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Underground ecology and natural history of the California tiger salamander

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UNDERGROUND ECOLOGY AND NATURAL HISTORY OF THE
CALIFORNIA TIGER SALAMANDER

A Thesis

Presented to

The Faculty of the Department of Environmental Studies
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by

Michael Gerrit van Hattem

May 2004

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ABSTRACT

UNDERGROUND ECOLOGY AND NATURAL HISTORY OF THE CALIFORNIA TIGER SALAMANDER

by Michael Gerrit van Hattem

Although the above ground ecology of the California tiger salamander (*Ambystoma californiense*) is well described its underground ecology is essentially unknown. This remains a significant information gap as the salamander spends more than 90% of its life span in small mammal burrows. In an attempt to fill this information gap, a large field enclosure was constructed with 42 artificial burrows to monitor salamander behavior from January–May 2002. Salamanders' monitored remained active in the burrows until at least May, and aestivating individual were not observed. However, the number of salamanders visible for monitoring dwindled to zero for unknown reasons by early summer. In addition to generating new observations of underground behavior the results are cautionary for resource managers proposing to create artificial burrows for mitigation or to benefit *Ambystoma californiense*.

Acknowledgements

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I. INTRODUCTION

Understanding a species life history is the first step in any management strategy intended to conserve or recover viable populations. Salamanders (class Amphibia, order Caudata) have a variety of life histories that allow them to exploit a wide range of habitats (Petranka, 1998). Many species have a biphasic life cycle, consisting of an aquatic larval stage and a semiaquatic or terrestrial adult stage (Stebbins and Cohen, 1995; Petranka, 1998). After metamorphosis, most pond-breeding amphibians are fossorial and rarely observed above ground (Semlitsch and Bodie, 2003). Their secretive nature and nocturnal habits make them one of the least understood groups of North American vertebrates (Petranka, 1998).

Surveys and studies of these animals are typically concentrated within stream and wetland sites where they are found seasonally, rather than in terrestrial habitats, where detection is more difficult. However, much of their life history occurs in terrestrial habitats (Loredo et al., 1996; Brown and Crespo, 2000; Semlitsch and Bodie, 2003). Although it is not surprising that the terrestrial ecology of semiaquatic species is often underappreciated or overlooked by managers and conservation planners, data on this life history stage is critical for confident management (Morey, 1996; Semlitsch and Bodie, 2003).

To circumvent the logistical challenges of studying both the aquatic and terrestrial ecology of amphibians, herpetologists have devised experimental techniques to study species in laboratory settings (Semlitsch, 1982), experimental

ponds (Wilbur, 1987), and in the terrestrial setting (Pechmann, 1995; Chazal and Niewiarowski, 1998).

The California tiger salamander (*Ambystoma californiense*) is a pond-breeding salamander that is now protected in some area (see Conservation Status, below). It has been repeatedly suggested that the *A. californiense*, once in the burrows of small mammals, aestivate (Barry and Shaffer, 1994; U. S. Fish and Wildlife Service, 2003), but this assumption has not been tested. Aestivation is defined as a state of dormancy and hypometabolism that occurs during the summer, usually as a means of surviving drought and/or intense heat (Purves et al., 1995).

The purpose of this thesis research project was to gain insight into the underground ecology of *A. californiense* in an artificial burrow complex. In particular this research sought to determine how commonly *A. californiense* aestivate and the factors that are associated with aestivation. In addition, data was gathered on how individuals distribute themselves within a burrow system, whether movements occur between burrows, how conspecifics interact in burrows, and if artificial burrows can function as suitable terrestrial habitat for this species.

Natural History

The family *Ambystomatidae* (mole salamanders) consists of two genera, *Ambystoma* and *Rhyacosiredon*. *Ambystoma* is represented by 26 extant species found through much of North America southward to south central Mexico (Petranka, 1998). Molecular and biogeographical evidence indicate that *Ambystoma* species rapidly colonized many regions of North America following postglacial retreats and other major climatic changes (Petranka, 1998). Metamorphic *Ambystomatid* salamanders generally spend their entire juvenile lives and the vast majority of their adult lives in terrestrial habitats (Petranka, 1998; Trenham et al., 2000).

Ambystoma californiense is a large stocky terrestrial salamander, with small protruding eyes, and a broadly rounded snout. The dorsal coloration of adults is black or dark brown with irregular yellow to ivory spotting concentrated mostly along the sides and intermittently or absent along the back. The ventral side or abdominal region tends to be grayish with some yellow spotting. *Ambystoma californiense* have 12 costal grooves and adults are 15–22 centimeters total length (Petranka, 1998). Males can be differentiated from females during the breeding season (October–February) by the presence of swollen cloacae, longer overall tail length, and a pronounced tail fin that extends to above the rear legs.

In California, the distribution and abundance of amphibians has been in a state of change for over 100 years (Jennings and Hayes, 1985). Although long-term historical data are lacking, scientists agree that populations of most North

American salamanders have declined markedly since European colonization (Petranka, 1998). *Ambystoma californiense* is endemic to California and geographically isolated from other North American Ambystomatids (Storer, 1925; Stebbins, 1985). Although this species still occupies its full historic range throughout the Central Valley and surrounding foothills and valleys, from Sonoma County south to Santa Barbara County, it has become increasingly rare over large portions of its range (Barry and Shaffer, 1994; Fisher and Shaffer, 1996) (Figure 1). *Ambystoma californiense* is currently found in the Central Valley and adjacent foothills and coastal grasslands (Storer, 1925), areas with a Mediterranean climate of cool, wet winters and hot, dry summers (Loredo et al., 1996). Historically, *A. californiense* reproduced mostly in vernal pools, but in recent times has colonized many ephemeral and perennial fish-free livestock ponds. Intensive human alteration of habitat over the past 150 years has resulted in the loss of more than 90% of California's historic vernal pool habitats and extensive fragmentation of that which remains (Holland, 1978).

These salamanders are highly nocturnal and aboveground movements are mainly associated with precipitation events (Loredo et al., 1996; Trenham et al., 2000), usually in November or December. Adult male salamanders arrive first to breeding ponds as early as the first measurable precipitation event (van Hattem pers. obs.) followed sequentially by adult females (Loredo and Van Vuren, 1996; Trenham et al., 2000). Breeding starts as soon as the pond begins to fill in the winter (van Hattem pers. obs.). Females attach their eggs singly or, more rarely, in groups of two to four, to twigs, grass stems, vegetation, or detritus (Storer,

1925; Twitty, 1941). Eggs hatch in 2–4 weeks and the larval period lasts 3–6 months (Petranka, 1998).

Metamorphosis, the physiologic change from aquatic larva to terrestrial salamander occurs as the natal pond dries in late spring and early summer, and is followed by nocturnal dispersal of transformed juveniles (metamorphs) into upland habitat. Loredó et al. (1996) found that recently metamorphosed *A. californiense* in their Contra Costa County study area moved 6–57 meters ($\bar{X} = 26$ meters) from the natal pond the first night. Adult salamanders in the same study moved 8–129 meters ($\bar{X} = 36$ meters) the first night after leaving the breeding pond and 83% of those individuals settled in California ground squirrel (*Spermophilus beecheyi*) burrows, slightly more than for metamorphs (54%). In a longer term assessment, Trenham (2000) found that adult *A. californiense* implanted with radio transmitters moved 16–248 meters ($n = 8$, $\bar{X} = 94$ meters $\pm$ 89 meters) after leaving the breeding pond and reinforced and expanded the conclusions of others (Loredó and Van Vuren, 1996; Barry and Shaffer, 1994) that *S. beecheyi* burrows represent critical terrestrial habitat elements for *A. californiense*.

Similar to other Ambystomatids, *A. californiense* has strong limbs, but the front feet are not clearly adapted for digging (Semlitsch, 1982). However, Jennings (1996) observed a single adult male successfully excavate a plugged pocket gopher (*Thomomys bottae*) mound, indicating that *A. californiense* are capable of digging to some extent. As with other adult Ambystomatids (Hamilton, 1946; Douglas and Monroe, 1981; Semlitsch, 1982), a strong

commensal relationship exists between *A. californiense* and small mammals (Loredo et al., 1996; Trenham, 2001), specifically *S. beecheyi* and *T. bottae*.

The importance of *S. beecheyi* burrows should not be underestimated, especially considering that *A. californiense* spend >90% of their life span underground. Small mammal burrows can be relatively simple to very complex depending on age and duration of occupancy. Although the complexity, length, and number of turns can vary between burrows, several components remain similar between burrows independent of age or slope. Berentsen and Salmon (2001) furthered the understanding of burrow structure by excavating and quantifying 15 *S. beecheyi* burrows on three different terrain types (slopes). Measurements indicated burrow diameter averaged 10.9 centimeters, consistent with Grinnell and Dixon (1918), while average depth through all 15 burrows was 43.0–45.8 centimeters, with maximum depths of 59.4–72.6 centimeters. Of the three slope categories (flat, moderately sloping, and steep), average burrow length was 5.0 meters, 6.1 meters, and 3.5 meters respectively (Berentsen and Salmon, 2001).

