensatus*).
(Photograph by Terry Goyan)

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Executive Summary

A survey was conducted in 1997–1998 to identify the distribution of non-native signal crayfish (*Pacifastacus leniusculus*) and larval California giant salamanders (*Dicamptodon ensatus*) within the upper Redwood Creek watershed (Marin County, California). The crayfish is widely distributed along the mainstem Redwood Creek. It was found in lower Fern Creek but not in any first order tributaries or above fish barriers. While present throughout the study area, larval California giant salamanders were found mainly in small headwater tributaries. Larval salamanders appear to use habitats in accordance to their availability, while signal crayfish were rarely found in shallow water habitats and appeared to prefer scour pools. Evidence of predation by signal crayfish on larval giant salamanders was found under confined conditions. Controlled laboratory and field experiments would be needed to determine whether competitive exclusion is occurring. Because of its widespread occurrence in the headwater streams surveyed in this project, California giant salamanders would be an appropriate indicator species for those interested in monitoring the health of small headwater streams. Future long-term monitoring using California giant salamanders should be based on permanent monitoring reaches with periodic basinwide habitat and animal surveys to determine if reaches are representative of basinwide conditions.

U.S. Geological Survey satellite photograph of the San Francisco Bay area showing the location of Redwood Creek watershed within the Golden Gate National Recreation Area (shown as yellow outlines).

Distribution and Abundance of California Giant Salamander (*Dicamptodon ensatus*) and Signal Crayfish (*Pacifastacus leniusculus*) in the Upper Redwood Creek Watershed, Marin County, California

By Darren Fong[1] and Judd A. Howell[2]

Introduction

The California giant salamander *(Dicamptodon ensatus)* is found from Sonoma to Santa Cruz County (Good 1989). Populations can be found at elevations ranging from sea level to 2,160 (m) meters (Nussbaum *et al*. 1983). Larvae can be found in a variety of waters ranging from pond habitats to irregularly intermittent and perennial streams (Blaustein *et al*. 1995). They occur in humid coastal forests, especially mixed conifer, Douglas-fir, redwood, red fir and riparian habitats (Zeiner *et al*. 1988).

Salamanders breed usually in the spring with eggs attached by gelatinous pedicels to the ceilings of nest chambers underneath cut banks, coarse woody debris, and rocks (Nussbaum 1969, Blaustein *et al.* 1995). Larval salamanders require at least one year of growth before they metamorphose (Nussbaum and Clothier 1973). Studies on giant salamanders in nearby Corte Madera Creek (Marin Co.) found larvae transforming at 135 (mm) millimeters mean total length at the end of their second summer (Kessel and Kessel 1943b, 1944). In their study, metamorphosis began in early summer and finished by late September (Kessel and Kessel 1944). Occasionally, larvae may remain in streams until their third summer before metamorphosis (Nussbaum and Clothier 1973) and in some cases neotenic specimens have been found (Kessel and Kessel 1944). Adults are found in terrestrial habitats under surface litter and underground (Zeiner *et al.* 1988).

The Golden Gate National Recreation Area (GGNRA) is a National Park Service unit that is comprised of several parcels along coastal areas of the San Francisco Bay area, California. Within the areas managed by the GGNRA, giant salamanders have been reported from the following drainages: east-side tributaries to Bolinas Lagoon (Marin Co.), Redwood Creek (Marin Co.), Oakwood Creek (Marin Co.), Rodeo Lagoon tributaries (Marin Co.), and West Union Creek (San Mateo Co.). Characteristics of typical larval and adult salamanders found in GGNRA streams can be seen figure 1.

A non-native species common to a variety of waterbodies in California, as well as many sites within GGNRA, is the signal crayfish, *Pacifastacus leniusculus* (Dana 1852) (figure 1). It is believed that the signal crayfish helped displace the native sooty crayfish, *Pacifastacus nigrescens*, which was present in creeks around San Francisco Bay in the 19th century (Riegel 1959; Kimsey *et al*. 1982). The signal crayfish is native to Oregon, Washington and British Columbia. Its date of introduction is unclear although Kimsey *et al*. (1982) reported that it was found in San Francisco County in 1898 (Cohen and Carlton 1996). The first reported occurrence of the signal crayfish within GGNRA was from a biological reconnaissance survey conducted in Redwood Creek within Muir Woods National Monument by a park ranger in 1954 (May 1954).

Signal crayfish are fairly long-lived with a maximum reported lifespan in a British population of 16 years although others have reported a lifespan between 5 and 10 years (Mason 1974; Shimizu and Goldman 1983). Females bear eggs for approximately 7 months with hatching around April–May and possibly later (June–July) in cooler climates (Bondar *et al.* 2005). It occupies a range of habitats including small creeks, rivers and lakes. It is an omnivore, feeding on algae, benthic insects, other crayfish, vascular detritus, and wood debris (Bondar *et al.* 2005).

Statement of Problem

GGNRA's project statement (GGNRA-N-032.000) for old growth forest species protection identified the goal to develop a long term monitoring plan for sensitive old growth forest species within GGNRA, Point Reyes National Seashore (PORE), and Marin County. However, prior to the development of a long term monitoring plan, appropriate species should be selected, sampling techniques tested, and baseline habitat and population data collected.

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California giant salamander adult. (Photograph by Mia Monroe, National Park Service)

California giant salamander larvae. (Photograph by Terry Goyan)

California giant salamander larvae. (Photograph by Terry Goyan)

Signal crayfish. (Photograph by Darren Fong, National Park Service)

Figure 1. Photographs of California giant salamander (*Dicamptodon ensatus*) and signal crayfish (*Pacifastacus leniusculus*).

It appears that giant salamanders could play an important role as biological indicator species. Larval salamanders remain in freshwater for at least a year and can be easily sampled via electrofishing or snorkeling. Unlike anadromous fish, giant salamanders are relatively sedentary; therefore, population trends are more likely to reflect local habitat conditions. Also, giant salamanders appear to be associated with specific habitat features that typically represent healthy stream conditions such as abundance of large substrate sizes and undercut banks.

The upper Redwood Creek watershed, which includes Muir Woods National Monument (MUWO), was selected as the study site for this project. California giant salamanders have been collected in the past from MUWO, with records dating back to 1897 (Data courtesy of the Museum of Vertebrate Zoology, U.C. Berkeley; also Storer 1925 cited in Kessel and Kessel 1944). However, no information is available regarding the density, distribution, and habitat association of larval giant salamanders within Muir Woods.

As noted previously, the signal crayfish also occurs in the same area and the scientific literature indicates similar habitat preferences (e.g., instream cover features) as giant salamanders. There is emerging concern that the crayfish can compete with native aquatic amphibians and potentially displace them. An inventory of southern California streams found no stream-dwelling California newts (*Taricha torosa*) in streams with introduced predators—mosquitofish (*Gambusia affinis*) and crayfish (*Procambarus clarkii*) (Gamradt and Kats 1996). Subsequent experiments indicated that crayfish consumed California newt egg masses and larvae (Gamradt and Kats 1996). Numerous studies have implicated the widely introduced signal crayfish in the decline of native crayfish both in California (Light *et al.* 1995) and in Europe (Soderback 1995).

Objectives

Objectives of this study were:

1. To estimate abundance and distribution of larval California giant salamander and signal crayfish during the summer within the upper Redwood Creek watershed.
2. To determine density, size class distribution, and standing biomass of larval California giant salamanders using survey techniques that would minimize injury to all aquatic wildlife.
3. To compare density of larval California giant salamanders between mainstem Redwood Creek and headwater tributaries.
4. To compare standing biomass of fish and larval giant salamanders within mainstem Redwood Creek.
5. To measure and identify simple physical habitat parameters that are known or suspected to influence use by larval giant salamanders.
6. To assess the feasibility of using the California giant salamander as an indicator species for monitoring of headwater streams.

Past Work

Past research looked at the association of larval giant salamanders and a variety of habitat features such as streambed substrate size, stream gradient, stream habitat type (e.g., pools vs. riffles), and canopy density, to name a few (Blaustein *et al.* 1995; Parker 1991; Hawkins *et al.* 1983). No information regarding the status of the California giant salamander is available for streams within the Redwood Creek watershed. Nearby Corte Madera Creek, Marin Co. had been sampled for giant salamanders in the 1940s (Kessel and Kessel 1943a,b).

Limited information is also available regarding the distribution and abundance of signal crayfish within Marin Co. streams. A survey for non-native aquatic animals conducted by the GGNRA found signal and swamp crayfish (*Procambarus clarkii*) to be present in many natural and artificial ponds within the GGNRA (Fong 1996). Signal crayfish have been encountered during surveys for juvenile salmonids and herpetofauna within GGNRA streams (Bratovich and Kelly 1988; K. Freel, USGS-BRD, pers. comm. 1996). However, no quantification of signal crayfish abundance has been reported. Given the potential ecological impacts associated with the presence of non-native signal crayfish in streams, we believe that developing reliable means of estimating abundance are very important. Developing baseline abundance estimates that are repeatable by future researchers could assist in assessing the effectiveness of future control activities for the crayfish.

Study Area

The Redwood Creek watershed area above MUWO's downstream boundary is 3.9 square miles. The geology of the area is dominated by sedimentary rocks of the Franciscan Formation. The vegetation of MUWO is a mosaic of coast redwood, Douglas-fir, hardwood, brush and grass dominated types (McBride and Jacobs 1978). The watershed is home to several special status species including the California red-legged frog, northern spotted owl, steelhead trout, and coho salmon.

The climate is characterized by relatively dry summers and mild, wet winters. Summer fog drip is common. Average annual precipitation in MUWO is 38 inches (1948–1998). Through MUWO, Redwood Creek is a perennial third order stream of gentle gradient with several steep tributaries (figure 2). The mainstem stream gradient is controlled, in part, by several channel modifications that date back to work by Civilian Conservation Corps in the 1930's. Further details of the physical setting are provided in table 1. Typical riparian and stream conditions are shown in figure 3.

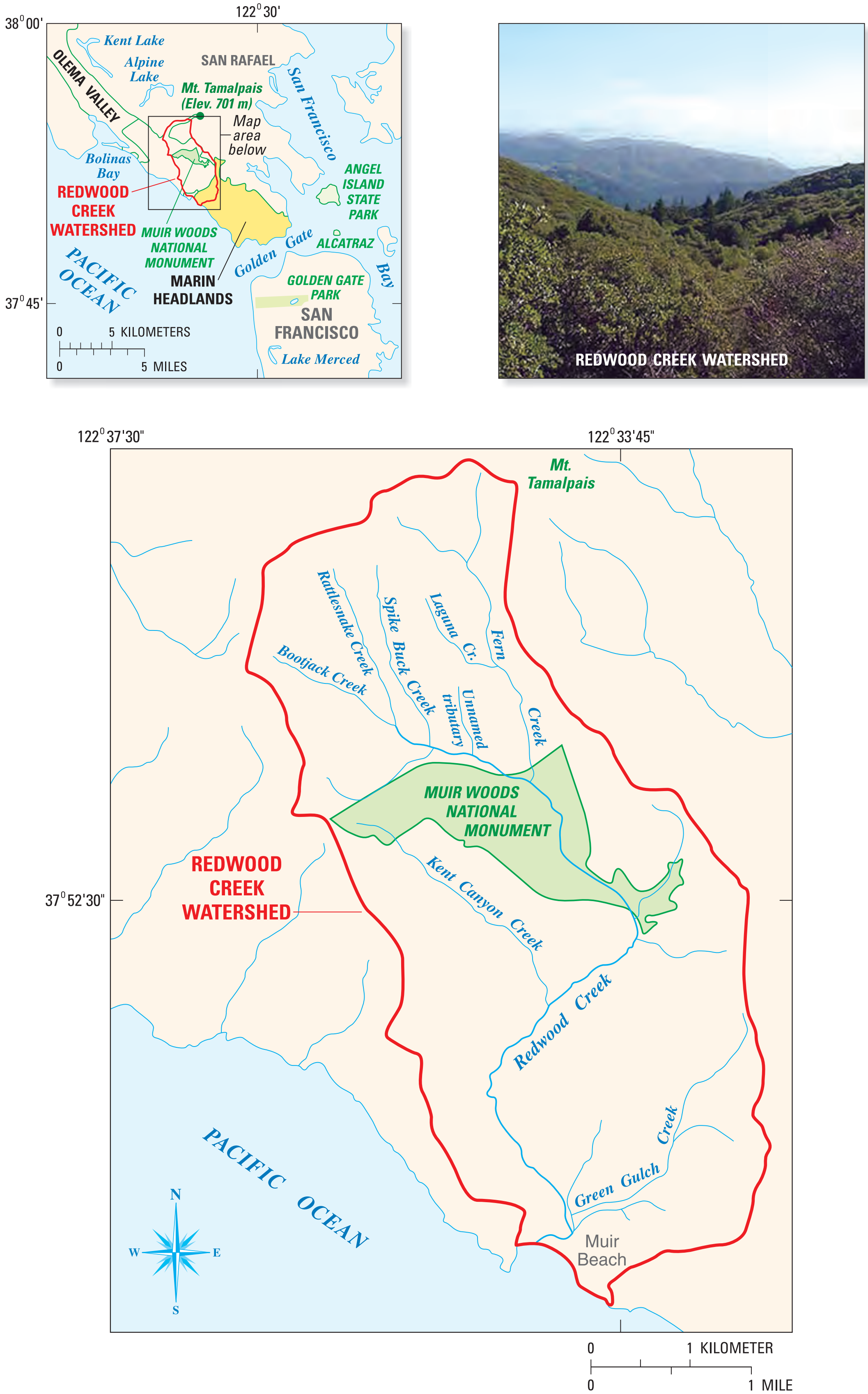


Figure 2. Location of upper Redwood Creek watershed study area and Muir Woods National Monument, Marin County, California.

Table 1. Study site characteristics for upper Redwood Creek watershed, Marin County, California.

