OBSERVATIONS OF UPLAND HABITAT USE BY CALIFORNIA TIGER SALAMANDERS BASED ON BURROW EXCAVATIONS

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Abstract: Upland habitat use by the California tiger salamander (*Ambystoma californiense*) is poorly understood with regard to the species' spatial distribution and population densities. Data obtained through burrow excavation within suitable upland habitat in Alameda County, California, identified adult *A. californiense* at a mean distance of 356 m from the nearest breeding pond (range = 120–510 m; *n* = 5), with a mean upland density of 2.2 salamanders/ha among sample plots (*n* = 24) and a mean of 4.1 salamanders/ha among plots with the greatest refugia densities (>14 refugia; *n* = 12). Adult salamanders were not evenly distributed within available habitat and were 4 times more abundant in plots with high refugia densities. The implication from this study for conservation planning is the need to manage and protect small-mammal colonies and their upland habitat within 500 m of salamander breeding sites.

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Key words: Alameda County, *Ambystoma californiense*, California tiger salamander, conservation, density, hand excavation, refugia, survey methods, upland distribution.

It is widely accepted that the population demographics of a species are often associated with the availability of environmental resources (Duellman and Trueb 1986). Repeated studies and observations of the California tiger salamander (*Ambystoma californiense*) have identified small-mammal burrows as essential upland habitat components used for refugia and aestivation, and as a limiting resource for this species (Barry and Shaffer 1994, Loredo et al. 1996, Semlitsch 1983, Trenham 2001). The functional relationship, however, between burrow availability and *A. californiense* population distribution remains largely unexamined. This data gap arises primarily because *A. californiense* are not readily available for observation; this species is rarely encountered in terrestrial habitat, even where abundant (Barry and Shaffer 1994).

The poor understanding of upland habitat use by *A. californiense* has produced a planning environment with species protection efforts currently based on small, arbitrarily derived conservation buffers around breeding ponds. Our present understanding of Ambystomid upland habitat use and distribution comes largely from a handful of studies using nocturnal visual tracking (Loredo et al. 1996), radiotracking (Trenham 2001, Faccio 2003), fiber-optic scopes (Semonsen 1998), visual study methods and casual observations (Twitty 1941, Holland et al. 1990, Jennings 1996, Douglas and Monroe 1981), and pitfall trap arrays at various distances from breeding ponds (Semlitsch 1981; Loredo et al. 1996; Trenham et al. 2000, 2001; Trenham and Shaffer 2005) to identify individuals. There are no published accounts of the use of small- mammal burrow excavation as a survey method for fossorial salamanders or mammals.

To add to these upland Ambystomid study techniques, habitat (burrow) excavation is a method that can be used to examine *A. californiense* upland habitat use and distribution. This method has received little scientific attention, most likely because it is highly labor intensive, destructive to upland habitat, and results in generally low species encounter rates. The opportunity to apply this method arose as a result of a 2002 California Department of Water Resources (DWR) maintenance project located in eastern Alameda County, California. Through hand excavation of all potential *A. californiense* refugia sites (e.g., burrows) within 24 study plots, the key objective of this study

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was to document and characterize subterranean adult *A. californiense* habitat use within suitable upland habitat, and, if possible, calculate upland species densities.

MATERIALS AND METHODS

This study was conducted 11 km east of Livermore in a rural portion of the Altamont Hills, Alameda County, California (37° 46’ N, 121° 39’ W). Twenty-four 30.5- by 30.5- m (0.093 ha) study plots were located roughly 0.1–0.25 km apart along a 3.8-km linear segment of the South Bay Aqueduct (SBA) pipeline in the Diablo Range portion of the Inner Coast Range. The study region is characterized by moderately steep rolling hills, fairly uniform annual grassland habitat, and minimal urban development. Habitat in the pipeline corridor had fully recovered in the 37 yr since the SBA was installed and appeared representative of regional vegetation, wildlife composition, and habitat availability. The elevation of plots ranged from 171 to 228 m and slopes varied from gentle to moderate (0–31°). Primary land uses in the study area were cattle grazing and wind power generation.

Study plots were selected from a larger pool of DWR maintenance sites based on the presence of at least 1 potential *A. californiense* breeding pond within 1.0 km. Each plot had between 4 and 8 ponds ($\bar{x}$ = 6.4) within 1.0 km. The distance between study plots and the nearest breeding pond ranged from 120 to 550 m, with a mean of 356 m $\pm$ 159 m SD (n = 24).