Berentsen and Salmon (2001) also provided evidence that *S. beecheyi* often create burrows parallel to the surface regardless of the terrain type. Burrows described by Berentsen and Salmon (2001) were shorter and shallower than those described by Grinnell and Dixon (1918), Linsdale (1946), and Fitch (1948), but provided support for previous descriptions by Grinnell and Dixon (1918) that male *S. beecheyi* burrows are short, shallow, and simple, whereas, female burrows

are more complicated with many turns. Attributes of these studies were used to design the artificial burrows in this experiment.

A short note was published on a technique for locating and observing *A. californiense* with a fiber optic scope. The technique was used in mitigation to locate and salvage salamanders within a proposed disturbance area (Semonsen, 1998). A number of juvenile *A. californiense* were located and observed during the summer months. They were generally active, located along the sides of the tunnels, and in one case within a bed of grass used by a squirrel. All observed salamanders were encountered within 2.1 meters from the burrow entrance, which was the full length of the scope. Since fiber optic scopes emit bright light it is unclear what the natural behavior of the salamanders might have been prior to their discovery.

Conservation Status

Regional and global amphibian declines have generated widespread attention and a great deal of controversy (Blaustein and Wake, 1990; Pechmann and Wilbur, 1994; Fisher and Shaffer, 1996). A number of direct and indirect anthropogenic stressors appear to have contributed to the decline of *A. californiense* throughout its historical range (U. S. Fish and Wildlife Service, 2003). The primary causes of this decline are conversion of grasslands to urban or agricultural uses (Barry and Shaffer, 1994), inappropriate water management (Barry and Shaffer, 1994), vehicle collisions during migration, exotic species

introductions (Fisher and Shaffer, 1996), and rodent control programs (Loredo et al., 1994).

Spermophilus beecheyi is considered a pest species and has been subject to persistent control programs aimed at reducing or eliminating local populations (Marsh, 1987). *Spermophilus beecheyi* is controlled on over four million hectares in California, keeping population sizes at 10–20% of estimated carrying capacity (Marsh, 1987). Eradication programs may either directly extirpate *A. californiense* with fumigant rodenticide applied to the burrows or indirectly by removing *S. beecheyi* which are critical for burrow maintenance and construction (Loredo et al., 1996). Unless maintained *S. beecheyi* burrows collapse within 18 months (Loredo et al., 1996). Reduction of burrowing mammal densities may reduce the availability of terrestrial habitat for *A. californiense*.

Ambystoma californiense is a Species of Special Concern in the State of California. Under the California Environmental Quality Act (CEQA), impacts to this species must be evaluated and mitigated. This can include the “salvage” of individuals (i.e., collection and relocation) and creation of breeding sites away from the disturbance area. *Ambystoma californiense* remained a Federal Candidate Species for listing range-wide from 1992 to 2000 when the Santa Barbara County Distinct Population Segment (DPS) was Emergency Listed as Endangered under the Federal Endangered Species Act (Act) (U. S. Fish and Wildlife Service, 2000). Shortly after that action, the U. S. Fish and Wildlife Service emergency listed the Sonoma County DPS as Endangered under the Act, as well (U. S. Fish and Wildlife Service, 2002). In 2003, the U. S. Fish and Wildlife Service proposed to

list *A. californiense* as Threatened range-wide. The intent of this action is to protect the species range-wide while using special provisions of the Act by allowing a 4(D) Rule exemption for “routine ranching activities.” For more detail see 68 FR 28648 for a summary of previous federal actions related to listing *A. californiense* (U. S. Fish and Wildlife Service, 2003).

Research on the upland ecology of this species is important for the conservation of *A. californiense* because the terrestrial life history of this species is completely unknown and constitutes the vast majority of the species life span. Information generated from this research project furthers our collective understanding of *A. californiense* underground ecology and natural history and will be useful to research biologists, land managers, and regulatory agencies concerned with the conservation and management of *A. californiense* populations. In addition, this data will help regulatory agencies design successful mitigation or at least avoid harmful practices.

Research Questions

The breeding biology and migration of *A. californiense* is fairly well understood (Loredo and Van Vuren, 1996; Loredo et al., 1996; Trenham et al., 2000; Trenham, 2001), yet this only represents a short period of the species yearly life cycle. The terrestrial phase, often referred to as the aestivation period, constitutes over 90% of the species life expectancy. However, how commonly salamanders aestivate, is not known. This project addressed the following

research questions through underground monitoring of *A. californiense* in artificial burrows from January–October 2002:

1. What behavior(s) does *A. californiense* exhibit while inhabiting artificial *S. beecheyi* burrow systems?
 - What percent of *A. californiense* observed in burrows appear to be aestivating?
 - Does the percent of individuals apparently aestivating increase from spring to summer?
 - Do the sexes differ in the percent of total observations of individuals that appear to be aestivating?
 - How do *A. californiense* distribute themselves spatially in a system of burrows?
 - How does density affect the distribution and behavior of *A. californiense* in a system of burrows?
 - How does *A. californiense* behavior differ between nocturnal and diurnal periods?
2. Does movement occur between burrows?
 - What percent of individuals moved to a different burrow system during the period of observation?
 - Does the number of burrows used differ between males and females?
 - Do *A. californiense* use burrow structures (tunnel/chamber) in proportion to their availability (area) or is one element favored?
3. What percent of time do *A. californiense* appear to be disturbed by the probe?

4. What are the biological and management implications of relocating salamanders to artificial burrows as a mitigation measure?

II. METHODS

This research focused on the terrestrial existence of *A. californiense* and testing the widely accepted assumption that this species aestivates while occupying the burrows of fossorial mammals. In order to address this fundamental information gap, a large field enclosure was built with forty-two simple to complex burrows designed to function as closely as possible to natural burrows. Salamanders were pitfall trapped at a nearby pond and released into the enclosure where they were monitored for the remainder of the year.

Study Area

This study was conducted in the Altamont Pass region of the Diablo Range, 17 miles northeast of the City of Livermore, California, on Contra Costa Water District's (CCWD) Los Vaqueros Watershed (LVW) property (Figure 2). LVW encompasses nearly 18,500 acres with a centrally located 100,000-acre foot capacity reservoir, which serves as a primary water source for the population of Contra Costa County. Approximately 40% of the total terrestrial habitat present within the LVW is accessible to the public for low impact recreational purposes (e.g., hiking, biking, and equestrian activities). Over the remainder of the

watershed access is restricted to protect sensitive biological and archeological resources, and to ensure appropriate water quality standards.

LVW is largely undeveloped and contains a mosaic of sage brush and chaparral floral communities, blue oak (*Quercus douglasii*) and valley oak (*Quercus lobata*) woodlands, annual grasslands and alkali wetlands. LVW is located on the eastern boundary of the San Francisco Bay Area, where the coastal range meets the Central Valley of California. Historically, ranching was the most common land use within the terrestrial uplands of the study area. LVW connects four existing regional parks, that when combined total approximately 50,000 acres of contiguous open space.

Approximately 30 acres of wetlands are found throughout the LVW, with creation of an additional 19 acres as part of mitigation requirements for the reservoir. At least 65 seasonal, semi-permanent, and permanent ponds exist within the upland portions of the watershed. These ponds are typical of the region, with many created to serve as water sources for cattle ranching (i.e., stock ponds). The hydroperiods of the ponds are similar, such that filling occurs early in the rainy season (October–January) and remains wet well into summer (June–July).

Study Site

LVW Habitat Management Unit G includes 13 stock ponds along the uppermost reach of Kellogg Creek. The G1 stock pond was selected at the top of

the watershed as the source population for *A. californiense*. Cattle ranching and wind energy generation (i.e., wind turbines) are the primary land uses in this section of the watershed. Physical dimensions of the pond vary depending on the season and yearly rainfall, but it is typically 29 meters long and 14 meters wide, with a maximum depth of 4 meters during peak accumulation. Similar to many of the stock ponds at LVW, G1 is partially divided by barbed wire to exclude cattle from part of the pond to benefit amphibians, specifically the California red-legged frog (*Rana aurora draytonii*). Approximately 40% of the pond is protected from cattle.

In spring 2001, preliminary surveys were conducted of the study pond and upland burrows to locate where *A. californiense* might emerge from once the rains started. Within G1, *A. californiense* larva, and all age classes of the California red-legged frog, western toad (*Bufo boreas*), and Pacific treefrog (*Pseudacris (Hyla) regilla*) were easily observed. Vegetation within the pond was minimal and consisted mostly of submerged algae. A small patch of cattails (*Typha latifolia*) was the only emergent littoral vegetation within G1 and was confined to the eastern (upstream) cattle excluded portion of the pond. G1 dried in August 2001 after most amphibians had metamorphosed.