Stream	Watershed area (acres)	Strahler stream order	Gradient (%)	Q (cfs)		Survey length (m)	
				1997	1998	1997	1998
Redwood (mainstem)	2,465	3	0.6	2.0	3.4	2,212	2,340
Fern (tributary)	702	2	8.5	0.2	1.4	994	1,086
Spike Buck (tributary)	174	1	25.0	N.A.	N.A.	63	65
Unnamed (tributary)	100	1	23.0	N.A.	N.A.	N.A.	56

[*] Note: Discharge estimates (Q) represent the single measurements during 1997–1998 summer sampling period.

Methods

We selected a two-stage sampling design that has been used extensively to produce unbiased estimates of stream-dwelling fish abundance (Hankin 1986; Dollof *et al.* 1993) and more recently, for stream amphibians (Welsh *et al.* 1997; Welsh and Ollivier 1998). Field biologists classified the stream within the project area into discrete habitat units, measured their length along the thalweg (deepest portion of the channel profile), and visually estimated the width of each habitat unit. To minimize observer discrepancies in the classification of stream habitat types, we distinguished between the following types:

- Pools (main channel, scour, step, and backwater)
- Riffle and flatwater
- Miscellaneous (cascade, dry)

More accurate width estimates using meter tapes were conducted on 20% of pool units and 10% of flatwater and riffle units (figure 4). The units were systematically selected from a random start (e.g., every fifth pool and every tenth riffle/flatwater). The total estimated habitat area was extrapolated using a ratio estimator that established the relationship between visual estimates and more accurate measurements (Dollof *et al.* 1993).

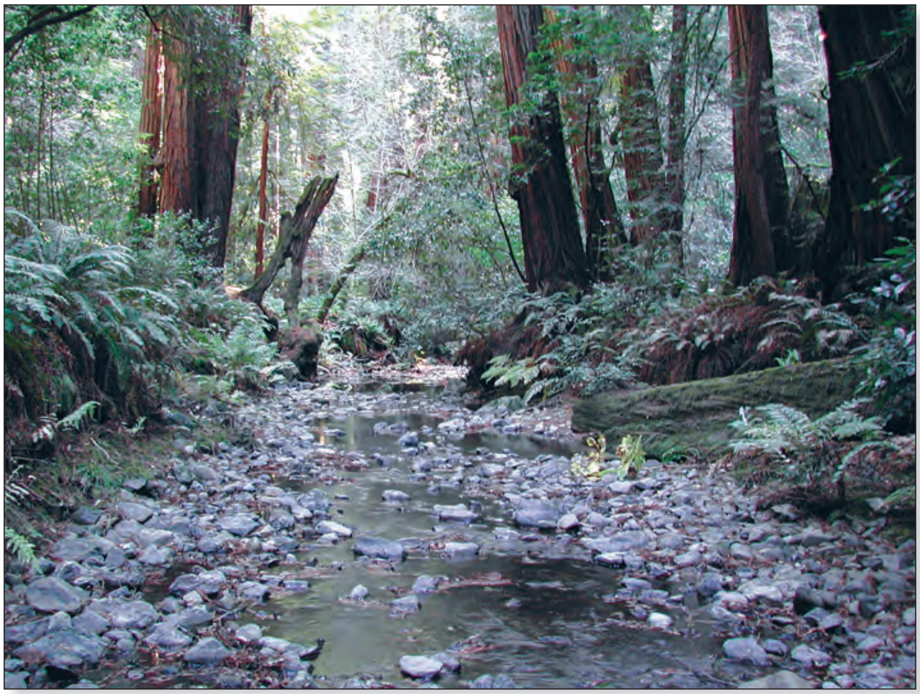
The habitat units selected for more accurate estimates of width also served as sites for aquatic animals surveys. Based on personal observations of crayfish encountered during past fish sampling activities in the Redwood Creek watershed, we believed that crayfish were more likely found in pools versus riffle/flatwater units. Therefore, we decided to focus sampling efforts in pools in hopes of obtaining more precise density estimates—at least for crayfish.

A variety of survey techniques have been used to capture or count stream amphibians and crayfish. Salamander survey techniques have involved viewbox and snorkel surveys of pools (Parker 1991; Welsh *et al*. 1997) and mark-recapture and removal-depletion electrofishing (Hawkins *et al*. 1983; Murphy *et al.* 1981; Murphy and Hall 1981). For crayfish, snorkel/scuba surveys and trapping are also standard sampling techniques (Light *et al*. 1995; Stuchelli 1991).

The selection of our techniques was guided by two objectives: (1) to utilize time-efficient sampling techniques for surveying crayfish and juvenile salamanders over a long distance and 2) to sample in a manner that would minimize any injury to target and non-target species. The latter objective was paramount because the Redwood Creek watershed supports the endangered coho salmon and threatened steelhead trout. Therefore, a standard fisheries tool, electrofishing, was not considered feasible because of incidental impacts to juvenile salmonids and the higher personnel costs. Also, there is no scientific literature assessing the impacts of electrofishing on salamander condition. Anecdotal information from Murphy *et al*. (1981) noted population declines in salamander and frogs after repeated electrofishing events.

During this project, surveys for giant salamanders and crayfish were conducted by capturing individuals by net or hand when snorkeling or wading along creeks (figure 5). Within the selected habitat unit, fist-sized rocks and larger substrates were moved and searched for individuals. We sampled habitat units less than 0.5 m deep with a clear plastic viewbox and dive light. We felt that the dive light was essential in closed canopy conditions. Snorkeling with dive lights was used for complex habitat units (e.g., undercut banks) and deep pools (depth >0.5 m). Sampled unit lengths were relatively short, ranging from 5 to 15 m. Therefore, with the exception of one or two instances, we searched the entire habitat unit rather than establishing belt transects as described in Welsh *et al*. (1997). We felt that the time savings gained by belt transects were offset by their problems in sampling bias. For example, crayfish were typically found in the deepest portion of pool habitat units and such areas were often centrally located. A single belt transect in the center of the unit (as described in Welsh *et al*. 1997) could have estimated pool crayfish densities higher than what was actually present in the field. Due to time constraints, mainly single-pass surveys were conducted with an occasional two-pass sampling.

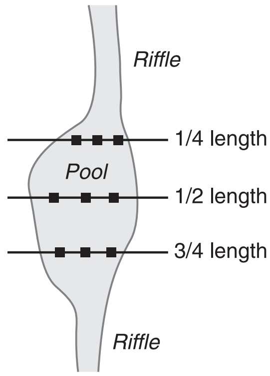
For captured individuals, we recorded species identification, sex (for crayfish), snout-vent and total length (for salamander), salamander weight (nearest 0.5 (g) gram, and rostrum-telson length (for crayfish). Unfortunately, we did not always capture observed individuals. For individuals observed but not captured, species identification and estimated lengths



Upper Redwood Creek

Fern Creek

Figure 3. Typical streamside and channel conditions for upper Redwood Creek and Fern Creek, Muir Woods National Monument, Marin County, California.



EXPLANATION

GENERAL

- RESIDUAL POOL DEPTH (max-min depths)
- UNDERCUT BANKS (percent of perimeter and average undercut distance)
- WOODY MATERIALS (percent of surface area)

TRANSECTS

- SUBSTRATE SIZE (modified Wolman pebble count)
- WATER DEPTH
- WETTED WIDTH

Figure 4. Types of physical data collected at generalized habitat unit (animal-surveyed units only).

were recorded. In addition, missing weights were estimated using a power function based on length-weight information.

We wanted to look at the significance of giant salamanders as part of the vertebrate aquatic biomass within mainstem Redwood Creek. In summer 1998, a basin-wide fish and habitat survey was conducted by the GGNRA and PORE's coho and steelhead restoration program. Their standing biomass and fish density estimates formed the basis of this comparison.

We compared the condition of larval salamanders collected in 1997 and 1998. Because they look like fish with tiny legs, we assumed that use of standard fish condition measures, Fulton's condition factor and weight-length power function, would be appropriate. The weight-length power function is represented by:

$$W = aL^b$$

where

W = wet weight (g),
L = total length (mm), and
a,b = estimated parameters (Anderson and Gutreuter 1983).

Fulton's condition factor (K) is represented by

$$K = \frac{\text{wet weight (g)}}{\text{total length (mm)}^3} \times 10{,}000$$

Typically, "plump" individuals have higher K and b values than "skinny" ones.

We also collected a handful of physical parameters from the sampled animal units. The list of parameters can be seen in figure 4. Several parameters were measured along transects perpendicular to the stream. For streambed materials, 50 equidistant points along the transects were selected and substrates measured along their intermediate axis and classified as fines (<2 mm), gravel (2–64 mm), small cobble (64–128 mm), large cobble (128–256 mm), boulder (>256 mm), and bedrock.

We estimated the total number of crayfish and salamanders and their 90% confidence interval within upper Redwood Creek and tributaries using procedures for stratified sampling described in Dollof *et al*. (1993). No surveys for crayfish or salamanders were conducted in cascade or dry habitats because of the unlikelihood of encountering animals.

Raw field data are presented in Appendices A–F. Appendices A–C provide capture data for all years, creeks, and sites. Appendices D–E provide all instream habitat data associated with capture sites. Appendix F provides a summary of basin-wide habitat inventory data for all years, creeks, and sites.

Data Analyses

The mean number of individuals for all strata and habitat units ($\bar{Y}_k$) was estimated as follows (Cochran 1977):

$$\bar{Y}_k = \frac{\sum_{i=1}^{k} N_i \bar{y}_i}{N}$$

where

$\bar{y}_i$ = the mean number of individuals for strata$_i$,
N_i = the total area or distance per strata$_i$,
k = the number of strata, and
N = the total area or distance for all strata.

Variance of the mean for individual strata (without replacement) was calculated as follows (Wensel 1991):

$$S_{\bar{y}}^2 = \left[\frac{S_y^2}{n}\right]\left[\frac{N-n}{N}\right]$$

where

S_y^2 = the sample variance within a strata,
n = the number of sampled habitat units within a strata, and
N = the total number of habitat units within a strata (Wensel 1991).

Correspondingly, the variance of $\bar{Y}_k$ was calculated as follows (Wensel 1991):

$$S_{\bar{Y}_k}^2 = \sum_{i=1}^{k}\left[\frac{N_i}{N}\right]^2\left[S_{\bar{y}_i}^2\right]$$

Viewbox and capture

Snorkel and capture

Snorkel and capture

Figure 5. Snorkel and viewbox survey procedures for giant salamander and signal crayfish.

The variance estimates using data from systematic sampling can be considered "conservative" because they are likely to be less than the true errors of estimation (Welsh *et al.* 1997; Wensel 1991).

Confidence intervals (90% confidence level) were established using Student's *t* distribution with the effective number of degrees of freedom calculated as follows (Wensel 1991):

$$n_e = \frac{\left[S^2_{\bar{Y}_k}\right]^2}{\sum_{i=1}^{k} \frac{\left[\frac{N_i}{N}\right]\left[S^2_{\bar{y}_i}\right]}{(n_i - 1)}}$$

We assessed the association of salamanders and crayfish using the non-parametric Spearman rank correlation (correction for ties). We removed instances where sampled habitats had neither crayfish or salamanders and looked at each sampled summer season separately.

Habitat overlap. We used a metric to determine the amount of overlap in use of the various habitats by salamander and crayfish (Krebs 1989; Crowder 1990). We compared only those sites below obvious barriers to movement for crayfish. Therefore, sampled areas above Fern Creek Falls were not used for this analysis. This index is as follows:

$$P_{jk} = \left[\sum_{i=1}^{n} (\text{minimum } p_{ij}, p_{ik}) \right] \text{x } 100$$

where

P_{jk} = percentage overlap between species j and species k,

p_{ij}, p_{ik} = proportions resource i, the total resources used by species j and species k, and

n = total number of resource states (e.g. habitat types).

Values for percentage overlap can range from 0 (no overlap) to 100 (complete similarity).

Habitat utilization differences. We compared the mean densities of salamanders and crayfish per habitat type. We looked separately at mainstem Redwood Creek and its tributaries by using a non-parametric test (Kruskal-Wallis) to discern significant differences among the habitat types ($P<0.10$).

Crayfish and salamander association with habitat characteristics. Multiple regression analyses were used to determine the independent habitat variables that best describe the abundance of crayfish and salamanders within our sample sites (SAS 1998). Of the collected data from each sampled habitat unit, we selected the following 15 independent variables for analyses:

- unit length (m)
- cumulative distance (m)
- fines (%)
- gravel (%)
- small cobble (%)
- large cobble (%)
- boulder (%)
- bedrock (%)
- undercut bank (% of perimeter)
- mean undercut width (m)
- instream wood (% area)
- mean water depth (m)
- mean width (m)
- mean volume (m^3)
- mean surface area (m^2)

The cumulative distance represents the thalweg distance of the sampled habitat unit from the downstream starting point of the survey. For this project, the starting point was the downstream boundary of Muir Woods. Tributary streams typically had higher cumulative distances than sampled units on mainstem Redwood Creek.

Frequency distribution of habitat variables were checked to determine closeness of fit to a normal distribution. Frequency distribution of dependent variables (salamander and crayfish abundance) were also plotted to determine closeness of fit to a normal distribution. Habitat variables that were expressed as proportions or percents were arcsin transformed prior to analyses (Zar 1984).

Results

Giant Salamander Distribution and Abundance

The giant salamander larvae were more abundant proceeding upstream from the MUWO downstream boundary (figure 6). The confluence of Fern Creek with mainstem Redwood Creek appears to be a threshold. Headwater tributaries enter mainstem Redwood above this point and steep gradient riffles, cascades and step pools become more commonplace. Larval giant salamanders were extremely rare in mainstem Redwood Creek—just 0 and 3 larvae per 100 m in 1997 and 1998, respectively (table 2). The few salamanders observed within the mainstem of Redwood Creek in 1998 may have been displaced from upstream sites after the El Niño winter.