Field work was conducted during clear, sunny weather conditions on 29–30 January, 5 February, 12–13 February, and 4 March 2002. A team of 4 surveyors walked parallel transect surveys within each 0.093-ha plot to locate potential *A. californiense* refugia sites. Grass height was between 2.5 and 7.5 cm at all plots, allowing excellent ground visibility during surveys. All potential refugia features within plots were carefully excavated using hand tools (hand trowel and garden spade). We examined and excavated small-mammal burrows, individual rocks and rock piles, and other accessible features with an entrance diameter of ≥1.3 cm, as well as valley pocket gopher (*Thomomys bottae*) digging piles and mounds. We excavated burrows to the terminus of each branch or until the burrow diameter was <1.3 cm. Two California ground squirrel (*Spermophilus beecheyi*) burrows reached vertical depths >1.2 m and were not fully excavated. When captured, *A. californiense* were relocated to massive boulder piles outside of study plots; each was vigorous and in good physical condition upon release. All salamanders retreated out of sight within 1 min of release and were not subsequently found.

We quantified 7 environmental parameters for each plot: slope; aspect; presence or absence of large rocks or boulders; study plot position on the upper-, middle-, or lower-third of the slope; distance to the nearest potential breeding pond; number of potential breeding ponds within 1.0 km; and the number of potential *A. californiense* refugia features within each plot. Slope and aspect data were determined using a clinometer and compass, respectively.

RESULTS

Five adult *A. californiense* were captured from 4 of the 24 study plots during the excavation of 331 suitable refugia features within a total study area of 2.23 ha. This translates to 1 salamander per 66 refugia excavated. Of these, 2 were in pocket-gopher burrows in short annual grasslands, 1 came from a boulder riprap mound with extensive gopher activity, and 2 were found 25 m apart in association with pocket-gopher burrows under large (roughly 45 kg) boulders. The mean density of *A. californiense* for all plots was 2.2 ± 5.5 SD adults/ha (n = 24); however, as a measure of actual habitat use, this statistic is misleading because it includes 3 plots that lacked burrows or other *A. californiense* refugia. Excluding these areas, plots with ≥1 refugia feature had a mean upland density of 2.6 adults/ha (n = 21). Although efforts were made to fully excavate each burrow, there is a possibility that some salamanders may have been overlooked. As a result, these figures should be considered a low estimate of *A. californiense* abundance.

We found *A. californiense* in plots with average slopes <5º, while slopes in plots without salamanders were >14º (Table 1). This study characterized *A. californiense* distribution as preferential to relatively gentle slopes and areas with relatively high refugia density (Table 1). We did not detect any *A. californiense* in any of the 12 plots with <15 refugia (16 refugia/0.1 ha).

To explore *A. californiense* upland habitat use relative to burrow density, study plots were grouped into high- and low-density data sets with comparable numbers of excavated refugia. The low-density data set, with densities of 0–22 refugia/0.1 ha, included 19 plots with 166 burrows and 1 adult *A. californiense*. The high-density data set, with a density of 23–38 refugia/0.1 ha, included 15 plots with 165 burrows and 4 adult *A. californiense*. Salamanders were 4 times more abundant on high-density plots (1 adult/41 refugia) than on low density plots (1 adult/166 refugia).

DISCUSSION AND CONCLUSIONS

Salamanders were not evenly distributed within available habitat and were more frequently found in areas with high burrow density. Upland abundance and distribution of *A. californiense* were found to correlate strongly with the availability of subterranean refugia habitat, particularly valley pocket gopher burrows, confirming a common belief that small-mammal burrows are a vital upland habitat element. Within study plots and across the regional area, burrows provided the only consistent shelter from heat, desiccation, and predation. It follows that a greater total availability of suitable upland refugia sites would help reduce exposure to these hazards and increase survival.

There was an overall density of 2.2 adults/ha, which, as an estimate, is most likely characteristic of uplands within 0.1– 0.5 km of breeding ponds in the regional study area. To refine these data, species density in areas that provided a bare minimum of habitat (≥1 available refugia feature) yielded an estimate of 2.6 adults/ha. Because of the inherent difficulties in excavating burrows, it is possible that some salamanders were missed within plots. These may have been overlooked in unexcavated, deep burrows or undetected refugia, or because of burrow backfilling by *A. californiense* or other animals. Therefore, these estimates are considered lower bound densities that are expected to fluctuate seasonally and annually from changes in pond productivity, rainfall cycles, animal movement patterns, or other factors. Given these complicating factors, this density estimate cannot be universally applied across a single landscape, let alone between distant and dissimilar *A. californiense* habitats.

While approximate, this estimate of adult *A. californiense* upland density has several practical applications. For example, it can be used to focus conservation planning efforts on high-quality species habitat or to assist habitat managers in estimating development impacts on individual salamanders, especially when considered in conjunction with recent studies of

Table 1. Descriptive statistics for slope and refugia density attributes within study plots for California tiger salamanders (*A. californiense*) in Alameda County, California, USA, January–March 2002. Sample statistics are mean and SD (range).