On the night of June 25, 2001 following an unusual summer rain event, seven adult *A. californiense* (five less than 100 meters from G1 and two en route within a kilometer of G1) were observed above ground, even though precipitation was minimal and had only occurred during the day. No other observation of adult *A. californiense* aboveground activity outside of the breeding

season has been documented for this species. These adults lacked tail fins or swollen cloacae as observed during the breeding season, appeared in good health, and showed no sign of desiccation or emaciation (Figure 3). These observations are important because they suggest that at least a portion of adult *A. californiense* were not aestivating when the unseasonal summer precipitation occurred.

Nocturnal surveys were reinitiated with the start of the rainy season. *Ambystoma californiense* were often encountered above ground during precipitation events and were readily observed within burrow entrances near the pond regardless of precipitation.

Artificial Burrow Enclosure

Natural *S. beecheyi* burrows are too complex to be completely monitored with the available technology (underground optics). While an optical probe can be used to determine presence of salamanders underground, absence is much more difficult to determine if not impossible in most cases. Artificial burrows were constructed that could be completely monitored with an optical probe while incorporating as many of the natural attributes of *S. beecheyi* burrows as possible.

A mildly sloped northern exposure (3,600-meter square area) was selected downstream of G1 for the artificial burrow enclosure (37°N 79'; 121° 72') (Figure 4). The experimental burrow complex (enclosure) was constructed 175 meters

downstream from G1, well within the emigration distances described by other researchers (Loredo et al., 1996; Trenham, 2000). The lower 25% of the enclosure was within a previously fenced (cattle excluded) riparian setback consisting mostly of annual grasses and forbs. The upper 75% of the enclosure was previously open to cattle and contained a few *S. beecheyi* burrows. All natural *S. beecheyi* burrows within the enclosure were excavated using hand tools and collapsed. The burrows were indicative of peripheral escape burrows found on the edge of established colonies and were less than one meter in length and contained no amphibians. Established squirrel colonies were located within 10 meters of the uppermost portion of the enclosure. Exotic annuals and forbs dominate the enclosure and are typical of the region (Table 1).

The enclosure was rectangular in shape and measured 150 meters wide by 70 meters tall paralleling the drainage (Figure 5). The overall enclosure was subdivided into three 70 meters by 50 meters cells (i.e., east, center, and west). The entire enclosure was fenced with five-strand barbed wire to exclude cattle and prevent trampling of the experimental units.

A mechanical trencher (11.5 centimeter cut width) was used for all drift fence installation and artificial burrow excavation (Figure 6). The perimeter drift fence and cell dividers were constructed of 60-centimeter tall aluminum flashing, buried 15 to 20 centimeters in the trench (Scott, 1990; Trenham et al., 2000). Aluminum flashing, although costly, was used because of durability, duration of the study, and the importance of keeping *A. californiense* within the enclosure. Drift fencing was secured within the trench with pine stakes and attached with

wood screws before backfilling. All seams were sealed with aluminum duct tape. It was necessary to fold the lower five centimeters into a "v" shape before backfilling to prevent loosening and removal by persistent winds.

Burrow placement within each replicate cell was uniformly distributed to avoid clumping, however, burrow type and orientation was randomized. Each trench prior to placement of the pipe was cleaned of loose debris and irregularities with a pick, swept clear, and cracks were filled. The burrow tunnel was built with 10-centimeter diameter non-perforated flex drain PVC pipe (pipe that is black on the inside). The pipe was cut longitudinally with the bottom third removed, fitted with circular PVC valve boxes at pivot points (30–45 degree bends) and terminal enlargements, and placed at the bottom of the trench and back-filled. The circular PVC valve boxes used were similar in size to *S. beecheyi* natal dens described in the literature (23 centimeter diameter). This tunnel construction strategy allowed *A. californiense* to be in contact with the soil surface.

Burrow Design

Three distinct types of experimental burrow structures were constructed (Figure 7). The burrow design allowed complex configurations that would also be suitable for complete monitoring with the Sandpiper Technologies Inc. near-infrared Peep-A-Roo™ optical probe (535 West Yosemite Ave., Manteca, CA. 95337) (Figure 8). This optical probe was 4.0 meters in length and constructed of

a rubber coated steel flex tube. The optical probe works in the dark with six infrared Light Emitting Diodes (LED) that do not emit visible light, making the probe ideal for monitoring light sensitive animals with minimal disturbance. The optical probe is versatile with the exception of cornering, because more than one turn will cause the probe to bind and jam in the tunnel. All burrow tunnels extended to 60 centimeters below the surface and reached maximum depth within one meter of each entrance.

Simple Burrow Design: The first and simplest burrow type was straight, approximately 3.5 meters in length, and ended at a circular sub-surface PVC valve box. This design was similar to *S. beecheyi* burrow structure described by Fitch (1948) (Figure 9). Twenty-four simple burrows were created (eight per enclosure).

Medium Burrow Design: The second burrow type mimicked male *S. beecheyi* burrows. These had two openings and two chambers connected at 30–45 degree bends, and were approximately 5 meters long (Figure 10). Nine medium burrows were created (three per enclosure).

Complex Burrow Design: The third burrow type was representative of female *S. beecheyi* breeding burrows. Each complex burrow contained two entrances, two chambers, multiple bends, and incorporated a terminally ending separate natal tunnel and associated circular PVC chamber, and were approximately 5 meters long (Figure 11). An additional “Y” fitting with internal baffle was fabricated in the field and placed in the junction before the natal den

to allow the optical probe to negotiate the turn into the natal den. Nine complex burrow structures of this type were created (three per enclosure).

General Burrow Construction Elements: In all burrow types joints between the pipes and valve boxes were sealed with duct tape to create a “seamless” tunnel to ensure that salamanders would be visible for monitoring and to prevent soil from filling the tunnel during backfilling. Each burrow entrance was marked with a numbered stake (Figure 12). Construction of the artificial burrow enclosure began on 1 June and was completed in early October 2001.

Onset HOBO™ (Forestry Suppliers, INC. 205 West Rankin Street, Jackson Mississippi 39284-8397) relative humidity and temperature data loggers were attached to valve boxes in one randomly chosen burrow of each type. A fourth data logger was caged and anchored within the entrance tunnel of a nearby natural *S. beecheyi* burrow at approximately the same elevation, slope, and exposure. Data loggers were in place for the duration of the study. Surface weather conditions were recorded hourly at a weather station 11 kilometers from the study site.

Pitfall Trapping

In order to legally capture and translocate *A. californiense* for use in this experiment the appropriate state and federal permits were obtained. The researcher amended his Scientific Collectors Permit #002814 and obtained a Memorandum of Understanding with the California Department of Fish and

Game, then was also added as a sub-permittee to federal 10(A)(1)(a) recovery permit #815537 to allow for incidental capture of *R. a. draytonii*. Furthermore, the San Jose State University Institutional Animal Care and Use Committee reviewed the research proposal and issued animal use permit #802.

A drift fence with pitfall traps was constructed in October 2001 to capture 52 (26 females and 26 males) post-breeding adult *A. californiense* for relocation to the artificial burrows. Since population estimates were not the intent of this study, *A. californiense* were allowed to enter and leave the pond freely until breeding was observed (Figure 13). The drift fence was completed and pitfall trapping commenced shortly after *A. californiense* eggs were observed in the pond (16 December 2001). The G1 drift fence was constructed of one centimeter thickness hardboard and pine stakes. The lower edge of the hardboard was buried in a 5-centimeter deep trench with approximately 25 centimeters above ground.

Fourteen pairs of pitfall traps were evenly spaced (10 to 15 meters) around the pond with one inside and one outside of the drift fence. This allowed *A. californiense* to be trapped immigrating and emigrating from the pond. Pitfall traps were individually numbered and consisted of a 7.5-liter "painter's bucket," equipped with a non-cellulose sponge. Pitfall traps were perforated with small holes 2 centimeters from the bottom to allow for draining during heavy rains and far enough from the bottom to hold water to avoid desiccation of captured animals. Each pitfall trap had an inverted lid with offset 10 centimeter legs that allowed the contents of the bucket to be shaded when activated, or flipped-over

and closed when de-activated (Figure 14). A brick was also used with each pitfall trap to weigh down the lid to prevent blow-off and reduce tampering by mammals.

At the conclusion of fossorial monitoring (October 2002) pitfall traps were installed in the experimental enclosures to determine if any *A. californiense* would leave the artificial burrows. The same pitfall trap design was used and buckets were buried in the corners of each cell ($n = 12$, 4 per replicate cell).

Pitfall traps were checked each morning they were open from December 17, 2001 to February 20, 2002. For each captured salamander the following data were recorded: pitfall trap number, reproductive status (adult or juvenile), and sex (adults only). In addition, for animals placed into the enclosure the following data were collected: snout-vent length (SVL), total length (TL), mass (grams), and left side, right side, and dorsal photographs. The photographs were used to identify individuals after monitoring. Captured salamanders not relocated to the artificial enclosure were released on the opposite side of the drift fence into a burrow.