The tributaries had higher abundances of larval salamanders than mainstem Redwood Creek. We estimated 38 and 12 larvae per 100 m in 1997 and 1998, respectively (table 2). Tributary abundances of larval salamanders were much less than those reported by Nussbaum and Clothier (1973) for larval Pacific giant salamanders in a small permanent spring in Oregon. They estimated 87 larvae per 100 ft (285 per 100 m). This is practically 8 times the abundance of individuals estimated within tributaries in 1997 (table 3).

The abundance of giant salamanders was not normally distributed. Graphs of frequency distribution for all sites and years indicate a preponderance of habitat units where no salamanders were found. Their distribution matched more closely, a negative binomial distribution. This patchy distribution of larval salamander can also be observed by looking at the coefficient of variation (standard deviation divided by sample mean) for larval salamander densities segregated by habitat types. With the exception of 1997 when no salamanders were observed in mainstem Redwood Creek, the coefficient of variation exceeded 1. Thus, the population estimates of larval giant salamanders within our project area had wide confidence intervals (table 2).

Signal Crayfish Distribution and Abundance

Crayfish were only found in the lower portion of the study reach in Redwood Creek and Fern Creek. Along Redwood Creek, the upstream limit of crayfish based on 1998 field surveys was near the confluence with Spike Buck Creek. There were no obvious movement barriers; however, the stream gradient steepens and large cobble-boulder step pools become more common. We found crayfish in Fern Creek to a series of natural cascades (3 to 7 m high), approximately 900 m from the confluence with Redwood Creek. No crayfish were found in any of the first-order, headwater tributaries surveyed (Kent Canyon, Spike Buck, and Unnamed Tributary). figure 7 illustrates the distribution of signal crayfish within the Redwood Creek watershed based on data from this study and past work by the GGNRA.

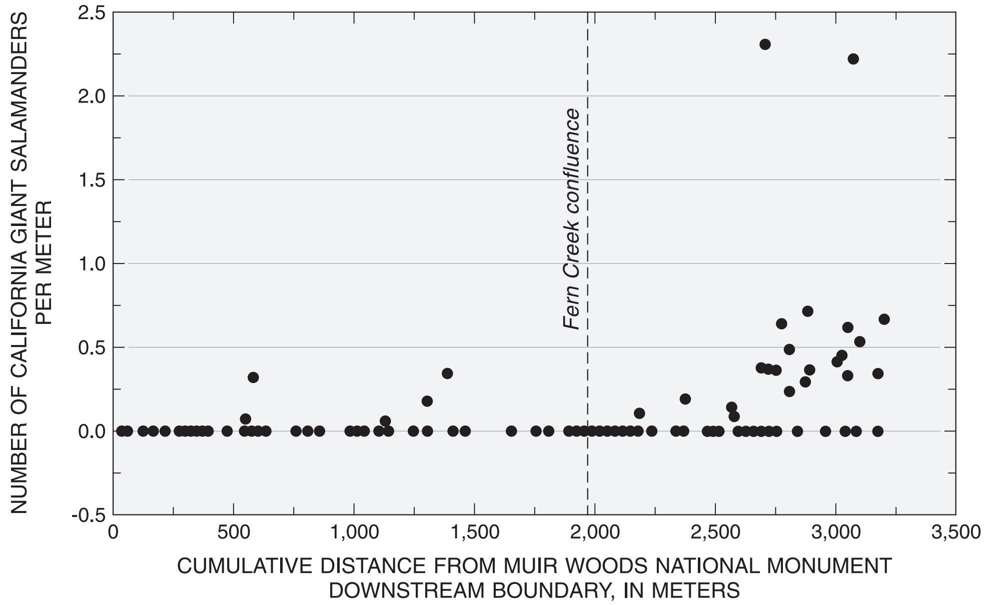


Figure 6. Distribution and abundance of California giant salamander larvae along the creek in the upper Redwood Creek watershed.

Table 2. Population estimates for signal crayfish and larval giant salamander within project area of mainstem Redwood Creek and Fern and Spike Buck in Muir Woods National Monument, Marin County, California, Summer 1997–1998.

Species	1997		1998	
	Project area (m^2)	Estimate (C.I.)	Project area (m^2)	Estimate (C.I.)
Redwood Creek	7,857		10,271	
Signal crayfish		450 ± 312		550 ± 261
Larval salamander		0		78 ± 85
Tributaries	2,109		3,258	
Signal crayfish		102 ± 95		208 ± 407
Larval salamander		448 ± 274		155 ± 109

Table 3. Abundance estimates for signal crayfish and larval giant salamander within project area of mainstem Redwood Creek and Fern and Spike Buck in Muir Woods National Monument, Marin County, California, Summer 1997–1998.

Species	1997		1998	
	Project length (m)	Estimate (No./100 m)	Project length (m)	Estimate (No./100 m)
Redwood Creek	2,359		2,597	
Signal crayfish		19		21
Larval salamander		0		3
Tributaries	1,168		1,255	
Signal crayfish		9		17
Larval salamander		38		12

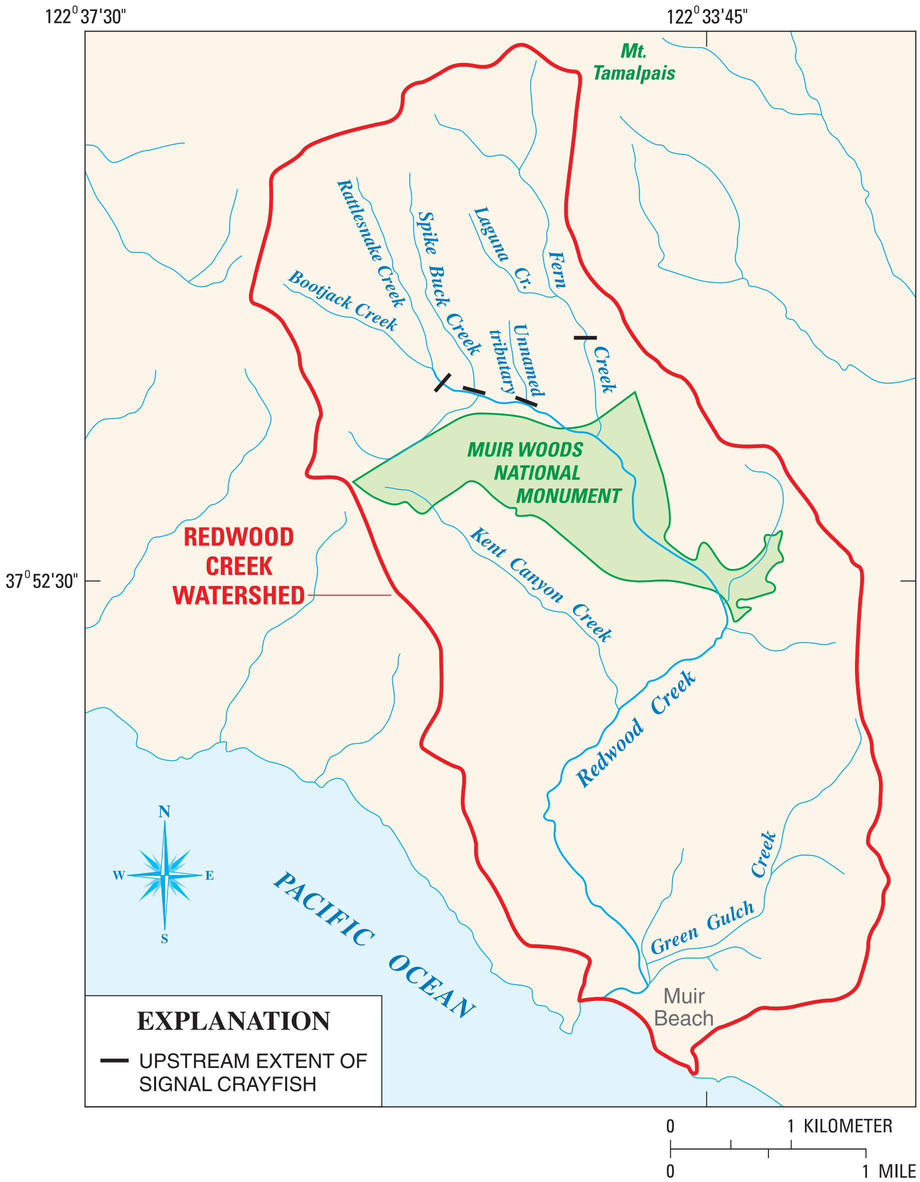


Figure 7. Distribution of signal crayfish (*Pacifastacus leniusculus*) in the Redwood Creek Watershed from Muir Beach to upstream locales, Marin County, California.

In general, crayfish were much more common than larval salamanders along the mainstem creek, while larval salamanders were more common in the tributary streams (tables 4–7).

As with salamanders, the abundance of crayfish was not normally distributed. Their distribution also matched more closely, a negative binomial distribution. The coefficient of variation for crayfish densities generally exceeded 1, with the exception of scour pool habitats in mainstem Redwood Creek in 1997. Because of this variability, our population estimates for crayfish also had wide confidence intervals.

Co-occurrence of Signal Crayfish and Salamander

Co-occurrence of both signal crayfish and larval salamanders depended upon whether sampled sites were along the mainstem creek or along smaller, tributary streams. In mainstem Redwood Creek, signal crayfish and salamander were rarely found together, irrespective of habitat type, (Wilcoxon paired-sample test, n=58, $p < 0.0001$). Interestingly, there was no significant difference in densities of crayfish and larval salamanders at tributary sites below passage barriers (Wilcoxon paired-sample test, n=44, p=0.84).

Table 4. Mean densities and standard deviations of larval giant salamander and signal crayfish by sampled habitats in mainstem Redwood Creek, Marin County, California, Summer 1997.

Habitat type	n	Salamander		Crayfish	
		No./m^2	No./m	No./m^2 (SD)	No./m (SD)
Main channel pool	10	0	0	0.08 (0.12)	0.29 (0.46)
Scour pool	4	0	0	0.20 (0.08)	0.60 (0.08)
Backwater pool	1	0	0	0	0
Riffle/flatwater	13	0	0	0.04 (0.11)	0.08 (0.23)
MEAN		**0**	**0**	**0.07**	**0.23**

Table 5. Mean densities and standard deviations of larval giant salamander and signal crayfish by sampled habitats in mainstem Redwood Creek, Marin County, California, Summer 1998.

Habitat type	n	Salamander		Crayfish	
		No./m^2 (SD)	No./m (SD)	No./m^2 (SD)	No./m (SD)
Main channel pool	12	0.01 (0.02)	0.03 (0.10)	0.09 (0.09)	0.38 (0.41)
Scour pool	10	0.01 (0.01)	0.02 (0.06)	0.09 (0.17)	0.25 (0.39)
Backwater pool	1	0	0	0	0
Riffle/flatwater	7	0.01 (0.03)	0.05 (0.12)	0.01 (0.02)	0.03 (0.05)
MEAN		**0.01**	**0.03**	**0.07**	**0.24**

Table 6. Mean densities and standard deviations of larval giant salamander and signal crayfish by sampled habitats in Spike Buck and Fern Creek, tributaries to Redwood Creek, Marin County, California, Summer 1997.

Habitat type	n	Salamander		Crayfish	
		No./m^2 (SD)	No./m (SD)	No./m^2 (SD)	No./m (SD)
Main channel pool	14	0.33 (0.69)	0.36 (0.59)	0.13 (0.22)	0.22 (0.40)
Scour pool	2	0	0	0.34 (0.48)	0.70 (0.99)
Riffle/flatwater	10	0.19 (0.30)	0.35 (0.73)	0.002 (0.01)	0.01 (0.02)
MEAN		**0.25**	**0.33**	**0.10**	**0.18**

Table 7. Mean densities and standard deviations of larval giant salamander and signal crayfish by sampled habitats in Spike Buck and Fern Creek, tributaries to Redwood Creek, Marin County, California, Summer 1998.

Habitat type	n	Salamander		Crayfish	
		No./m^2 (SD)	No./m (SD)	No./m^2 (SD)	No./m (SD)
Main channel pool	15	0.07 (0.10)	0.18 (0.23)	0.04 (0.06)	0.13 (0.22)
Scour pool	3	0.02 (0.03)	0.04 (0.06)	0.42 (0.68)	1.05 (1.73)
Riffle/flatwater	6	0.04 (0.08)	0.07 (0.13)	0.003 (0.01)	0.02 (0.04)
MEAN		**0.06**	**0.13**	**0.10**	**0.22**

Stream Habitat Associations

Crayfish appear to be associated with pool habitats in both tributaries and mainstem Redwood Creek. Conversely, their abundances were consistently lowest in shallower flatwater/riffle habitats. Over 90% of crayfish were found in pool habitat types (table 8). Specifically, mean crayfish densities were greatest in scour pools for all years and locations. A large proportion of crayfish was found in scour pools despite being a relatively scarce habitat type (table 8).

On the other limb, salamanders do not appear to be associated with any habitat type. For both tributaries and mainstem Redwood Creek, the proportion of larval salamander was similar to the availability of stream habitat types. There was more habitat overlap between the two species in mainstem Redwood Creek (77%) than in the tributaries (59%).

Instream Habitat Associations

Fifteen instream habitat variables were used in a stepwise regression to determine variables for the multiple regression model. For a dataset that includes all sites and years, larval salamander abundance was positively associated with mean depth and cumulative thalweg distance (table 9). A significant positive relationship existed between the mean width of undercut banks and crayfish abundance (table 9). This relationship between crayfish abundance and undercut banks may also help explain the high proportion of crayfish found in scour pools. The habitat units with the widest undercut banks were always associated with lateral scour pools.

Table 8. Habitat overlap and proportional abundance of larval California giant salamander and signal crayfish at sample sites in upper Redwood Creek watershed, Marin County, California, Summer 1997–1998.