	Study plot attributes		
Study parameter	All study plots *n* = 24	Plots without *A. californiense* *n* = 20	Plots with *A. californiense* *n* = 4
Slope	13.0 ± 8.1º (0.0–31.0º)	14.4 ± 8.1 (0.0–31.0º)	4.6 ± 4.4º (0.0–10.0º)
Refugia density (No. per 0.1 ha)	14.9 ± 12.8 (0–37.7)	11.6 ± 10.7 (0–34.4)	32.5 ± 9.3 (16.1–37.7)

A. californiense migratory ranges (Trenham et al. 2001).

There was a reduction in *A. californiense* upland habitat use with refugia densities <14 refugia/0.1 ha. Furthermore, adults were 4 times more abundant within high-density sites, identified as areas >23 refugia/0.1 ha, than within low-density sites. The wider implications of these data are that the density and availability of upland refugia sites can directly affect local adult *A. californiense* densities and can presumably affect population carrying capacity. It follows that areas with the highest refugia densities may possess considerably greater conservation value for *A. californiense* than previously recognized.

We observed abundant refugia opportunities on steep slopes; therefore, the observed absence of *A. californiense* from steeper plots is most likely a result of factors other than refugia site availability. This species' preference for relatively level plots, generally <14^{o}, was not explained by this study. It was established, however, that level ridgetop plots located within 500 m of breeding ponds were readily and frequently used for upland refugia without regard to the slope of adjacent terrain. Three of the *A. californiense* came from hilltop sites.

Breeding *A. californiense* congregate at breeding sites for only a brief time in any year (Loredo et al. 1996), and because of dry climatic conditions in winter 2001-2002, the majority of breeding was most likely in December 2001. It is therefore reasonable to postulate that *A. californiense* distribution from January to March 2002 was minimally influenced by associational breeding behavior that follows rainfall events. In contrast, if conducted during a period of sustained rainfall, burrow excavation would presumably result in a lower upland density estimate because adult salamanders are at aquatic breeding sites.

Because of the rarity and federal listing status of *A. californiense*, hand excavation should be used only with species recovery activities. This method is highly labor intensive, destructive to habitat, and potentially injurious to salamanders; therefore, it cannot be routinely used as a study technique. Drawbacks to this method include the inherent rigidity of the study design, sampling uncertainties because of environmental variations, substantial time and labor costs, and lower encounter rates of animals.

For this study, we spent 160 labor hours to identify and excavate 331 burrows within a 2.23-ha area. Using a hypothetical labor rate of \$50/hour, this work cost \$8,000 for burrow excavation activities, or roughly the price of 0.5–0.7 ha of grazing land in Alameda County (approximately \$12,000–\$17,000/ha.). The high cost of work required to recover 5 salamanders begs the question for projects such as this: are limited conservation funds more effective when used for animal salvage and relocation or for land acquisition? Indeed, such an issue must be resolved on a case-by-case basis based on both the magnitude of the planned activity and the resiliency and dynamics of the local *A. californiense* population.

Although the present study examined adult *A. californiense* distribution in remote rural land with no public access, a mean of 6.4 accessible ponds within 1.0 km of each study site, and no salamander migration barriers, our findings are also relevant to populations at risk of extirpation elsewhere, such as those in Sonoma County where habitat conditions differ. Given the importance of upland habitat to *A. californiense* and rapid urban expansion near many breeding sites, habitat managers should incorporate management of upland habitat components into their overall species management strategy. The strong correlation between species use of upland habitat and refugia availability, particularly small-mammal burrows, provides a good indicator of habitat quality. In managing *A. californiense* upland habitat, a rigorous effort should be made to identify and maintain sufficient upland resources to support salamanders and small-mammal populations.

Recent studies for radio-tagged animals are beginning to describe adult postbreeding *A. californiense* movements in upland habitats; however, conservation planners should be wary of applying such animal tracking studies to the determination of minimum urban buffers needed to ensure population survival in perpetuity. In 2 prominent tracking studies, 95% of postbreeding adult *A. californiense* upland occurrences were within 164 m (Semlitsch 1998) and 173 m (Trenham 2001) of breeding sites. Recently, the latter value was revised to 620 m (Trenham and

Shaffer 2005), which is in line with current observations of habitat use. Although this study did not sample areas within 120 m of breeding ponds, based on salamander occurrences between 120 and 510 m from breeding sites, it is apparent that the earlier distribution estimates are atypical for this species throughout its range. The identified differences in upland habitat use between this and earlier studies cannot be readily explained. Whatever the source of this disparity, it is evident that conservation buffers considered for *A. californiense* conservation planning purposes should be larger than those currently derived from the scientific literature. If the objective is to include the majority of the population, we recommend that the minimum upland conservation buffer should be 500 m from breeding pools, with particular preference given to areas with large small-mammal populations and/or high densities of small-mammal burrows.

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