Enclosure Stocking and Monitoring

Twenty-six adult female *A. californiense* were collected first and translocated to the enclosure followed by 26 adult males (Table 2). Female salamanders were collected first since they stay in the pond for less time and arrive after many of the male salamanders. Only post-breeding females were

collected that appeared in good health. Post-breeding females were easily discerned, as they appeared deflated with loose skin in the torso region. Males were collected after all 26 females were relocated to the enclosure. Males were collected as they left the pond.

The three replicate cells were stocked with a different numbers (i.e., 10, 14, and 28 salamanders) of individuals, but with equal sex ratios, to investigate possible density effects. Cell densities were randomly assigned and individuals were released in roughly equal proportions as they became available. Stocking was completed in the lower density cells (center and west) first since fewer individuals were needed to reach the target density. The west enclosure was stocked with 14 individuals, or a 1:1 salamander to burrow ratio; the center enclosure was stocked with 10 individuals, or less than one individual per burrow; and the east enclosure was stocked with 28 individuals, or a 2:1 salamander to burrow ratio.

All salamanders were released at night on the surface and not into an artificial burrow. To assign release locations each cell was divided into a meter grid, and a random numbers table (inset by one meter to reduce edge-effect) was used to select release points. The following morning after release, the enclosures were surveyed and any individual found above ground was placed into the closest artificial burrow to minimize death due to desiccation or surface predation.

Underground monitoring with the optical probe began after all individuals had been translocated into their assigned cell. Monitoring was

conducted in the morning or evening on a bi-monthly basis with at least 10 days between observations. Most monitoring was conducted at night because the LCD screen was difficult to view during the day. Each burrow structure was probed and for any *A. californiense* encountered behavior was noted and recorded on 8-millimeter videotape. Videotapes were subsequently reviewed in the lab and individuals were identified using the photo record. Positive identification was made only if two or more characters (e.g., spotting pattern, tail irregularities) could be matched. Within each tunnel probed I collected data on the first individual encountered. If a second individual came into view while observing the first individual that encounter was also noted and the interaction recorded.

Once individuals were encountered with the probe, behaviors were initially quantified for 3–10 minutes, and later in the study for as long as 45 minutes. The monitoring period was lengthened because as much data as possible needed to be collected per observation because the number of salamanders encountered in the enclosures was declining (Figure 15). Upon discovery each salamander's distance into the burrow from the entrance was noted, direction the individual was facing in the burrow (i.e., out or in), posture, whether its eyes were open, if any part of its body moved, if it was breathing, and if other species were within the field of view. Invertebrate presence was noted only if the insect was within the field of view of the salamander being observed. Other vertebrates were noted including *S. beecheyi*; also changes to the burrow environment due to squirrel activity or nesting was noted.

Ambystoma californiense were observed within artificial burrows from January 21, 2002 until April 28, 2002. From May through October 2002, no salamanders were detectable within any of the burrows. Each cell took approximately 2–4 hours to monitor, with more time required initially and less later because the burrows were less frequently muddy and difficult to observe and also because the researcher became more efficient with the technique.

III. RESULTS

Natural History Observations

Pond G1 began to fill on December 1, 2001, and 13 adult *A. californiense* were observed within the shallow waters (approximately 15-centimeters deep) of the pond. Most of the individuals were active, moving about seemingly in search of other individuals, swimming rapidly and then settling. The salamanders appeared to pursue each other and several swam headfirst into the flank of other individuals. The contact typically lasted a few seconds with the salamanders swimming together, overlapping to some extent, followed by the individuals separating and moving off in opposite directions. No individuals were captured to confirm their sex, but all of the salamanders appeared to be males with pronounced tail fins.

The following morning the remains of nine male *A. californiense* (tails only and tails with back legs attached) were discovered at the pond (Figure 16). As

the pond continued to fill and became turbid, no evidence of additional salamander predation was observed. The sign (i.e., tracks and scat) of raccoon (*Procyon lotor*) and coyote (*Canis latrans*) were observed along the pond margins during subsequent visits.

On December 9, 2001 eggs were observed in G1. On December 16, 2001 the final sections of drift fence were installed, completely encircling the pond, and the pitfall traps were opened. Pitfall traps were operated continuously through February 20, 2002 with the exception of December 25, 2001 and January 29 through February 7, 2002 because of dry, cold conditions. Pitfall traps at G1 were open for a total of 57 trapping days.

During the trapping period at G1, 565 *A. californiense* were captured (Figure 17), 41 sub-adult (i.e., 2-year old) *R. a. draytonii*, six sub-adult and adult *B. boreas*, 53 *H. regilla*, three ornate shrews (*Sorex ornatus*), and one California vole (*Microtus californicus*). Because animals were not marked, many may have been captured multiple times and numbers do not reflect population size. No amphibians were harmed during pitfall trapping, but three of the mammals died. *Ambystoma californiense* entry / exit into the G1 breeding pond was typically associated with rain events (Figure 18).

Spatial Distribution Within Burrows

Using the optical probe, 53 total salamander observations were made (Table 3). Within burrows *A. californiense* were on average encountered within

1.65 meters $\pm$ 2.3 meters SD from the closest burrow entrance and were most often observed in the first or second tunnel segment (94%, $n = 50$). Two were in the "Y" junction (4%), and one was found in a natal chamber (2%) of a complex burrow. Twenty-three salamanders were observed in simple burrows, 16 were in complex burrows, and 14 were in medium burrows, suggesting that salamanders may have favored simple burrows. Considering the overall availability of burrow openings (24 simple; 18 medium; and 18 complex), salamanders appear to have settled without preference for burrow type.

Re-sighting and Movements

Of the 53 salamander observations, 20 could not be individually identified. Inability to identify animals was a function of their position within the burrow (i.e., longitudinal), debris in view, and their distance from the optical probe. Of the 33 positive identifications, 16 individuals were observed one time, seven were observed two times, and one individual was observed three times (Table 4). Females were re-sighted and identified more often than males in the west (5:2) and center (6:2) enclosures, whereas in the east cell males were re-sighted more often than females (6:3) (Figure 19).

Two confirmed movements between artificial burrows were documented, one in the high-density east cell and one in medium-density west cell (one male and one female). Of the identified observations, animals in the west cell ($< 1:1$ density cell) moved furthest from their release point, followed by the center (1:1

density cell) and the east cell (2:1 density cell). Furthermore, re-sighted females moved further from the release point than males (26.5 meters versus 20.0 meters) (Table 5). Since 20 individuals could not be conclusively identified it is probable that additional movements occurred.

Behavior

As the optical probe was inserted into each artificial burrow extreme care was taken to avoid collision with any salamanders. Two distinct elements of behavior were recorded for each observation: 1) initial movement, and 2) orientation within the burrow. Fifty-three percent ($n = 28$) of salamanders encountered were facing into the burrow, whereas, 47% ($n = 25$) were facing out. At that observation point movement was noted, defined as the focal individual physically up and walking during the observation period. Upon initial observation 64% ($n = 34$) were stationary and remained so for the duration of monitoring, 23% ($n = 12$) moved away from the entrance during monitoring, and 12% ($n = 7$) moved toward the entrance.

As a means to determine if salamanders were aestivating, posture and other details were also noted. Of the salamanders for which position could be determined, 91% ($n = 48$) of salamanders observed were not curled up and remained extended in the burrow; the remaining individuals were slightly curled or the body was not visible upon discovery. Furthermore, head movement was observed in 68% ($n = 36$) of salamander observations. The tapedum was highly

reflective to the near-infrared probe if the eyes were open. Nearly all (89%, $n = 47$) of the salamanders observed had their eyes open and blinking was observed on most occasions. The results of these observations indicate that no salamanders observed during the monitoring period exhibited behaviors consistent with aestivation.

Although *A. californiense* were most often observed singly (41 individuals), pairs (i.e., two individuals in the same field of view) were observed on six occasions (12 individuals). Paired salamanders were not typically in contact with each other, but were always in close proximity (approximately 15 centimeters). On two occasions, one individual walked past the other salamander with no noticeable interaction. On one occasion, a focal individual (male) was being observed (for approximately ten minutes) and another salamander (female) emerged from beyond view and walked over the salamander being observed and ventured about a meter before reversing direction.

Since invertebrate presence within the burrows was ubiquitous, no attempt to quantify their presence was made unless they were within the field of view during a salamander observation. Spiders (order Aranea) were most commonly observed (27% of observations) on the walls of the tunnel. Broad-necked darkling beetles (*Coelocnemis californicus*) were very common on the surface of the enclosure and were observed in the burrows during 20% of observations. The beetles were observed contacting salamanders, and when these interactions occurred, salamanders responded by sharp movements or flicking motions. Millipedes (class Diplopoda) were only observed on two

occasions within the field of view but were common overall. In general, smaller invertebrates were difficult to see with the optical probe.