Locale	Habitat type	Habitat occurrence (%)	Salamander (%)	Crayfish (%)
Tributaries	Flatwater/riffle	42	45	4
	Main channel/step pool	46	50	50
	Scour pool	12	5	46
	% OVERLAP		**59**	
Mainstem	Flatwater/riffle	30	30	7
	Main channel/step pool	42	40	57
	Scour pool	28	30	36
	% OVERLAP		**77**	

Table 9. Significant multiple regression models and regression statistics to predict abundance of larval California giant salamander and signal crayfish (per m) in upper Redwood Creek watershed, Marin County, California.

Y	Adj. R^2	P	Model coefficients															
			Intercept	Unit Len.	Cum. Dist.	Fines	Gravel	Small cobble	Large cobble	Boulder	Bedrock	U-cut	Mean U-cut	Wood	Mean D	Mean W	Mean V	Mean A
DIEN biomass (g/m)	0.13	0.0008	-0.619							3.188					1.099			
DIEN (#/m)	0.17	<0.0001	-0.095		9.323×10^{-5}										0.091			
PALE (#/m)	0.15	<0.0001	0.105										0.802					

KEY TO ABBREVIATIONS

DIEN, California giant salamander; PALE, signal crayfish
Unit Len, thalweg length of habitat unit (m); Cum. Dist, the cumulative thalweg distance of sampled unit from downstream boundary of MUWO (m)
U-cut, percentage of undercut bank along perimeter of sampled unit (arcsin); Mean U-cut, mean width of undercut bank in sampled unit (m)
Wood, percent cover of wood (arcsin); Mean D, mean water depth of unit (m); Mean W, mean water surface width of unit (m); Mean V, mean volume of unit (m^3); Mean A, mean area of unit (m^2)

Giant Salamander Age Distribution

We observed two size classes of giant salamander larvae within the creeks (figure 8) during our late-spring and early-summer sampling. We assumed that these two size classes corresponded to two different age classes (year 1 and 2) as described by Kessel and Kessel (1943) for nearby Corte Madera Creek (Marin Co.). However, the modes of these two size classes were smaller than the mean lengths of year 1 larvae caught in June 1942 (67 mm) and year 2 larvae (135 mm) by Kessel and Kessel (1943, 1944). For both years, the 51 to 60-mm size class represented the first mode. In 1998, the 91 to 100-mm size class represented the second mode.

The total length of captured salamanders ranged between 25 and 140 mm. A 25-mm individual was observed on June 8, 1998. However, the length of this individual was visually estimated by field staff because it was not captured; therefore, its true length may have been underestimated. Citing laboratory work, Nussbaum and Clothier (1973) note that giant salamander embryos hatched at minimum total lengths of 33.3 mm. An individual of 130 mm (67.2 g) was captured on June 16, 1997 on Fern Creek with reduced gills and a fin-like tail (figure 9). Based on descriptions provided by Kessel and Kessel (1944), we assumed that this individual was undergoing metamorphosis. No neotenic forms were observed or captured, although they have been reported from the study area. A monstrous 247-mm "axolotl-like" giant salamander was captured in April 1897 from Muir Woods (Storer 1925 cited in Kessel and Kessel 1944).

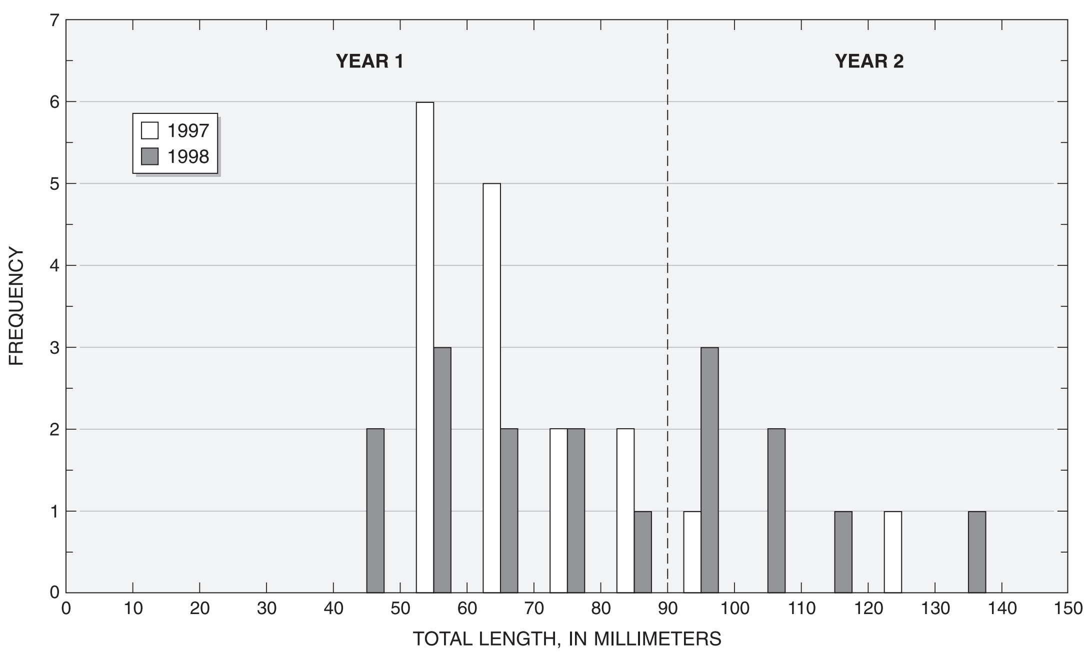


Figure 8. Length-frequency and estimated age class distribution of larval California giant salamanders from upper Redwood Creek watershed, Marin County, California, Summer 1997–1998.

Figure 9. California giant salamander undergoing metamorphosis, Fern Creek, Marin County, California, June 1997.

Crayfish Age Distribution

We used data from Kirjavainen and Westman (1999) to set the threshold for young-of-the-year juveniles at less than 30 mm. For Age 1+ to 4+, we used age class thresholds at roughly 20 mm intervals reported by McGriff (1983) and the appearance of distinct modes in our data to determine age classes. Length-frequency data from crayfish indicate that four age classes are present within the study area (figure 10).

Salamander Biomass

Standing biomass of salamanders was much less than fish biomass for mainstem Redwood Creek. In September 1998, a few months after salamander sampling, electrofishing sampling occurred at 11 pool habitat units within Muir Woods (about 10% of available pool habitat by length). Mean fish biomass estimates of pools were 17.7 g/m. As a rough, minimum estimate of overall standing fish biomass in mainstem Redwood Creek in MUWO, we expanded mean biomass estimate by the total amount of pool habitat (1,195 m). Minimum fish biomass was calculated to be 21,159 g.

By comparison, mean salamander biomass in mainsteam Redwood Creek in 1998 was 0.15 g/m for all sampled habitats. Of the collected larval salamanders, half were year 1 and year 2. Using mean weights of the two age classes and estimated abundance of larval salamanders in mainstem Redwood Creek (table 10), overall standing biomass of larval salamanders was 616 g. Therefore, larval salamanders comprise less than 3 percent of the aquatic vertebrate biomass in mainstem Redwood Creek in MUWO.

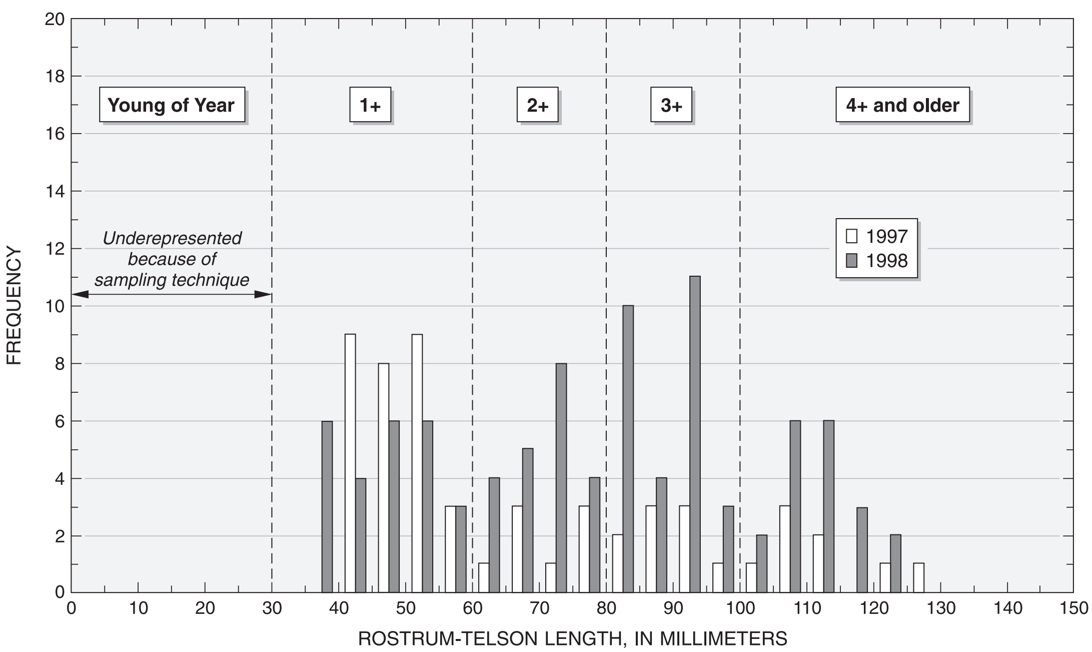


Figure 10. Length-frequency and estimated age class distribution of signal crayfish from the upper Redwood Creek watershed, Marin County, California, 1997–1998.

Table 10. Mean wet weight (g) and total length (mm) of larval giant salamanders in upper Redwood Creek watershed, Marin County, California.

	1997		1998	
	Redwood	Tributaries	Redwood	Tributaries
YEAR 1*				
Number weighed	0	15	2	5
Mean TL (std. dev.)		67.4 (11.3)	51.0 (1.4)	70.6 (11.7)
Mean weight (std. dev.)		1.8 (1.1)	2.5 (0.7)	3.3 (2.6)
YEAR 2*				
Number weighed	0	2	3	3
Mean TL (std. dev.)		113.0 (24.0)	115.7 (21.5)	105.3 (14.5)
Mean weight (std. dev.)		36.4 (43.6)	13.3 (5.9)	11.0 (3.6)

*Year 1 individuals less than or equal to 90 mm TL. Year 2 individuals greater than 90 mm TL.

Salamander Condition

Based on our limited data, salamanders captured in 1998 were in much better condition than those in 1997. To demonstrate, a hypothetical 70-mm larval salamander caught in 1997 would weigh 1.8 g, while an individual of the same length in 1998 would weigh 3.3 g. Similarly, the mean Fulton's condition factor for salamanders in 1998 was almost double that in 1997, also indicating "plumper" individuals (table 11).

Table 11. Summary of larval California giant salamander condition factors for upper Redwood Creek watershed, Marin County, California.

Year	n	Power function where w = weight (g), L = total length (mm)	Mean Fulton's condition factor
1997	16	$W = 7.587 \times 10^{-6} \times L^{2.9092}$, $R^2 = 0.61$	0.56
1998	12	$W = 4.145 \times 10^{-5} \times L^{2.6596}$, $R^2 = 0.75$	1.04

Discussion

Stream Habitat Conditions

Streamflow was much higher in summer 1998 than in 1997 and this influenced the amount and type of available habitat. In mainstem Redwood Creek flows were 70% higher than in 1997. Overall habitat surface area was about 30% greater in 1998. Much larger differences were present in Fern Creek. Streamflows were 600% higher in 1998 and overall habitat area was 55% greater than the prior year. Our field data for Fern Creek indicate that increased streamflow from 1997 to 1998 increased pool habitats at the expense of shallower habitats. For example, on Fern Creek, pool habitats represented about 27% of the stream length in 1997 whereas in 1998 the amount of pool habitats grew to 50% (figure 11). Because of the increased flows in 1998, many transitional areas associated with pools such as pool tailouts were likely included as pool habitat types rather than being identified as flatwater or riffle units. In fact, more riffle and flatwater habitats were identified in 1997 than in 1998 (figure 11).

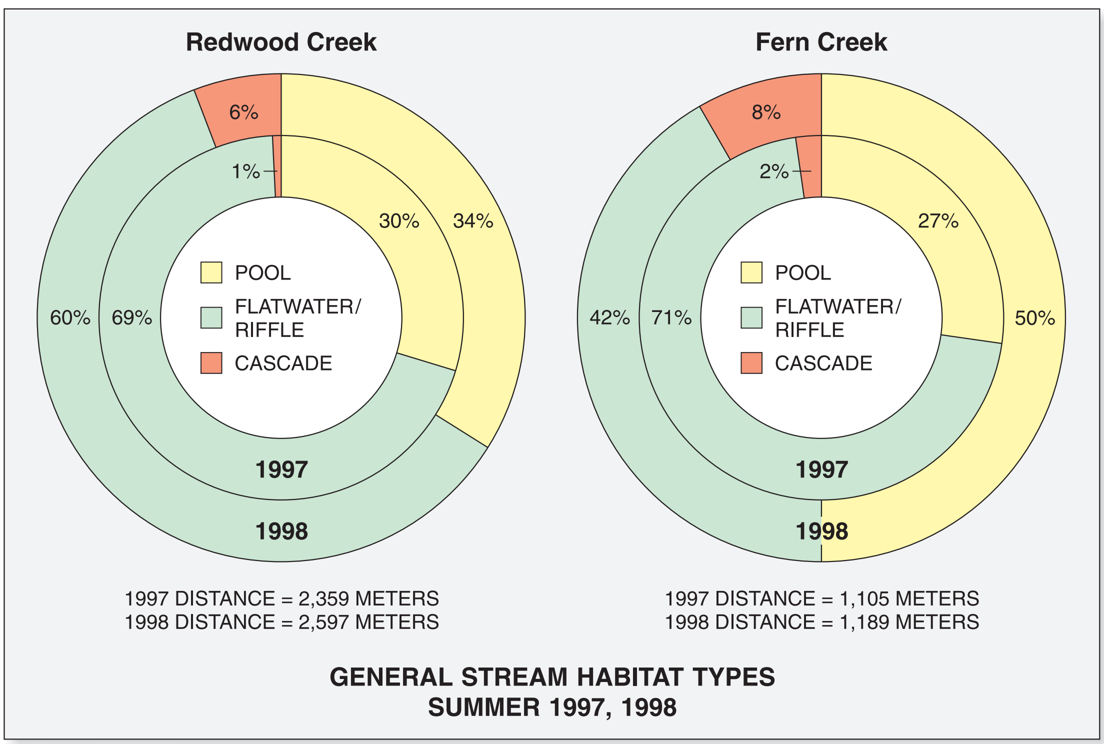


Figure 11. Percent composition of stream habitat types in upper Redwood and Fern Creeks, Marin County, California, 1997–1998.

Not all the differences in amount of habitat can be explained by differences in streamflow. There were likely discrepancies in the delineation of habitat types by different field crews. For each summer, different field personnel were responsible for delineating habitat types. Field staff in 1997 and 1998 expressed problems differentiating main channel from step pools. This problem is clearly seen in the data. In 1998, field staff identified more step pool habitats than in 1997 despite the overall gain in pool habitats due to higher streamflows. Because of this problem, all of our data analyses lumped problematic habitat units into broader categories. We lumped step and main channel pools together as well as flatwater and riffle units.

Salamander Condition

It is not clear why condition of larval salamanders was better in 1998 versus 1997. The presence of much more streamflow in 1998 could have increased the wetted perimeter of the stream and useable surface areas. Many of the riffle and flatwater habitats in the upper Redwood Creek watershed are composed of small cobbles that become exposed as flows decline in the late spring through fall. Because of greater streamflows in 1998 than in 1997, there may have been more primary and macroinvertebrate production in riffle and flatwater habitats. Increased food production could have resulted in "plumper" larval salamanders which feed predominantly on aquatic invertebrates (Parker 1994).

Habitat Associations

The results from the multiple regression models should be viewed with several grains of salt. While the models describe significant associations between the independent and dependent variables, the low coefficient of determinations (r^2) generally indicate a poor fit. Part of this problem may lie in the violation of the data assumptions for use of multiple regression.

Morrison *et al*. (1992) describes four assumptions (multivariate normality, equality of the variance/covariance, linearity, and independence of error terms) that, when violated, can taint analysis of results. Graphs of frequency distributions of dependent variables show the absence of normal distribution and a predominance of "zeros." Standard transformations such as inverse hyperbolic sine were tried but had frequency distributions similar to the untransformed data. Collinearity is also likely present between some of the independent variables. For example, habitat unit dimensions (mean volume, width, area, and depth) are correlated with each other. However, we were not able to decide which of the four variables would be most important to include by themselves. Streambed substrate size and cumulative distance are also correlated with each other. Generally, streambed substrate size increases in an upstream direction (cumulative distance) and vice-versa. Both correlated variables explain the abundance of crayfish. It is likely that the relationship between habitat variables and crayfish and salamander densities is non-linear. A reviewer noted that alternative analyses which use curvilinear habitat preferences such as habitat suitability indices (used in U.S. Fish and Wildlife Service's habitat evaluation procedures) are available (Vadas and Orth 2001).

Crayfish and Larval Salamander Interactions

We learned the hard way that crayfish still actively feed when captured. During initial sampling activities, captured crayfish and salamanders were placed in the same holding container (5-gallon bucket). After completion of sampling activities, one 60 mm salamander which was captured live was found partly consumed by a signal crayfish in the holding bucket. Thereafter, all crayfish and salamanders were kept in separate holding buckets. In 1996, trapping activities for western pond turtles in the Redwood Creek watershed resulted in the mortality of a juvenile steelhead captured along with signal crayfish. This predatory behavior has also been documented for other crayfish. Under laboratory conditions, the swamp crayfish (*Procambarus clarkii*) consumed California newt (*Taricha torosa*) egg masses and larval newts (Gamradt and Kats 1995).

Field data show crayfish have a much higher preference and usage of scour pools in tributaries than larval salamander. Yet, the same pattern was not evident in mainstem Redwood Creek. It is possible that larger habitat units in the mainstem creek afforded more space for crayfish and salamanders to segregate themselves. Habitat units in tributaries were smaller and therefore, opportunities to segregate use of a habitat are minimal. Furthermore, our experience with holding crayfish and larval salamanders in the same 5-gallon bucket indicates the much stronger competitive (and predatory) nature of crayfish over larval salamander.

Further research would be necessary to determine whether salamanders would use tributary scour pools more frequently if crayfish were absent. A future field study could remove crayfish from various habitat units and assess whether any changes in proportional use of habitats by larval salamander occurs. Alternatively, a similar stream lacking crayfish could be surveyed to determine larval salamander use of scour pools.

If competitive exclusion of salamanders is occurring, laboratory and field experiments would be useful in determining the causes. Experiments may involve crayfish and salamanders of different size classes under different habitat conditions (e.g., riffles vs. pools, cover vs. no cover).

Management Recommendations

Mainstem Redwood Creek has sustained many habitat alterations. Large portions of the creek within Muir Woods have been confined with rock riprap and large woody materials which form pool habitats have been removed until recently.

This has resulted in long stretches of flatwater/riffle habitats which are not optimal for crayfish or juvenile salmonids. The GGNRA is currently undergoing actions to help restore pool habitats lost because of past activities. However, such restoration actions will also serve to increase the abundance of signal crayfish, especially if lateral scour pools are created.

Habitat alterations have been touted as the best means for controlling non-native species in a cost-effective and sustainable fashion. For crayfish control, this would involve the modification of stream habitats to favor riffle and flatwater habitat units. However, such actions would have a detrimental effect on two federally-listed fish-steelhead and coho salmon. Juveniles of both species require pool habitats.

The best strategy may be to attempt manual control of crayfish over several seasons within MUWO prior to large-scale stream restoration projects. Costs for crayfish control would likely be higher following the creation of more pool habitats.

Field research on crayfish movements would be needed prior to any large-scale control efforts. Tagging studies that track upstream movements of crayfish below barriers of various heights and designs under low and high flow conditions would be invaluable. It is unlikely that control of crayfish would occur throughout the entire Redwood Creek watershed. Therefore, identification of crayfish barriers would be used to determine the extent of control activities.

Inventory and Monitoring Recommendations

One of the project objectives was to develop a long-term monitoring program that would use resident species such as giant salamanders as an "indicator" of ecosystem health. As previously noted, many anadromous species such as salmonids which are typically used as barometers of stream health are often affected by factors, such as ocean productivity, that are not directly linked with local stream and riparian conditions. Stream-breeding salamanders are an attractive monitoring device. Larval salamander can be sampled quantitatively both in biomass and numbers, and can be used to describe the vertebrate productivity of headwater streams. They also seem to require large substrates for concealment cover and undercuts and rock overhangs for breeding. Such habitat features are sensitive to changes in sediment transport and deposition. Disturbance to watershed sediment dynamics is often a major concern in urbanized and agricultural watersheds.

The following are recommendations for the development of a long-term monitoring program for larval giant salamander:

1. *Ensure monitoring design provides some community level data or cross-linkages to other monitoring programs.* Trends in larval salamander abundance may be linked to trends in co-occurring taxa- such as declines in fish or crayfish abundance. For instance, the long-term stream fish monitoring program for GGNRA and PORE has established index monitoring sites throughout the watershed. Field crews for the stream fish monitoring program have been instructed to sample and record non-fish taxa at these index sites. Similarly, any salamander monitoring program should collect and record non-salamander animals.

2. *Get complete biological data.* In hindsight, there were several types of information that would have been useful to gather from the field. A major oversight in the initial study design was the omission of weight measurements for signal crayfish. Estimates of standing biomass for signal crayfish could have been compared to biomass estimates for juvenile salmonids and larval giant salamanders. We should have also collected tissue samples and voucher specimens. Collection of tissue samples may assist future efforts in characterizing the genetic diversity of salamanders. Voucher specimens would be useful for documenting the identified species.

3. *Focus monitoring efforts at tributaries for larval salamander.* While larval salamander where occasionally found in mainstem Redwood Creek, sampling should be directed to 1st and 2nd order tributaries.

4. *Retain collection of physical habitat data.* Analysis of instream habitat and natural abundance data has been useful in determining future habitat variables to monitor. We would recommend continued collection of substrate composition (modified Wolman pebble count), undercut bank, and habitat unit dimensions.

5. *Standardize data collection to ensure comparison with outside datasets*. It is important to ensure that data collected within this watershed are comparable to datasets elsewhere. While some studies involving crayfish have used rostrum-telson length (McGriff 1983), most crayfish studies have collected carapace length. Future work regarding crayfish in this watershed should collect carapace length data as well as a subset of both carapace and rostrum-telson lengths to adjust previously collected data as needed.

6. *Establish permanent monitoring reaches.* Our field data suggest that salamanders are using habitats in accordance to their occurrence in streams. Therefore, a stratified sampling effort (as was conducted with this project) would not be necessary. Monitoring reaches should be established based on physical habitat conditions (e.g., above and below barriers to fish/crayfish; stream gradient/character). Fern Creek would be an ideal location for two monitoring reaches (above and below fish/crayfish barrier). Although it was not surveyed in this project, another monitoring reach could include Camino del Canyon (above and below hillslope failure). Our recommended reach length would be approximately 100 m so that 35–40 mean stream widths are included (Simonson *et al*. 1994). Periodic, basin-wide habitat and animal inventories would be useful to determine whether

monitoring reaches are representative of basin-wide conditions. A similar approach is being considered as a long-term monitoring approach for streams in GGNRA and Pt. Reyes National Seashore that support salmonids.

7. *Increase precision in delineation of stream habitat types.* Several papers have addressed problems of observer discrepancy in habitat typing (Roper and Scarnecchia 1995, Archer *et al.* 2004). Because of obvious habitat associations by crayfish, our ability to accurately and consistently delineate stream habitat types remains an important concern.

   There are some possible options. In a review of the PORE and GGNRA's coho and steelhead assessment and monitoring program, technical reviewers suggested using a more rigorous means of determining habitat types. Their suggestion involved the use of standard rod and level profile surveys. However, this process is much more time intensive and is also fraught with the same field interpretation discrepancies in identifying breaks in slope. In fall 2000, a field crew of 3 were needed to conduct a profile survey along Redwood Creek in MUWO. The third person was needed to push branches away from level line of sight. The survey took 11 days to complete. By comparison, the stream habitat typing over the same distance took two individuals 3 days to complete.

   We would recommend a combination of the two techniques. A periodic basinwide inventory of habitats should be conducted in conjunction with the streamfish monitoring program (once every 5–10 years). This inventory would serve as the basis for determining whether established reference reaches are still representative of overall distribution of habitats. A topographic survey of reference reach would be conducted with a rod and level for each monitoring reach. Such topographic surveys would not have to be repeated except after extreme storm events. Within the monitoring reach, all habitat units would be characterized and physical habitat measurements obtained. To ensure consistency in habitat delineation, field personnel would be required to review color photos of habitat types and to be trained in their identification by qualified personnel. The California Department of Fish and Game's habitat classification system would continue to serve as the basis for identifying habitat types (Flosi and Reynolds 1994).

8. *Frequency of surveys.* The frequency of surveys is currently undecided. Because two salamander year classes may be observed at any one time, we would recommend that at least two consecutive years be sampled. This would assist in determining year class strength. We would also recommend that surveys be conducted in the early summer/late spring period when the likelihood of detecting the two year classes is the highest.

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Appendixes A–F

APPENDIX A: Fern Creek Capture Data

Table A-1. 1997 data

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus*, PALE-*Pacifastacus leniusculus*, ONCO-*Oncorhynchus sp.*, ONKI-*O. kisutch*, ONMY-*O. mykiss*. RT-rostrum telson length, SV-snout vent length

Pass	Habitat ID	Species	Sex	No.	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	FW3	NONE						embedded substrate, small, little cover
1	R7	NONE						
1	MC3	PALE	F	1		65		
1	MC3	PALE	M	1		60		
1	MC3	PALE	F	1		55		
1	MC3	PALE	M	1		50		
1	MC3	PALE	F	1		45		
1	MC3	PALE	F	1		47		
1	MC3	PALE	F	1		37		
1	MC3	PALE	M	1		45		
1	SC3	NONE						very small
1	R17	PALE	F	1		79		
1	R17	COTT						
1	MC8	NONE						2 age classes of steelhead
1	MC8	ONMY						
1	MC8	COTT						
2	MC8	PALE	F	1		75		
3	MC8	NONE						
1	R27	NONE						
2	R27	NONE						
1	MC13	PALE	F	1		40		
1	MC13	ONMY						
1	MC13	PALE		1				no animal, molted skin only
1	MC13	PALE		1				missed, small
1	SC8	PALE		1		40		dead
1	SC8	PALE	F	1		105		1 claw
1	SC8	PALE	F	1		65		no claws, missing legs
1	SC8	PALE	F	1		70		
1	SC8	PALE	M	1		50		
1	SC8	PALE	F	1		50		
1	SC8	PALE	M	1		40		
1	SC8	PALE	M	1		72		no claws
2	SC8	PALE						missed, huge
1	FW13	NONE						
2	FW13	DIEN		1	55	25	1.1	missing rt hind foot, dark, under rock near shore
2	FW13	PALE		1				no animal, claw only
2	FW13	PALE	F	1		50		
3	FW13	NONE						
1	R37	DIEN						missed, grey
2	R37	DIEN		1	70	37	3.0	caught previously missed animal
1	MC23	NONE						small unit
1	SP4	PALE	M	1		46		
1	SP4	ONMY						
1	SP9	PALE		1		40		