On one occasion, a salamander was observed consuming what appeared to be a moth. The interaction was observed for approximately 45 minutes and was mid-consumption upon discovery. The salamander appeared to struggle with the final stages of swallowing the insect, as it took several bites followed by several sharp movements, and rubbing on the tunnel wall. The insect was ultimately consumed, and the salamander stopped and settled facing into the tunnel.

Observer Interference

Ambystoma californiense movements upon initial discovery could be interpreted as interference by the optical probe, observer, or both. When arriving at each burrow entrance, care was taken to limit movement (possible vibration) and light. Light, even indirectly shined at salamanders in natural burrows, produces an instant response and retraction into the burrow. Possible indications of disturbance (e.g., movement upon initial visual contact) only occurred in 21% (n=11) of observations, versus 79% (n=42), in which salamanders appeared unaffected. This is likely an overestimate, as salamanders could have been in transit upon discovery and not disturbed by monitoring. Furthermore, individuals in transit most often settled within one meter of the initial point of detection. On only two occasions (4%) a salamander was

contacted with the optical probe making any response most likely due to this event, both of which were during daytime observations when the LCD screen was difficult to view.

Burrow Temperature

Temperature data collected by the HOBO data loggers within each burrow type indicates that burrow ambient condition remained relatively constant per month and showed the same general trend with temperature gradually increasing through the summer then decreasing later in the monitoring period. Although temperature trends were similar when averaged, individual burrow temperatures were more dynamic and suggest that burrows became unsuitable by mid-summer for salamander occupation. The simple and complex burrow types had similar highs (25.4 ° Celsius and 24.7 ° Celsius), but the medium complexity burrow type was warmer (29.5 ° Celsius). Lows for all three-burrow types were similar ($\bar{X} = 29.5$ ° Celsius). The natural burrow appears similar to the artificial burrow when averaged by month but was actually more dynamic with peak temperatures exceeding 37.7 ° Celsius and lows approaching freezing. The natural burrow temperature is not an ideal reference measurement because this sensor was located close to the entrance (1.5 meters), and was often disturbed by the resident squirrels, regardless of how it was positioned in the tunnel.

Underground Monitoring

Monitoring was initially difficult due to flooding of some burrows and mud obscuring the optical probe. Flooding occurred in the burrows closest to the drainage or bottom of the enclosure. All burrows remained wet internally through January and February with visible condensation on the tunnel walls but dried in March and April. Burrow monitoring did not occur if it was raining because the video recorder could not get wet. By late April and May many of the burrows formed large desiccation cracks longitudinally that would cause the optical probe to get wedged in the floor of the burrow and prevented passage and complete monitoring. Cracks were backfilled along the enclosure drift fence as encountered (May–July) but salamander escape was possible since cracks were observed in excess of one meter.

Squirrel activity within the majority of the burrows (71%, $n = 30$) often changed the structure and view ability of each burrow during subsequent visits despite attempts to exclude them. *Spermophilus beecheyi* were common within the enclosure and increased in numbers during the span of burrow building through monitoring. *Ambystoma californiense* were never observed in a burrow with visible *S. beecheyi* activity (i.e., squirrel present, nesting (grass), or scat). Within nine burrows, *A. californiense* were observed in surveys prior to squirrel presence being detected, but never after. One desiccated *A. californiense* was collected on the surface of the east cell burrow complex and two individuals were observed

dead within burrow tunnels of the east cell. One of these individuals was collected from the tunnel and it was decapitated.

IV. DISCUSSION

This study represents a new strategy for studying the terrestrial phase of pond-breeding salamanders, using large field enclosures and monitoring *A. californiense* in situ. The experiment had one primary objective and a series of related ecological and management questions under the following categories: 1) do *A. californiense* aestivate and what behaviors do they exhibit, 2) how do *A. californiense* move and distribute themselves in an artificial burrow complex, and 3) what are the biological and management implications of using artificial burrows as terrestrial habitat for *A. californiense*. All objectives were addressed but only a partial data set was collected as salamander occupancy decreased over time.

Behavior and Aestivation

Behavioral responses to drying conditions include: (1) reducing exposure of moist surfaces by closing the eyes, tucking in the limbs, curling the body, crouching, and clustering with other individuals; (2) burrowing; (3) nocturnality; and (4) dormancy (Stebbins and Cohen, 1995). Using the optical probe we observed salamanders in underground burrows looking for behaviors that we

would consider indicative of aestivation (i.e., body curled, eyes closed, clustering).

During the observation period for this research we observed no individuals exhibiting behaviors consistent with aestivation. All *A. californiense* detected were alert and active while occupying artificial ground squirrel burrows. Most were stationary; but with head movement and eye shine clearly demonstrating that salamanders were alert and not aestivating. When stationary, most salamanders' bodies were flat and in contact with the ground, with roughly 75% of the body touching the soil. The head was typically elevated with slight lateral and vertical movements. Head movements were always subtle or sluggish. Eyes were easily observed, as the tapetum reflected well, even to the point where blinking was easily discerned. The tail was either slightly curled or straight in all observations. These positions overall represent a resting posture or in term of this research was quantified as stationary.

Curling posture is known to be a strong indicator of moisture conservation in salamanders (Stebbins and Cohen, 1995). If salamanders were aestivating during the monitoring period, it is likely that this posture would have been observed. None of the salamanders we observed were curled up, although in five cases limited view prevented confident determination. Based on the results of this study we conclude that at least from January to May 2002 *A. californiense* were consistently active and not predominately aestivating within artificial burrows. These observations are similar to telemetry results from Monterey County (Trenham, 2001).

Although it might be suggested that the optical probe disturbed the salamanders, our observations suggest that this was not the case. When salamanders moved away from the entrance during monitoring their movements were always deliberate. Movement was never hurried as might be expected if the salamander detected a threat and they typically became stationary again less than a meter from where first observed. Salamanders that approached the entrance upon discovery walked in a similar way to salamanders that moved away from the entrance. During monitoring, additional behavioral observations of interest were made. On one occasion, a salamander appeared to be stimulated from a stationary position by the approaching optical probe. Subsequently, the salamander appeared to stalk the probe as it was retracted from the burrow. The salamander was standing with only the tail contacting the soil, with the head elevated and angled downward as it slowly approached the optical probe. The pursuit covered about a meter until the probe was removed from the burrow.

Although it has been suggested that *A. californiense* eat very little while in burrows (Shaffer et al., 1993), both stalking behavior and the consumption of a moth were observed during this study. These are the first documented accounts of underground foraging behaviors or feeding in a field setting. Considering the limited number of overall observations, it is likely that *A. californiense* are predatory while in burrows.

In addition to my failure to observe behaviors consistent with aestivation, my observations of aboveground activity in June and feeding in the burrow further suggests that *A. californiense* aestivation may occur less often than

previously implied. However, because individuals in this research disappeared before the hottest months of the year, the potential for aestivation remains a topic worthy of further investigation.

Salamander Interactions

Defense of territory may involve posturing, and ultimately an attack. An attack may involve snapping, lunging, chasing, and sometimes biting, the latter occasionally causing some physical injury, sometimes including loss of the tail (Stebbins and Cohen, 1995). Aggressive behavior and territoriality is unknown for *A. californiense*, but has been reported for the spotted salamander (*Ambystoma maculatum*) (Ducey and Ritsema, 1988), marbled salamander (*Ambystoma opacum*), and long-toed salamander (*Ambystoma macrodactylum*) (Ducey, 1989). These interactions were noted in the laboratory and usually involved adult males avoiding conspecifics or biting of the snout or forebody.

On six occasions *A. californiense* were observed in pairs or within very close proximity (< 20 centimeters) to each other. These mostly consisted of stationary postures, where both individuals were alert, but half of the cases involved some contact between the individuals. Two of the six pairs were positively identified as male/female combinations. One interesting interaction was observed when a stationary male was being observed and from beyond the field of a view a female arrived and crawled over the male, and proceeded to near the entrance of the burrow. The male showed no reaction to the female as

she passed over him; similarly the female made no attempt to avoid the male. Semonsen (1998) also observed juvenile *A. californiense* in close proximity to each other in a squirrel nest. The conclusions of this study and others suggest that *A. californiense* are not territorial or aggressive towards conspecifics.

Distribution and Movements

Salamanders were located in all burrow types in similar percentages. Only one salamander was found in the natal chamber where they might have been expected to reside since this structure was the most distant point from the entrance in both the complex and simple burrow types, the least likely point in the burrows to be influenced by temperature, and the most likely point for aggregation. Salamanders were almost always encountered in tunnels within two meters of the entrance.