APPENDIX A: Fern Creek Capture Data—Continued
Table A-1. 1997 data—Continued

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus*, PALE-*Pacifastacus leniusculus*, ONCO-*Oncorhynchus sp.*, ONKI-*O. kisutch,* ONMY-*O. mykiss.*
RT-rostrum telson length, SV-snout vent length

Pass	Habitat ID	Species	Sex	No.	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	SP9	DIEN		1				missed, by undercut boulder
1	SP14	PALE	M	1		47		
1	SP14	ONMY						
1	R47	DIEN		1	130	110	67.2	reduced gills, bad shape, light morph
1	R47	DIEN		2	~40			missed, dark morph
1	R47	DIEN		1	55	25	1.1	located near shore, dark morph
1	R47	DIEN		1	70	30		located near shore, dark morph
1	R47	DIEN		1	58	30	1.2	located near shore, dark morph
1	FW23	DIEN		1	56	25	0.7	
1	FW23	DIEN		1	60	30	1.1	
1	SP18	DIEN		1				missed
1	MC28	DIEN		2	~40			missed, strong current
1	MC33	DIEN		1	70	32	2.5	
1	MC33	DIEN		1	>100			poor condition, large,
1	R57	DIEN		1	~60			missed
1	R57	DIEN		1	96	50	5.5	
1	R57	DIEN		1	71	30	0.9	
1	R57	DIEN		1	65	35	0.5	
1	R57	DIEN		1	68	43	3.6	
1	MC38	DIEN		1	90	42	3.0	

APPENDIX A: Fern Creek Capture Data

Table A-2. 1998 data

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus*, PALE-*Pacifastacus leniusculus,* ONCO-*Oncorhynchus sp.*, ONKI-*O. kisutch*, ONMY-*O. mykiss.*
RT-rostrum telson length, SV-snout vent length, j-juvenile

Pass	Habitat ID	Species	Sex	No.	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	R2	NONE						
1	MC1	FISH						
1	SC6	DIEN		1				Missed
1	SC6	PALE		1				Missed
1	SC6	ONCO						
2	SC6	PALE	M	1		84		
2	SC6	PALE	M	1		64		
2	SC6	PALE	F	1		65		
2	SC6	ONMY						
1	R12	COTT						
1	SC11	ONMY						
1	SC11	COTT						
1	MC6	ONKI						
1	MC6	DIEN		1	120	63	15.0	
1	MC6	PALE	M	1		79		
1	MC11	COTT						
1	MC11	ONCO						
1	R22	ONCO						
1	R22	PALE		1		~90		Missed
1	R22	COTT						
1	R22	DIEN		1	105	50	10.0	
1	MC16	ONCO						
1	MC16	COTT						
1	R32	NONE						
1	MC21	PALE	M	1		90		
1	MC21	PALE	M	1		110		
1	MC21	PALE		1		40		
1	MC21	PALE		1		50		
1	MC21	PALE	M	1		85		
2	MC21	PALE		3				Missed
2	MC21	PALE	F	1		60		
2	MC21	ONCO						
1	MC36	ONCO						
1	MC36	PALE	M	1		90		
1	MC36	PALE		1				Missed
1	MC46	NONE						Highly turbid
1	SC16	PALE	M	1		71		
1	SC16	PALE	J	1		37		
1	SC16	PALE	J	1		35		
1	SC16	PALE	M	1		70		
1	SC16	PALE	M	1		65		missing 1 claw
1	SC16	PALE	J	1		35		
1	SC16	PALE	J	1		48		
1	SC16	PALE	M	1		94		

APPENDIX A: Fern Creek Capture Data—Continued
Table A-2. 1998 data—Continued

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus,* PALE-*Pacifastacus leniusculus*, ONCO-*Oncorhynchus sp*., ONKI-*O. kisutch,* ONMY-*O. mykiss*.
RT-rostrum telson length, SV-snout vent length, j-juvenile

Pass	Habitat ID	Species	Sex	No.	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	SC16	PALE	M	1		97		missing 1 claw
1	SC16	PALE	M	1		115		
1	SC16	PALE	M	1		90		
1	SC16	COTT						
1	SC16	ONKI						
1	SC16	PALE		3				Missed
1	MC26	PALE	J	1		~20		Missed
1	MC31	DIEN	J	1	57	28	0.5	scale resolution = 0.5g
1	MC41	DIEN	J	2	~50			Missed
1	MC41	PALE	F	1		80		
1	MC41	ONCO						
1	MC41	PALE		1				Missed
1	MC51	DIEN		1	65	32	4.0	
1	MC51	DIEN		1	68	32	2.0	
1	MC51	DIEN		2				Missed
1	MC56	NONE						
1	R42	DIEN		1				
1	MC61	DIEN		1	91	47	8.0	missing right front foot/part of tail.
1	MC61	DIEN		1	88	45	6.5	
1	MC61	DIEN		1				Missed

APPENDIX B: Spike Buck Capture Data
Table B-1. 1997 data

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus,* PALE-*Pacifastacus leniusculus*, ONCO-*Oncorhynchus sp.,* ONKI-*O. kisutch*, ONMY-*O. mykiss*. RT-rostrum telson length, SV-snout vent length., j-juvenile

Pass	Habitat ID	Species	Sex	No.	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	SP2	NONE		0	0	0	0	water clouded easily
1	SP7	DIEN		1	80	40	3.7	
2	SP7	NONE		0	0	0	0	
1	SP13	DIEN		1	60	31	1.6	
1	SP13	DIEN		1	63	29	1.5	
2	SP13	NONE		0	0	0	0	
1	FW5	NONE		0	0	0	0	
2	SP2	DIEN		1	~50			missed

APPENDIX B: Spike Buck Capture Data
Table B-2. 1998 data

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus,* PALE-*Pacifastacus leniusculus*, ONCO-*Oncorhynchus sp.,* ONKI-*O. kisutch*, ONMY-*O. mykiss*. RT-rostrum telson length, SV-snout vent length., j-juvenile

Pass	Habitat ID	Species	Sex	No.	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	MC1	DIEN		1	75	40		
1	R2	NONE						
1	SP8	DIEN		1	75	30		missing left hind foot

APPENDIX C: Mainstem Redwood Creek Capture Data
Table C-1. 1997 data

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus*, PALE-*Pacifastacus leniusculus,* ONCO-*Oncorhynchus* sp., ONKI-*O. kisutch*, ONMY-*O. mykiss*. RT-rostrum telson length, SV-snout vent length, j-juvenile.

Pass	Habitat ID	Species	Sex	No	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	SC6	PALE		5				Missed
1	SC6	PALE	F	1		95		
1	SC6	COTT						
1	SC6	ONMY						
1	SC6	ONKI						
1	SC6	PALE	F	1		120		
1	SC6	PALE	F	1		110		Soft-recently molted
1	R8	NONE						
1	MC2	PALE		7				Missed
1	MC2	PALE	M	1		52		
1	MC2	PALE	M	1		105		Soft-recently molted
1	MC2	PALE	M	1		85		
1	MC2	PALE		1		42		Sex undetermined
1	MC2	PALE	F	1		65		Soft-recently molted
1	MC2	PALE	F	1		82		
1	MC2	PALE	M	1		85		
1	MC2	PALE	M	1		43		
1	MC2	PALE	M	1		49		
1	MC2	PALE		1		42		
1	SC1	PALE		2				Missed
1	SC1	PALE		1				Molted Exoskeleton
1	SC1	PALE	M	1		125		
1	SC1	PALE	F	1		74		
1	MC7	COTT						
1	MC7	ONMY						
1	FW9	COTT						
1	MC12	NONE						
1	BW5	COTT						
1	R18	NONE						
1	MC17	PALE		1				
1	MC17	COTT						
1	MC17	ONMY						
1	SC11	PALE	M	1		90		
1	SC11	PALE	F	1		90		
1	SC11	PALE		5				Missed
1	SC11	PALE		3				Dead
1	R28	ONMY						
1	FW19	COTT						
1	MC22	COTT						
1	MC22	ONMY						
1	SC16	PALE		1				Dead
1	SC16	PALE		2				Missed
1	SC16	ONMY						

APPENDIX C: Mainstem Redwood Creek Capture Data—Continued
Table C-1. 1997 data—Continued

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus*, PALE-*Pacifastacus leniusculus*, ONCO-*Oncorhynchus* sp., ONKI-*O. kisutch,* ONMY-*O. mykiss*. RT-rostrum telson length, SV-snout vent length, j-juvenile.

Pass	Habitat ID	Species	Sex	No	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	SC16	COTT						
1	R38	PALE	F	1		45		
1	MC27	PALE		1				Missed
1	MC27	ONMY						
1	FW29	NONE						
1	MC32	PALE		1				Dead
1	MC32	PALE		1				Missed
2	MC32	PALE	M	1		100		
2	MC32	PALE	M	1		110		
1	R48	NONE						
1	FW39	NONE						Bottom blanketed in algae
1	MC37	NONE						
1	FW49	PALE	F	1		80		
1	FW49	PALE		3				Missed-small
1	FW49	PALE		1		55		Soft-recently molted
1	FW49	PALE	F	1		40		
1	MC42	PALE	F	1		45		
1	MC42	PALE	M	1		50		
1	MC42	PALE	F	1		45		
1	R58	NONE						
1	MC47	PALE	F	1		40		
1	MC47	COTT						
1	MC47	ONMY						
1	MC47	PALE	F	1		36		
1	MC47	PALE		1				Missed
1	MC47	PALE		3				Dead-large
1	MC47	PALE	F	1		105		1 claw-molt
1	MC47	PALE	M	1		90		Soft-recently molted
1	R68	NONE						
1	FW59	PALE	F	1		36		
1	FW59	COTT						

APPENDIX C: Mainstem Redwood Creek Capture Data
Table C-2. 1998 data

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus*, PALE-*Pacifastacus leniusculus*, ONCO-*Oncorhynchus sp.,* ONKI-*O. kisutch*, ONMY-*Oncorhynchus mykiss.* RT-rostrum telson length, SV-snout vent length, j-juvenile.

Pass	Habitat ID	Species	Sex	No	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	R2	NONE						
1	MC1	PALE	M	1		70		
1	MC1	PALE	M	1		107		
1	MC1	PALE		1		105		
1	MC6	PALE		2				Missed
1	MC6	ONCO						
1	MC6	COTT						
1	SC6	COTT						
1	SC6	ONCO						
1	R12	ONCO						
1	MC11	ONCO						
1	MC11	COTT						
1	MC16	COTT						
1	SC11	PALE		2				Missed
1	MC21	DIEN		1	50	25	3.0	
1	MC21	PALE	F	1		90		
1	MC21	PALE	M	1		52		
1	MC21	PALE	F	1		48		
1	MC21	PALE	M	1		45		
1	MC21	PALE	M	1		43		
1	MC21	COTT						
1	MC21	ONKI						
1	R22	DIEN		2				Missed
1	R22	DIEN		1	52	27	2.0	
1	MC31	PALE	M	1		72		
1	MC31	COTT						
1	SC26	PALE	M	1		110		
1	SC26	COTT						
1	SC26	ONCO						
1	SC26	PALE	M	1		93		
1	SC26	PALE	M	1		100		
1	SC26	PALE	M	1		119		
1	SC26	PALE	F	1		78		
1	SC26	PALE	F	1		86		
1	SC26	PALE	M	1		101		
1	SC26	PALE	F	1		66		
1	SC26	PALE	M	1		80		
1	SC26	PALE	M	1		90		
1	SC26	PALE	F	1		78		
1	SC26	PALE		2				Missed
1	SC26	DIEN		1	99	56	11.0	missing right hind foot
1	MC36	PALE	M	1		106		
1	MC36	PALE	M	1		104		

APPENDIX C: Mainstem Redwood Creek Capture Data—Continued
Table C-2. 1998 data—Continued

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus*, PALE-*Pacifastacus leniusculus*, ONCO-*Oncorhynchus sp.,* ONKI-*O. kisutch,* ONMY-*Oncorhynchus mykiss.* RT-rostrum telson length, SV-snout vent length, j-juvenile.

Pass	Habitat ID	Species	Sex	No	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	MC36	PALE		1				Missed
1	MC36	PALE	F	1		89		
1	MC36	PALE	F	1		90		
1	MC36	PALE	F	1		120		
1	MC36	PALE	M	1		106		
1	MC36	PALE	F	1		94		
1	MC36	COTT						
1	MC36	ONCO						
1	SC16	PALE	M	1		101		
1	SC16	PALE	U	1				Missed
1	SC16	COTT						
1	SC16	ONCO						
1	FW5	PALE	M	1		66		
1	FW5	COTT						
1	MC26	PALE	M	1		90		
1	MC26	COTT						
1	SC21	PALE		1				Missed
1	SC21	ONKI						
1	BW9	NONE						
1	R32	COTT						
1	SC31	DIEN		1	140	68	20. 0	
1	SC31	DIEN		1	100			Missed
1	SC31	COTT						
1	SC31	ONCO						
1	MC41	COTT						
1	MC41	ONCO						
1	MC41	DIEN		1	25			Missed
1	MC41	DIEN		1	60			eaten by crayfish
1	MC41	DIEN		1	108	57	9. 0	
1	MC41	PALE	F	1		78		
1	MC41	PALE	M	1		90		
1	MC41	PALE	M	1		48		
1	MC46	PALE	M	1		80		
1	MC46	PALE	M	1		67		
1	MC46	PALE		1		115		
1	MC46	PALE		1		77		
1	MC46	PALE	M	1		107		
1	MC46	PALE	F	1		113		
1	MC46	PALE	F	1		65		
1	MC46	PALE	M	1		35		
1	MC46	PALE	M	1		51		
1	MC46	PALE	M	1		44		
1	MC46	PALE	F	1		40		
1	MC46	COTT						

APPENDIX C: Mainstem Redwood Creek Capture Data—Continued
Table C-2. 1998 data—Continued

KEY: COTT-Unid. cottid, DIEN-*Dicamptodon ensatus*, PALE-*Pacifastacus leniusculus*, ONCO-*Oncorhynchus sp.,* ONKI-*O. kisutch*, ONMY-*Oncorhynchus mykiss*. RT-rostrum telson length, SV-snout vent length, j-juvenile.

Pass	Habitat ID	Species	Sex	No	Total Length (mm)	RT or SV length (mm)	Weight (g)	Notes
1	MC46	ONMY						
1	SC36	COTT						
1	SC36	PALE	M	1		102		
1	SC36	PALE	F	1		102		
1	SC36	PALE	F	1		69		
1	SC36	PALE	M	1		68		
1	SC36	PALE	F	1		64		
1	SC36	PALE	M	1		71		
1	SC36	PALE	F	1		57		
1	SC36	PALE	F	1		60		
1	SC36	ONMY						
1	SC36	PALE	F	1		72		
1	R42	COTT						
1	MC51	COTT						
1	MC51	PALE	F	1		56		
1	MC51	PALE	F	1		80		
1	MC51	PALE	F	1		51		
1	MC51	PALE	F	1		38		
1	MC51	PALE	F	1		42		
1	MC51	PALE	F	1		31		
1	MC51	PALE	F	1		35		
1	MC51	PALE	M	1		85		
1	MC51	PALE	M	1		32		
1	MC51	PALE		2				Missed
1	MC51	PALE		4				Missed
1	MC51	PALE	M	1		80		
1	SC41	COTT						
1	MC56	PALE	F	1		47		
1	MC56	PALE	F	1		44		
1	MC56	PALE		1		48		
1	MC56	PALE	F	1		42		
1	MC56	COTT						
1	MC56	PALE		1				Missed
1	SC46	COTT						
1	R52	COTT						
1	R52	PALE		1				Missed
1	SC51	PALE	F	1		68		
1	SC51	PALE	M	1		82		

Appendix D: Instream Habitat Characteristics at Mainstem Redwood Creek Capture Sites

Table D-1. 1997 data

Habitat	Unit ID	Length (m)	Cumulative Distance (m)	Fines (%)	Gravel (%)	Small Cobble (%)	Large Cobble (%)	Boulder (%)	Bedrock (%)	Undercut (%)	Mean Undercut Width (m)
BW	5	4.7	366	24	64	12	0	0	0	5.0	0.2
FW	9	7.4	323	12	51	33	4	0	0	0.0	0.0
FW	19	7.1	754	2	63	26	6	4	0	0.0	0.0
FW	29	4.9	1,025	20	22	8	18	31	0	0.0	0.0
FW	39	10.7	1,459	0	55	23	16	5	0	0.5	0.0
FW	49	7.1	1,749	5	54	23	5	13	0	0.0	0.0
FW	59	12.7	2,106	2	77	6	6	2	8	0.0	0.0
MC	2	11.3	53	18	64	16	2	0	0	0.0	0.0
MC	7	3.2	161	100	0	0	0	0	0	0.0	0.0
MC	12	4.8	329	41	49	10	0	0	0	0.0	0.0
MC	17	5.6	539	17	71	6	0	6		5.0	0.2
MC	22	8.1	796	8	53	4	2	34	0	0.0	0.0
MC	27	3.5	995	0	59	9	4	28	0	0.0	0.0
MC	32	13.5	1,300	11	59	26	2	2	0	0.0	0.0
MC	37	3.9	1,653	7	43	30	14	5	0	0.0	0.0
MC	42	6.9	1,803	0	62	15	13	10	0	0.0	0.0
MC	47	23.0	2,085	18	48	16	18	0	0	30.0	0.6
R	8	3.5	120	6	60	31	4	0	0	0.0	0.0
R	18	15.6	391	0	44	40	12	4	0	0.0	0.0
R	28	8.0	624	2	69	22	7	0	0	0.0	0.0
R	38	9.5	990	0	73	18	10	0	0	0.0	0.0
R	48	11.2	1,410	0	67	18	16	0	0	25.0	0.3
R	58	8.1	1,811	0	53	16	13	18	0	5.0	0.1
R	68	7.7	2,093	0	49	25	24	2	0	0.5	0.0
SC	1	9.1	40	40	51	9	0	0	0	10.0	0.4
SC	6	12.5	290	42	48	10	0	0	0	5.0	0.1
SC	11	19.0	566	33	49	11	4	4	0	35.0	1.2
SC	16	4.3	980	0	72	21	8	0	0	0.0	0.0

KEY TO ABBREVIATIONS

BW–backwater; FW–flatwater; MC–main pool channel; R–riffle; SC–scour pool

Instream Wood (% area)	Max Pool Depth (m)	Min Pool Depth (m)	Residual Pool Depth (m)	Mean Depth (m)	Mean Width (m)	Mean Area (m^2)	Mean Volume (m^3)	DIEN	PALE	Habitat
70.0	0.23	0.00	0.23	0.1	1.5	6.8	0.6	0	0	BW
1.0				0.1	2.6	19.2	1.7	0	0	FW
7.0				0.1	3.6	25.3	1.4	0	0	FW
0.0				0.1	2.1	10.5	1.0	0	0	FW
0.0				0.1	5.1	54.9	4.9	0	0	FW
1.0				0.1	2.1	14.9	2.0	0	6	FW
0.0				0.1	3.0	38.5	3.8	0	1	FW
25.0	0.57	0.08	0.49	0.2	4.0	45.2	10.3	0	17	MC
0.0	0.57	0.00	0.57	0.3	2.5	7.9	2.1	0	0	MC
5.0	0.25	0.02	0.23	0.1	3.0	14.4	1.7	0	0	MC
2.0	0.34	0.10	0.24	0.1	2.2	12.5	1.7	0	1	MC
10.0	0.27	0.09	0.18	0.1	4.3	34.8	5.1	0	0	MC
1.0	0.35	0.04	0.31	0.1	4.8	16.9	2.1	0	1	MC
8.0	0.53	0.03	0.50	0.2	4.4	59.0	10.5	0	2	MC
0.5	0.30	0.09	0.21	0.1	3.8	14.8	1.8	0	0	MC
1.0	0.35	0.10	0.25	0.1	2.9	19.8	2.9	0	3	MC
15.0	0.62	0.10	0.52	0.2	3.6	83.6	18.2	0	8	MC
0.0				0.0	2.2	7.6	0.3	0	0	R
10.0				0.1	5.4	83.7	4.3	0	0	R
2.0				0.0	2.9	22.9	0.7	0	0	R
2.0				0.1	1.7	16.2	0.9	0	1	R
0.0				0.1	2.3	25.8	1.4	0	0	R
0.0				0.1	2.8	22.4	1.7	0	0	R
20.0				0.1	2.5	19.0	1.1	0	0	R
0.0	0.72	0.06	0.66	0.2	3.3	29.7	6.5	0	5	SC
20.0	0.55	0.15	0.40	0.2	2.5	31.3	6.8	0	8	SC
3.0	1.31	0.08	1.23	0.4	5.3	100.1	35.7	0	10	SC
80.0	0.50	0.11	0.39	0.2	2.7	11.4	2.1	0	3	SC

Appendix D: Instream Habitat Characteristics at Mainstem Redwood Creek Capture Sites
Table D-2. 1998 data

Habitat	Unit ID	Length (m)	Cumulative Distance (m)	Fines (%)	Gravel (%)	Small Cobble (%)	Large Cobble (%)	Boulder (%)	Bedrock (%)	Undercut (%)	Mean Undercut Width (m)
BW	9	13.9	1,096	10	33	10	3	45	0		
FW	5	10	756	6	49	36	6	2	0	0.0	0.0
MC	1	16.4	43	13	52	27	8	0	0		
MC	6	4.8	208	32	62	6	0	0	0	15.0	0.2
MC	11	9.2	333	15	73	9	3	0	0	2.5	0.1
MC	16	4.7	464	0	59	25	16	0	0	0.0	0.0
MC	21	15.2	543	2	35	10	21	31	0	0.0	0.0
MC	26	18.4	847	8	43	5	16	27	0	5.0	0.1
MC	31	7.4	1,030	0	40	34	17	9	0	0.0	0.0
MC	36	12.9	1,137	28	22	44	6	0	0	50.0	0.5
MC	41	8.6	1,382	7	37	33	23	0	0	0.0	0.0
MC	46	17.6	1,647	13	48	30	5	3	0	50.0	0.5
MC	51	10.7	1,893	12	42	18	23	5	0	0.0	0.0
MC	56	14.5	2,049	19	41	14	22	5	0	50.0	0.2
R	2	15.2	29	15	65	18	3	0	0		
R	12	9.5	267	18	44	31	8	0	0	0.0	0.0
R	22	9.2	578	0	52	35	13	0	0	0.0	0.0
R	32	10.6	1,243	2	41	46	11	0	0		
R	42	11.2	1,758	4	31	26	35	4	0	0.0	0.0
R	52	9	2,174	6	22	14	10	48	0	0.0	0.0
SC	7	24.7	333	22	67	7	4	0	0	20.0	0.2
SC	11	11.8	464	21	56	19	4	0	0	20.0	0.3
SC	16	15.1	609	7	48	25	14	7	0	20.0	0.4
SC	21	6	975	0	77	10	6	6	0	30.0	0.2
SC	26	21.7	1,125	13	44	41	3	0	0	25.0	0.5
SC	31	11.2	1,302	2	51	19	14	14	0	0.0	0.0
SC	36	7.2	1,654	2	23	23	26	5	21	15.0	0.2
SC	41	8.4	1,930	7	34	18	27	14	0	0.0	0.0
SC	46	11	2,093	5	34	20	32	10	0	30.0	0.2
SC	51	10.5	2,234	2	41	10	10	7	29	20.0	0.5

KEY TO ABBREVIATIONS

BW–backwater; FW–flatwater; MC–main pool channel; R–riffle; SC–scour pool

Instream Wood (% area)	Max Pool Depth (m)	Min Pool Depth (m)	Residual Pool Depth (m)	Mean Depth (m)	Mean Width (m)	Mean Area (m²)	Mean Volume (m³)	DIEN	PALE	Habitat
				0.0	1.1	15.8	0.7	0	0	BW
0.0				0.1	5.8	57.5	6.8	0	1	FW
	0.57	0.10	0.47	0.2	4.4	72.7	16.7	0	3	MC
10.0	0.70	0.20	0.50	0.2	3.3	16.0	3.6	0	2	MC
15.0	0.60	0.10	0.50	0.3	4.4	40.8	11.6	0	0	MC
0.0	0.25	0.15	0.10	0.1	3.1	14.7	2.0	0	0	MC
0.0	0.55	0.01	0.54	0.2	4.1	61.8	13.6	1	5	MC
5.0	0.43	0.20	0.23	0.1	6.8	125.1	16.2	0	1	MC
5.0	0.35	0.10	0.25	0.2	3.5	26.1	4.6	0	1	MC
10.0	0.90	0.26	0.64	0.4	5.3	67.9	25.1	0	8	MC
25.0	0.35	0.15	0.20	0.2	4.5	38.4	6.4	3	3	MC
0.0	0.70	0.15	0.55	0.2	5.0	87.4	20.2	0	11	MC
0.0	0.49	0.10	0.39	0.2	4.5	48.3	11.6	0	16	MC
0.0				0.1	4.2	60.7	7.8	0	5	MC
				0.1	2.4	36.0	2.9	0	0	R
0.0				0.1	4.0	38.0	3.7	0	0	R
2.5				0.1	4.6	42.0	5.1	3	0	R
				0.1	7.9	83.7	6.1	0	0	R
5.0				0.1	5.5	62.0	6.4	0	0	R
0.0				0.1	2.7	24.6	2.5	0	1	R
10.0	1.05	0.30	0.75	0.3	3.1	77.4	25.0	0	0	SC
5.0	0.55	0.09	0.46	0.2	3.8	45.2	11.1	0	2	SC
0.0				0.1	5.3	80.3	8.2	0	2	SC
10.0	0.65	0.32	0.33	0.2	2.3	13.6	2.4	0	1	SC
5.0	0.77	0.14	0.63	0.3	5.4	117.2	30.6	1	13	SC
7.0	0.31	0.20	0.11	0.1	4.3	48.2	5.7	2	0	SC
1.0	0.65	0.30	0.35	0.3	2.2	16.1	4.6	0	9	SC
0.0	0.30	0.06	0.24	0.1	4.2	35.0	3.8	0	0	SC
0.0	0.28	0.03	0.25	0.1	3.1	34.1	3.4	0	0	SC
2.5	0.60	0.35	0.25	0.1	1.8	19.3	2.9	0	2	SC

Appendix D: Instream Habitat Characteristics at Mainstem Redwood Creek Capture Sites
Table D-3: Summary by habitat type

	1997				1998			
	BW	MC	RIFFLE/FW	SC	BW	MC	SC	RIFFLE/FW
Sample Sites	**1**	**10**	**13**	**4**	**1**	**12**	**10**	**7**
Mean % Fines	24	22	4	29	10	12	8	7
Mean % Gravel	64	51	57	55	33	46	48	43
Mean % Small Cobble	12	13	22	13	10	21	19	29
Mean % Large Cobble	0	6	11	3	3	13	14	12
Mean % Boulder	0	8	6	1	45	7	6	8
Mean % Bedrock	0	0	1	0	0	0	5	0
Mean % Undercut (length)	5	4	2	13		16	18	0
Mean Width of Undercut (m)	0.15	0.08	0.03	0.43		0.14	0.25	0.00
Mean % Wood (area)	70	7	3	26		6	4	2
Mean Water Depth (m)	0.08	0.17	0.07	0.24	0.04	0.21	0.19	0.10
Mean Res. Pool Depth (m)	0.23	0.35		0.67		0.40	0.37	

Appendix E: Instream Habitat Characteristics at Tributary Animal Survey Sites
Table E-1. 1997 data