Movement between burrows was documented on two occasions but probably occurred more often since 20 individuals observed could not be identified. Furthermore, telemetry studies of *A. californiense* suggest that radio-marked individuals made one or more subsequent movements during rainy nights after initial emigration from the breeding pond (Trenham, 2001). It is likely that these movements were missed as surveying with the optical probe started after all individuals were introduced into the enclosure and was limited by rain and wet or flooded burrows. The majority of movements within each enclosure may have happened before monitoring would have detected the

activity. It is clear, however, that salamander above ground activity within the enclosure did occur, but was mostly associated with salamanders that were released the night before and either didn't find an artificial burrow entrance or wandered because of unknown site fidelity effects or response to relocation. One desiccated salamander was found on the surface of the east enclosure, which could have been the result of an unsuccessful movement attempt.

Identified salamanders in the low density west cell moved furthest from their release point, followed by the center cell, with the high density salamanders moving the shortest overall distance from the release point. Collectively, female salamanders moved further than male salamanders. Since 20 salamanders remained unknown it is unclear whether these parameters are valid.

Salamander Disappearance

The disappearance of salamanders by May, could have been the result of several factors, and may have acted synergistically. Predation, escape, and temperature all likely played an important role in the persistence of *A. californiense* in the artificial burrows.

By April air temperature in the burrows had reached 15.5 °Celsius. Temperature tolerance for *A. californiense* is unknown, but in the lab, temperatures between 15.0–20 ° Celsius appear optimal. Extended exposure to temperature above 20 ° Celsius is likely to be intolerable and possibly lethal (H. B. Shaffer pers. comm., 2003). Temperature within all three-burrow types

increased steadily from the point of salamander introduction through the summer months, reaching a lethal range by midsummer.

Desiccation cracks in the enclosure and within the burrows were problematic for monitoring and reduced the integrity of the perimeter drift fence. It is possible that salamanders sought refuge within interstitial spaces provided by the desiccation cracks within the burrow, therefore avoiding detection. It is also likely that the two individuals that were recaptured in pitfall traps at the conclusion of monitoring survived in the cracks, avoiding lethal temperatures. Trespass may have occurred as a result of the drift fence being compromised.

Although it was not determinable which species was responsible for at least one salamander mortality, or even if the injury killed the animal, but *S. beecheyi* activity was observed in nearly every artificial burrow. *Spermophilus beecheyi* are known amphibian predators (Fitch, 1948; Callahan, 1992). The simplistic nature of the artificial burrows may have led to increased opportunistic predation by *S. beecheyi*.

Spermophilus beecheyi also limited monitoring attempts throughout the duration of the study. Nearly every burrow was being used by *S. beecheyi* at some intensity, several for the entire duration of the study regardless of exclusion attempts. Artificial burrows were often blocked by grass (nests), digging, debris, or the squirrel itself. Several attempts were made to extract grass through the burrow entrance or exclude squirrels with chicken wire, but squirrels were relentless once they developed an affinity for the burrow. It is

unclear whether a portion of the study animals utilized squirrel activity or nests as cover within the burrows, avoiding detection (Semonsen, 1998).

In addition, *A. californiense* may skip breeding attempts on any given year, and may breed only once, so salamander emergence from the artificial burrows should not be concluded as mortality.

Recommendations

Future Research

The use of large field enclosures is a valid method for studying pond breeding terrestrial salamanders (Pechmann, 1995). The techniques employed in this research showed great promise, but fell short of expectations. It would be beneficial to re-create this experiment at a location where *S. beecheyi* either do not occur or have been extirpated. It is unclear how much of an effect *S. beecheyi* had on the outcome of this experiment but removing as many variables as possible from future experimental attempts to study underground ecology would certainly be advantageous. Furthermore, lengthening the burrows and simplifying the design by having only one entrance, and several turns may have reduced and stabilized temperature better than the burrow designs in this experiment. Unfortunately, contemporary optical probes would not work for this recommendation so the secrets of *A. californiense* terrestrial ecology will need to be resolved in other creative ways.

Mitigation Strategies

Artificial burrows have been used as a successful conservation strategy for other vertebrates such as birds (Trulio, 1995), and reptiles (Milne et al., 2003), but their value for slow moving temperature sensitive species such as *A. californiense* needs further investigation. The artificial burrows used in this study were purposely limited in complexity so they could be monitored with an optical probe. Nevertheless, great care and considerable effort was put forth to design and build burrows that would provide suitable terrestrial salamander habitat. The problem remains, as it did when the burrows were created, that we simply do not know what makes a particular burrow "good" for *A. californiense*. Clearly, this study has furthered our collective knowledge of the fossorial ecology of *A. californiense*, but these findings should be seen as cautionary. *Ambystoma californiense* appear to be more sensitive to environmental factors, such as temperature and humidity, than other vertebrates which artificial burrows have been successfully used for to date. Until the secrets of *A. californiense* natural history and ecology are unearthed, the success of this strategy for anything beyond studying underground ecology should be questioned.

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Table 1. Vegetation Within Enclosure: Vegetation found within the study enclosure in order of dominance.

Common Name	Scientific Name
Italian ryegrass	<i>Lolium multiflorum</i>
Stinkweed or dog fennel	<i>Phalaris cotula</i>
Black mustard	<i>Brasica nigra</i>
Unknown forb	<i>Scrophulariaceae</i>
Curly dock	<i>Rumex crispus</i>

Table 2. Release Summary, Size, and Weight: Twenty-six adult female *A. californiense* were collected first and translocated to the enclosure followed by 26 adult males. Females had a slightly longer SVL but weighed less than males.
Note: NA= Not available, data not taken for SVL or weight on particular outing.

DATE	ENCLOSURE	LOCATION	SAL ID	SEX	SVL	WEIGHT
12/17/01	CENTER	34 21	SAL1	F	NA*	NA*
12/17/01	CENTER	29 12	SAL2	F	NA	NA
12/17/01	CENTER	12 5	SAL3	F	NA	NA
12/18/01	CENTER	31 17	SAL4	F	NA	31
12/18/01	CENTER	17 10	SAL5	F	NA	30
12/18/01	EAST	25 22	SAL6	F	NA	39
12/19/01	EAST	46 9	SAL7	F	92	28.5
12/19/01	EAST	2 20	SAL8	F	89	28.5
12/19/01	WEST	11 3	SAL9	F	93	30.5
12/19/01	WEST	35 22	SAL10	F	98	31.5
12/19/01	WEST	48 22	SAL11	F	93	30
12/19/01	WEST	2 13	SAL12	F	85	29
12/23/01	EAST	28 20	SAL13	F	85	26
12/23/01	EAST	26 15	SAL15	F	90	29.5
12/23/01	EAST	13 5	SAL16	F	87	NA
12/23/01	WEST	37 18	SAL14	F	92	31
12/28/01	WEST	49 4	SAL17	F	95	30
12/28/01	WEST	28 4	SAL18	F	84	26
01/01/02	EAST	42 11	SAL19	F	93	30
01/01/02	EAST	37 20	SAL20	F	97	31
01/01/02	EAST	11 14	SAL21	F	90	28.5
01/01/02	EAST	35 1	SAL22	F	95	28
01/01/02	EAST	5 18	SAL23	F	88	24
01/01/02	EAST	16 10	SAL24	F	90	21.5
01/01/02	EAST	42 8	SAL25	F	NA	NA
1/2/02	EAST	45 13	SAL26	F	NA	NA
				Average	91mm	29.7g
				SD	4.1	3.4
1/27/02	WEST	33 14	SAL27	M	90	36
1/28/02	WEST	14 5	SAL28	M	88	36
1/28/02	WEST	31 10	SAL29	M	83	30.5
1/28/02	WEST	25 21	SAL30	M	88	32
1/28/02	WEST	5 19	SAL31	M	91	33
1/28/02	WEST	17 6	SAL32	M	84	31
1/29/02	WEST	24 16	SAL33	M	93	40
2/8/02	EAST	21 21	SAL34	M	94	38
2/8/02	EAST	12 22	SAL35	M	90	36
2/14/02	CENTER	25 5	SAL36	M	92	38
2/14/02	CENTER	48 7	SAL37	M	89	39
2/14/02	CENTER	23 4	SAL38	M	86	30
2/14/02	CENTER	47 13	SAL39	M	95	34
2/14/02	CENTER	1 16	SAL40	M	85	28

DATE	ENCLOSURE	LOCATION	SAL ID	SEX	SVL	WEIGHT
2/14/02	EAST	34 6	SAL41	M	88	30
2/14/02	EAST	4 3	SAL42	M	93	34
2/14/02	EAST	2 11	SAL43	M	86	34
2/14/02	EAST	32 5	SAL44	M	88	34
2/14/02	EAST	23 10	SAL45	M	94	31
2/14/02	EAST	49 22	SAL46	M	82	29
2/14/02	EAST	26 12	SAL47	M	82	32
2/14/02	EAST	49 15	SAL48	M	90	34
2/14/02	EAST	28 17	SAL49	M	87	30
2/14/02	EAST	6 6	SAL50	M	83	29
2/14/02	EAST	31 21	SAL51	M	80	29
2/14/02	EAST	11 18	SAL52	M	87	30
				Average	88mm	33.0g
				SD	4.1	3.4