Stream	Habitat	Unit ID	Length (m)	Cumulative Distance (m)	Fines (%)	Gravel (%)	Small Cobble (%)	Large Cobble (%)	Boulder (%)	Bedrock (%)	Undercut (%)
Fern	FW	3	5.5	1,969	0	56	19	22	4	0	2
Fern	FW	13	4.1	2,521	0	45	7	20	27	0	5
Fern	FW	23	5.5	2,729	0	50	6	13	31	0	0
Fern	MC	3	6.0	2,014	4	42	16	16	0	23	0
Fern	MC	8	5.5	2,358	7	59	13	9	11	0	5
Fern	MC	13	3.7	2,466	2	65	17	9	7	0	10
Fern	MC	23	2.4	2,645	0	47	2	18	33	0	40
Fern	MC	28	3.1	2,773	0	15	0	4	2	79	5
Fern	MC	33	4.1	2,806	0	38	9	15	19	19	20
Fern	MC	38	2.7	2,894	18	45	0	18	15	4	0
Fern	R	7	7.4	1,982	0	77	16	5	2	0	0
Fern	R	17	16.4	2,130	0	62	21	15	2	0	0
Fern	R	27	2.8	2,370	0	39	22	37	2	0	0
Fern	R	37	7.2	2,568	0	100	0	0	0	0	0
Fern	R	47	2.6	2,711	0	43	9	5	43	0	0
Fern	R	57	7.0	2,887	0	45	4	21	15	15	0
Fern	SC	3	3.0	2,093	6	80	14	0	0	0	0
Fern	SC	8	5.7	2,472	4	55	9	19	13	0	15
Fern	SP	4	3.8	2,669	4	48	6	4	38	0	15
Fern	SP	9	2.6	2,694	23	32	11	21	13	0	5
Fern	SP	14	3.0	2,706	2	91	2	4	2	0	5
Fern	SP	18	2.7	2,753	0	38	10	10	42	0	
Spike Buck	FW	5	2.2	3,081	43	49	6.6	1.6	0	0	
Spike Buck	SP	3	2.2	3,028	2	47	8.2	10	33	0	10
Spike Buck	SP	7	1.6	3,050	20	60	13	7.3	0	0	10
Spike Buck	SP	13	0.9	3,077	28	30	4	10	28	0	

KEY TO ABBREVIATIONS

FW–flatwater; MC–main pool channel; R–riffle; SC–scour pool; SP–step pool

Mean Undercut Width (m)	Instream Wood (% area)	Max Pool Depth (m)	Min Pool Depth (m)	Residual Pool Depth (m)	Mean Depth (m)	Mean Width (m)	Mean Area (m^2)	Mean Volume (m^3)	DIEN	PALE	Stream
0.1	5				0.07	2.13	11.73	0.84	0	0	Fern
0.3	0				0.10	2.27	9.29	0.96	0	0	Fern
0	0				0.07	1.47	8.07	0.58	2	0	Fern
0	0	0.59	0.05	0.54	0.27	2.23	13.40	3.66	0	8	Fern
0	10	0.29	0.08	0.21	0.11	2.67	14.67	1.64	0	0	Fern
0.3	20	0.3	0.09	0.21	0.14	1.40	5.18	0.70	0	3	Fern
0.5	0	0.35	0.04	0.31	0.15	1.25	3.00	0.46	0	0	Fern
0.2	0	0.45	0.03	0.42	0.13	1.60	4.96	0.66	2	0	Fern
0.3	5	0.4	0.05	0.35	0.16	1.37	5.60	0.87	2	0	Fern
0	10	0.3	0.06	0.24	0.09	1.50	4.05	0.34	1	0	Fern
0	5				0.04	2.07	15.29	0.68	0	0	Fern
0	5				0.05	2.67	43.73	2.30	0	1	Fern
0	35				0.02	2.07	5.79	0.14	0	0	Fern
0	5				0.03	0.57	4.08	0.13	1	0	Fern
0	1				0.03	2.70	7.02	0.20	6	0	Fern
0	2				0.04	1.30	9.10	0.40	5	0	Fern
0	10	0.25	0.15	0.1	0.12	1.70	5.10	0.60	0	0	Fern
0.4		0.52	0.07	0.45	0.17	2.07	11.78	1.95	0	8	Fern
	0	0.31	0.02	0.29	0.11	2.50	9.50	1.00	0	1	Fern
0.1	30	0.31	0.03	0.28	0.11	1.07	2.77	0.30	1	1	Fern
0.1	0	0.3	0.05	0.25	0.16	1.87	5.60	0.88	0	1	Fern
					0.10	2.07	5.58	0.57	1	0	Fern
					0.47	0.02	1.03	0.01	0	0	Spike Buck
0.3	10	0.25	0	0.25	0.1	1.62	3.56	0.59	0	0	Spike Buck
0.2	10	0.27	0	0.27	0.1	1.43	2.29	0.32	1	0	Spike Buck
		0.21	0	0.21	0.14	0.83	0.75	0.08	2	0	Spike Buck

Appendix E: Instream Habitat Characteristics at Tributary Animal Survey Sites
Table E-2. 1998 data

Stream	Habitat	Unit ID	Length (m)	Cumulative Distance (m)	Fines (%)	Gravel (%)	Small Cobble (%)	Large Cobble (%)	Boulder (%)	Bedrock (%)	Undercut (%)
Spike Buck	MC	1	2.9	3,172	17	58	14	8	3	0	25
Spike Buck	R	2	1.9	3,176	17	71	12	0	0	0	0
Spike Buck	SP	8	1.5	3,196	3	3	14	14	3	64	50
Unk. trib	MC	1	1.8	2,719	3	41	34	22	0	0	
Unk. trib	SP	8	2.6	2,741	10	64	7	0	14	5	
Fern	MC	1	6.3	2,055	0	31	36	19	14	0	0
Fern	MC	6	5.4	2,377	0	62	18	20	0	0	0
Fern	MC	11	6.3	2,500	0	34	29	37	0	0	0
Fern	MC	16	8.5	2,626	8	41	8	30	14	0	0
Fern	MC	21	7.0	2,700	0	38	27	27	8	0	
Fern	MC	26	3.5	2,750	5	43	20	23	9	0	0
Fern	MC	31	4.2	2,808	17	37	26	14	0	6	0
Fern	MC	36	4.0	2,842	11	22	26	30	11	0	35
Fern	MC	41	6.8	2,877	9	43	4	15	17	13	25
Fern	MC	46	7.2	2,957	0	31	11	14	11	33	3
Fern	MC	51	9.5	3,006	10	38	10	25	3	15	3
Fern	MC	56	2.8	3,045	0	40	6	20	14	20	3
Fern	MC	61	5.6	3,098	0	35	11	13	39	2	10
Fern	R	2	7.0	2,039	2	55	28	13	2	0	0
Fern	R	12	9.0	2,332	0	48	31	21	0	0	0
Fern	R	22	10.0	2,578	5	55	24	14	2	0	3
Fern	R	32	7.6	2,696	0	100	0	0	0	0	0
Fern	R	42	3.0	3,050	0	10	23	20	8	40	3
Fern	SC	6	9.3	2,183	6	50	22	22	0	0	25
Fern	SC	11	7.0	2,340	0	38	22	38	2	0	0
Fern	SC	16	4.6	2,591	6	42	17	31	4	0	30

KEY TO ABBREVIATIONS

MC–main pool channel; R–riffle; SP–step pool; SC–scour pool

Mean Undercut Width (m)	Instream Wood (% area)	Max Pool Depth (m)	Min Pool Depth (m)	Residual Pool Depth (m)	Mean Depth (m)	Mean Width (m)	Mean Area (m^2)	Mean Volume (m^3)	DIEN	PALE	Stream
0.5	2.5	0.40	0.10	0.30	0.16	2.40	6.96	1.09	1	0	Spike Buck
0.0	0.0				0.03	0.70	1.33	0.04	0	0	Spike Buck
0.2	10.0	0.35	0.01	0.34	0.11	2.00	3.00	0.33	1	0	Spike Buck
		0.15	0.10	0.05	0.06	1.27	2.28	0.13	0	0	Unk. trib
		0.29	0.09	0.20	0.09	1.05	2.73	0.25	0	0	Unk. trib
0.0	0.0	0.43	0.05	0.38	0.17	2.37	14.93	2.53	0	0	Fern
0.0	2.5				0.09	3.40	18.36	1.67	1	1	Fern
0.0	2.5	0.36	0.09	0.27	0.15	2.97	18.69	2.71	0	0	Fern
0.0	2.5	0.35	0.15	0.20	0.14	2.70	22.95	3.10	0	0	Fern
		0.95	0.10	0.85	0.38	4.03	28.23	10.80	0	5	Fern
0.0	0.0	0.30	0.13	0.17	0.11	3.33	11.67	1.29	0	1	Fern
0.0	15.0	0.41	0.12	0.29	0.13	1.72	7.21	0.93	1	0	Fern
	5.0	0.55	0.05	0.50	0.17	3.45	13.80	2.35	0	2	Fern
0.2	0.5	0.57	0.15	0.42	0.16	3.37	22.89	3.57	2	2	Fern
0.2	2.5	0.50	0.10	0.40	0.17	2.50	18.00	3.08	0	0	Fern
0.2	2.5	0.50	0.16	0.34	0.20	2.70	25.65	5.02	4	0	Fern
0.2	2.5	0.32	0.05	0.27	0.18	1.70	4.76	0.86	0	0	Fern
0.4	2.5				0.30	3.33	18.67	5.52	3	0	Fern
0.0	2.5				0.07	2.86	20.04	1.32	0	0	Fern
0.0	0.0				0.07	3.17	28.50	1.90	0	0	Fern
0.1	2.5				0.03	5.37	53.67	1.52	1	1	Fern
0.0	80.0				0.04	0.67	5.07	0.19	0	0	Fern
0.1	2.5				0.13	1.67	5.00	0.65	1	0	Fern
0.3	0.0	0.40	0.12	0.28	0.15	1.87	17.39	2.61	1	1	Fern
0.0	10.0	0.25	0.12	0.13	0.07	2.25	15.75	1.08	0	0	Fern
1.0	20.0	0.75	0.10	0.65	0.28	2.53	11.65	3.27	0	14	Fern

Appendix E: Instream Habitat Characteristics at Tributary Animal Survey Sites:
Table E-3. Summary by habitat type for Fern Creek

Year	**1997**			**1998**		
Habitat	**MC/SP**	**R/FW**	**SC**	**MC**	**R/FW**	**SC**
Sample Sites	11	9	2	13.0	5.0	3.0
Mean % Fines	5	0	5	4.6	1.4	3.9
Mean % Gravel	47	57	67	37.9	53.6	43.1
Mean % Small Cobble	8	11	12	17.9	21.0	20.4
Mean % Large Cobble.	12	15	9	22.0	13.6	30.4
Mean % Boulder	17	14	7	10.7	2.4	2.1
Mean % Bedrock	11	2	0	6.8	8	0
Mean % Undercut (length)	11	1	8	6.5	1.0	18.3
Mean Width of Undercut (m)	0.2	0	0	0.11	0.0	0.42
Mean % Wood (area)	8	6	10	3.2	17.5	10.0
Mean Water Depth (m)	0.14	0.05	0.14	0.18	0.07	0.17
Mean Res. Pool Depth (m)	0.30		0	0.37		0.35

Table E-4: Summary by habitat type for Spike Buck Creek

Year	**1997**		**1998**	
Habitat	**MC/SP**	**R/FW**	**MC/SP**	**R/FW**
Sample Sites	3	1	2	1
Mean % Fines	16.7	42.6	10	17
Mean % Gravel	45.6	49.2	31	71
Mean % Small Cobble	8.3	6.6	14	12
Mean % Large Cobble.	9.2	1.6	11	0
Mean % Boulder	20.2	0.0	3	0
Mean % Bedrock	0.0	0.0		
Mean % Undercut (length)	10.0		38	0
Mean Width of Undercut (m)	0.3		0.35	0
Mean % Wood (area)	10.0		6	0
Mean Water Depth (m)	0.11	0.47	0.13	0.03
Mean Res. Pool Depth (m)	0.24		0.32	

KEY TO ABBREVIATIONS

MC–main pool channel; SP–step pool; R–riffle; FW–flatwater; SC–scour pool

Appendix F: Summary of Basinwide Habitat Inventory Data

Table F-1. Summary of instream habitat types for mainstem Redwood Creek

Year	1997			1998		
Habitat Type	**N**	**AREA (m^2)**	**LENGTH (m)**	**N**	**AREA (m^2)**	**LENGTH (m)**
Main Channel Pool	51	1,411	482	60	3,186	793
Scour Pool	20	600	190	53	2,635	751
Backwater Pool	10	39	35	11	212	98
Riffle/Flatwater/Cascade	135	5,807	1,652	74	4,238	954
TOTAL	**216**	**7,857**	**2,359**	**198**	**10,271**	**2,597**

Table F-2. Summary of instream habitat types for Fern Creek

Year	1997			1998		
Habitat Type	**N**	**AREA (m^2)**	**LENGTH (m)**	**N**	**AREA (m^2)**	**LENGTH (m)**
Main Channel Pool	57	463	237	64	1,195	420
Scour Pool	10	101	54	22	370	169
Backwater Pool	4	16	9	1	11	7
Riffle/Flatwater/Cascade	94	1,470	805	63	1,603	593
TOTAL	**165**	**2,050**	**1,105**	**150**	**3,179**	**1,189**

Table F-3. Summary of instream habitat types for Spike Buck Creek

Year	1997			1998		
Habitat Type	**N**	**AREA (m^2)**	**LENGTH (m)**	**N**	**AREA (m^2)**	**LENGTH (m)**
Main Channel Pool	16	36	29	12	45	33
Scour Pool	0			2	8	4
Backwater Pool	1	2	2	0		
Riffle/Flatwater/Cascade	10	21	31	8	26	29
TOTAL	**27**	**59**	**62**	**22**	**79**	**66**

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