Table 3. Behavior Data: For each salamander observed a series of behaviors were recorded including distance into the burrow that the salamander was encountered, its orientation, posture, alertness, whether invertebrates were present, and if the behavior may have been influenced by the observer. *U = Unknown

CELL	BURROW TYPE	BURROW ENTRANCE	SURVEY DATE	TIME (24 HOUR)	DISTANCE PROBED (Meters)	BURROW BLOCKED (Yes/No)	# OF <i>A. californiensis</i>	<i>A. californiensis</i> IDENTIFICATION #	DEPTH TO <i>A. californiensis</i> (Meters)	HIT WITH PROBE (Yes/No)	IN/OUT/STATIONARY MOVEMENT	FACING (In/Out)	TUNNEL/CHAMBER	CURLED UP (Yes/No)	HEAD MOVED (Yes/No)	EYES OPEN (Yes/No)	HEAD UP (Yes/No)	OBSERVER INTERFERENCE (Yes/No)	SPIDER	BEEBLE	CRICKET	OTHER INVERTEBRATE	VERTEBRATE
W C	2W	2/22/02	1900	1.5	N	1	14	1.5	N	S	I	T	N	Y	Y	Y	N	0	1	0	0	0	
W C	2W	3/1/02	2009	2.6	N	1	U*	2.6	N	S	O	T	N	Y	Y	Y	Y	0	0	0	0	0	
W S	4W	2/22/02	1900	0.9	N	1	18	0.9	N	S	I	T	N	N	Y	Y	N	4	0	0	0	0	
W S	4W	3/1/02	2027	1.2	N	1	17	0.9	N	I	I	T	N	Y	Y	Y	Y	0	0	0	0	0	
W S	4W	3/14/02	2040	1.5	N	1	12	1.4	N	I	I	T	N	Y	Y	Y	N	1	3	0	0	0	
W S	4W	4/27/02	1040	1.8	N	1	12	1.8	N	I	I	T	N	Y	Y	Y	N	0	0	0	0	0	
W M	6W	3/1/02	2041	1.2	N	1	33	1.2	N	I	I	T	N	N	U	N	Y	0	0	0	0	0	
W M	8W	2/22/02	1900	2.4	N	1	18	2.4	N	S	I	T	N	Y	Y	Y	N	3	0	0	0	0	
W M	8W	3/1/02	2104	2.6	N	1	29	2.1	N	I	I	C	N	N	Y	Y	Y	0	0	0	0	0	
W S	9W	3/1/02	2114	1.2	N	1	U	1.2	N	S	O	T	N	N	Y	Y	N	0	0	0	0	0	
W S	18W	2/22/02	1900	1.8	N	1	9	1.8	N	S	I	T	N	N	U	U	N	0	0	0	1	0	
W C	19W	3/1/02	2211	2.4	N	2	U/U	2.4	N	O/O	O/O	Y	N	YY	YY	YY	N	0	0	0	0	0	
C S	21C	2/22/02	1900	1.8	N	1	11	1.8	N	S	I	T	N	Y	Y	Y	N	0	0	0	0	0	
C S	24C	2/22/02	1900	1.8	N	1	3	0.6	N	I	I	T	N	Y	Y	Y	N	1	0	0	0	0	
C S	24C	3/1/02	1908	1.4	N	2	36/U	1.4	N	S/S	I/I	T	N	YY	YY	YY	Y	0	0	0	0	0	
C S	24C	4/7/02	2106	0.9	N	1	24	0.3	N	S	0	T	U	Y	Y	Y	N	0	0	0	0	0	
C S	30C	3/1/02	1838	0.6	N	1	40	0.6	N	I	0	T	N	Y	Y	Y	Y	0	0	0	0	0	
C M	33C	2/23/02	2046	2.4	N	1	2	2.4	N	S	0	T	N	Y	Y	Y	N	0	2	0	1	0	
C M	33C	4/7/02	2155	1.2	N	1	2	1.2	N	S	I	T	N	Y	Y	Y	N	0	0	0	0	0	
C S	38C	2/23/02	1956	1.8	N	1	4	1.5	N	S	O	T	N	Y	Y	Y	N	1	0	0	0	0	
C M	40C	1/21/02	1900	0.9	N	1	1	0.9	N	S	I	T	N	N	U	N	N	0	0	0	0	0	
C M	40C	2/23/02	1945	0.9	N	1	U	0.9	N	O	O	T	N	Y	Y	Y	N	0	0	0	0	0	
E C	41E	2/23/02	1924	0.9	N	1	16	0.9	N	S	I	T	N	Y	Y	N	N	0	1	0	0	0	
E C	41E	3/3/02	1911	2.7	N	1	16	2.4	N	I	O	T	N	Y	Y	Y	N	0	1	0	0	0	
E C	41E	4/15/02	1800	1.5	N	2	15/35	1.5	N	I/O	I/I	T	N	YY	YY	YY	Y	0	0	0	0	0	
E C	42E	2/23/02	1939	0.9	N	1	42	0.9	N	S	O	T	N	N	Y	Y	N	0	0	0	0	0	

CELL	BURROW TYPE	BURROW ENTRANCE	SURVEY DATE	TIME (24 HOUR)	DISTANCE PROBED (Meters)	BURROW BLOCKED (Yes/No)	# OF <i>A. californiensis</i>	<i>A. californiensis</i> IDENTIFICATION #	DEPTH TO <i>A. californiensis</i> (Meters)	HIT WITH PROBE (Yes/No)	IN/OUT/STATIONARY MOVEMENT	FACING (In/Out)	TUNNEL/CHAMBER	CURLED UP (Yes/No)	HEAD MOVED (Yes/No)	EYES OPEN (Yes/No)	HEAD UP (Yes/No)	OBSERVER INTERFERENCE (Yes/No)	SPIDER	BEE	CRICKET	OTHER INVERTEBRATE	VERTEBRATE
E C 42E			3/16/02	1900	1.5	N	2	42/15	1.5	N	O	O/O	T	N	YY	YY	YY	N	0	0	0	0	0
E C 42E			4/28/02	1546	2.7	N	1	34	2.7	N	S	I	T	N	Y	Y	N	N	0	0	0	0	0
E S 43E			2/23/02	1947	0.9	N	1	U	0.9	N	S	O	T	N	Y	Y	Y	N	2	0	0	0	0
E S 44E			2/23/02	1957	0.8	N	2	46/U	0.8	N	S/O	I/O	T	N	YN	YY	YY	N	0	1	0	0	0
E S 44E			3/3/02	1941	1.2	N	1	49	1.1	N	I/O	I	T	N	N	Y	Y	Y	1	0	0	0	0
E S 44E			3/16/02	1932	0.6	N	2	U/U	0.9	N	I/S	O/O	T	N	YN	YY	YY	Y	1	2	0	0	0
E S 44E			4/15/02	1800	0.9	N	1	49	0.9	N	S	I	T	N	Y	Y	Y	N	0	0	0	0	0
E S 44E			4/28/02	1607	2.1	N	1	49	2.1	N	S	I	T	N	Y	U	N	N	0	0	0	0	0
E M 47E			3/3/02	1952	2.6	N	1	U	2.6	N	S	I	T	Y	N	N	N	N	0	0	0	0	0
E M 48E			2/23/02	2014	2.3	N	1	U	2.3	N	S	O	T	N	N	N	Y	Y	0	0	0	0	0
E M 48E			3/3/02	1959	2.7	N	1	U	2.7	N	S	O	T	Y	N	N	N	N	0	0	0	0	0
E M 48E			3/16/02	2051	2.7	N	1	U	2.7	N	S	O	T	Y	N	N	N	N	0	0	0	0	0
E M 51E			2/23/02	2059	2.1	N	1	35	2.1	N	S	I	T	N	N	U	U	N	0	0	0	0	0
E M 56E			2/23/02	2136	2.6	N	1	20	2.6	N	S	I	T	N	N	U	U	N	0	0	0	0	0
E M 56E			3/3/02	2057	1.2	N	1	20	1.2	N	S	I	T	N	Y	Y	N	N	0	0	0	0	0
E S 58E			2/23/02	1921	1.7	N	1	U	1.7	N	S	O	T	N	Y	Y	Y	N	0	0	0	0	0
E S 58E			3/3/02	2113	1.7	N	1	45	1.7	N	S	O	T	Y	N	Y	Y	N	0	0	0	0	0
E C 59E			2/23/02	1935	1.1	N	1	U	1.1	N	S	O	T	N	Y	Y	Y	N	0	0	0	0	0
E C 60E			1/21/02	2100	2.4	N	1	U	2.4	N	S	I	Y	N	Y	Y	Y	N	0	0	0	0	0
E C 60E			3/3/02	2122	1.8	N	1	U	1.8	Y	S	O	T	N	Y	Y	Y	Y	0	0	0	0	1
E C 60E			3/16/02	2123	2.1	N	1	U	2.1	N	I	O	T	N	Y	Y	Y	N	1	0	0	0	0

Table 4a. Re-sight Data: The west cell was stocked with 14 (7 male and 7 female) *A. californiense*, six individuals were re-sighted and identified once and one individual was re-sighted and identified twice during the monitoring period. On five occasions salamanders were observed but not identified (UNK) including a pair of salamanders. This cell was stocked with a 1:1 salamander per available burrow density.

CELL	Burrow Type	Burrow Entrance	Date	CTS ID
WEST	COMPLEX	2W	2/22/02	SAL14
WEST	COMPLEX	2W	3/1/02	UNK
WEST	SIMPLE	4W	2/22/02	SAL18
WEST	SIMPLE	4W	3/1/02	SAL17
WEST	SIMPLE	4W	3/14/02	SAL12
WEST	SIMPLE	4W	4/27/02	SAL12
WEST	MEDIUM	6W	3/1/02	SAL 33
WEST	MEDIUM	8W	2/22/02	UNK
WEST	MEDIUM	8W	3/1/02	SAL 29
WEST	SIMPLE	9W	3/1/02	UNK
WEST	SIMPLE	18W	2/22/02	SAL 9
WEST	COMPLEX	19W	3/1/02	UNK UNK

Table 4b. Re-sight Data: The center cell was stocked with 10 (5 male and 5 female) *A. californiense*, seven individuals were re-sighted and identified once and one individual was re-sighted and identified twice during the monitoring period. On two occasions salamanders were observed but not identified (UNK) including a paired situation. This cell was stocked with less than one salamander per available burrow density.

CELL	Burrow Type	Burrow Entrance	Date	CTS ID
CENTER	SIMPLE	21C	2/22/02	SAL11
CENTER	SIMPLE	24C	2/22/02	SAL 3
CENTER	SIMPLE	24C	3/1/02	SAL 36 UNK
CENTER	SIMPLE	24C	4/7/02	SAL 24
CENTER	SIMPLE	30C	3/1/02	SAL 40
CENTER	MEDIUM	32C	2/23/02	SAL 2
CENTER	MEDIUM	33C	4/7/02	SAL 2
CENTER	SIMPLE	38C	2/23/02	SAL 4
CENTER	MEDIUM	40C	1/21/02	SAL 1
CENTER	MEDIUM	40C	2/23/02	UNK

Table 4c. Re-sight Data: The east cell was stocked with 28 (14 male and 14 female) *A. californiense*, three individuals were re-sighted and identified once and five individuals were re-sighted and identified twice and one individual was re-sighted three times during the monitoring period. Thirteen individuals were not identified. Four salamander pairs were observed. This cell was stocked with a 2:1 salamander to available burrow density.

CELL	Burrow Type	Burrow Entrance	Date	CTS ID
EAST	COMPLEX	41E	2/23/02	SAL16
EAST	COMPLEX	41E	3/3/02	SAL16
EAST	COMPLEX	41E	4/15/02	SAL 15 SAL 35
EAST	COMPLEX	42E	2/23/02	SAL 42
EAST	COMPLEX	42E	3/16/02	SAL 42 SAL 15
EAST	COMPLEX	42E	4/28/02	SAL 34
EAST	SIMPLE	43E	2/23/02	UNK
EAST	SIMPLE	44E	2/23/02	SAL 46 UNK
EAST	SIMPLE	44E	3/3/02	SAL 49
EAST	SIMPLE	44E	3/16/02	UNK UNK
EAST	SIMPLE	44E	4/15/02	SAL 49
EAST	SIMPLE	44E	4/28/02	SAL 49
EAST	MEDIUM	47E	3/3/02	UNK
EAST	MEDIUM	48E	2/23/02	UNK
EAST	MEDIUM	48E	3/3/02	UNK
EAST	MEDIUM	48E	3/16/02	UNK
EAST	MEDIUM	51E	2/23/02	SAL 35
EAST	MEDIUM	56E	2/23/02	SAL 20
EAST	MEDIUM	56E	3/3/02	SAL 20
EAST	SIMPLE	58E	2/23/02	UNK
EAST	SIMPLE	58E	3/3/02	SAL 45
EAST	COMPLEX	59E	2/23/02	UNK
EAST	COMPLEX	60E	1/21/02	UNK
EAST	COMPLEX	60E	3/3/02	UNK
EAST	COMPLEX	60E	3/16/02	UNK

Table 5. Salamander Movements: West cell (< 1:1 density cell) *A. californiense* moved furthest from their release point, followed by the center (1:1 density cell) and the east cell (2:1 density cell) salamanders. Furthermore, re-sighted females move further from the release point than males. Reported values are means $\pm$ SD.

Enclosure	n	Approximate distance moved (Meters)
West Cell	7	32.1 $\pm$ 9.9
Center Cell	7	21.4 $\pm$ 17.7
East Cell	8	18.6 $\pm$ 12.1

Sex	n	Approximate distance moved (Meters)
All Males	8	20.0 $\pm$ 16.0
All Females	13	26.5 $\pm$ 16.0

Figure 1. Species Range: The family *Ambystomatidae* is represented by 26 extant species and is found throughout much of North America. The California tiger salamander (*Ambystoma californiense*) is endemic to in California and geographically isolated from other *Ambystomatid* salamanders (Stebbins, 1985).

Figure 2. Study Area: The study area was located in the southwest portion of the Los Vaqueros Watershed, Contra Costa County California. Map provided by J. Alvarez, The Wildlife Project 2002. Scale is reported in miles.

Figure 3. Summer Salamanders: On 25 June 2001, 7 adult *A. californiense* were observed above ground in close proximity and at the G1 study site after trace precipitation during the day. Of important note is the lack of any tail fin or swollen cloacae indicative of breeding adults. All salamanders appeared in good health, were not desiccated, and appeared in transit away from burrow entrances.

Figure 4. Study Site: The study enclosure was located on a mildly sloped 3,600 square meter northern exposure between the G1 and G2 Stock ponds. The study enclosure is not to scale. Contour interval is 20 feet (Byron Hot Springs 7.5 Minute USGS Topographical Map).

Figure 5. Artificial Burrow Enclosure: Photograph of artificial enclosure with G1 just out of view. Photo is looking south on December 2001.

Figure 6. Trencher: A large, self-driven trencher (12 centimeter cut) was used for all drift fence installation and artificial burrow excavation.

Figure 7. Burrow Construction: Three distinct types of artificial burrows were constructed with tunnels extending 60 centimeters beneath the surface.

Figure 8. Peeper Video Probe: Sandpiper Technologies Inc. near-infrared Peeper Video Probe (535 West Yosemite Ave., Manteca, CA. 95337) with 4-meter optical probe, LCD monitor, and Sony 8-millimeter digital recorder modified to fit within a single Pelican case. This unit produced no visible light and was ideal for fossorial monitoring of *A. californiense*.

Figure 9. Simple Burrow: Each simple burrow was approximately 3.5 meters long with one entrance and ending with a valve box.

Figure 10. Medium Burrow: Medium burrows were approximately 5 meters long, with two 30-45 degree bends at each valve box, and two entrances.

Figure 11. Complex Burrow: Complex burrows were approximately 5 meters long, with two 30-45 degree bends at each valve box, two entrances, and a separate natal den.

Figure 12. Burrow Entrance: Each artificial burrow entrance was individually marked in all enclosures.

Figure 13. G1 Drift Fence: Photograph of the G1 pond and drift fence used to capture salamanders. Gaps in the drift fence allowed animals to enter and leave the pond freely until trapping began in December 2001, at which times these missing segments were installed.

Figure 14. Pitfall Traps: Activated paired pitfall traps with lids.

Figure 15. Observations by Month: Although the artificial burrows were probed each month from January through October 2002, the number of detectable salamanders declined to zero by May.

Figure 16. Salamander Predation: On the night of December 1, G1 began to fill and 13 salamanders were observed in the shallow waters of the pond. On the morning of December 2, the remains of nine partially consumed salamanders were recovered. All appeared to be male based on the tail fin.

Figure 17. Salamander Captures: Five hundred and sixty-five *A. californiense* were captured during 57 pitfall trap days at the G1 breeding pond. Data does not represent actual population numbers since individuals were not marked and may have been caught more than once. Note: IN= moving into the pond, OUT= moving away from the pond.

Figure 18. Capture Frequency: At the G1 breeding pond, *Ambystoma californiense* temporal pattern of entry/exit at G1 (between December 17, 2001 and February 20, 2002) was associated with rain. One hundred and forty-four individuals were captured entering the pond on a single night. Furthermore, female entry and exit was notably concentrated into a few events, whereas, male activity was sporadic. Note: IN/odd= moving into the pond, OUT/even= moving away from the pond.

Figure 19. Re-sight by Sex: Females were re-sighted and identified more often males in the west (5:2) and center (6:2) enclosures, whereas in the east cell males were re-sighted more often than females (6:3). This data does not include the number of times each individual was observed as a re-sight.