Use of A24 Self-resetting Traps for California Ground Squirrel (*Otospermophilus beecheyi*) Control

Kenneth L. Gilliland
Department of Ecology, Evolution, and Marine Biology, University of California at Santa Barbara, Santa Barbara, California

ABSTRACT: California ground squirrels have been implicated in causing damage to anthropogenic structures, critical infrastructure, sensitive wildlife species, and agricultural areas in California. Current methods employed to reduce the abundance of California ground squirrels include trapping, shooting, exclusion, fumigation, filling of burrows, natural predation, habitat modification, and use of rodenticides. Recent technological advances in rodent traps provide an opportunity to test CO_2-powered, self-resetting traps to reduce California ground squirrel abundance. Goodnature A24 automatic rat+stoat traps deployed in three 80 × 80 m trapping arrays reduced the relative abundance of California ground squirrels on average by 84.8% over a period of nine days. When trapping arrays were compared to control arrays, A24 automatic traps also significantly reduced the relative abundance of California ground squirrels. Inspection of California ground squirrel carcasses indicated that A24 automatic traps successfully controlled adult male and adult and juvenile female California ground squirrels. Although these data are preliminary, A24 self-resetting traps show promise as an effective and efficient means to reduce California ground squirrel abundance, potentially reducing the need to implement less efficient methods and methods that pose a risk to non-target wildlife in higher trophic levels, including rodenticides. Logistical issues, non-target wildlife effects, human safety concerns, and future directions of this research are also discussed.

KEY WORDS: California ground squirrel, Goodnature A24, *Otospermophilus beecheyi*, rodent damage control, rodent management, self-resetting trap

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INTRODUCTION

California ground squirrels (*Otospermophilus beecheyi*) have been implicated in causing damage to numerous structures, critical infrastructure, sensitive species, and agricultural areas in California (Ruane 2010, Ruane 2011, Ruane 2012, Van Vuren and Ordeñana 2012, Cobos-Roa et al. 2014, Ferrara 2017). California ground squirrel burrow complexes can be expansive and have been identified to undermine and significantly reduce the structural integrity of critical pieces of infrastructure including airfield tarmacs, building foundations, and waterbody levees (Cobos-Roa et al. 2014, Van Vuren and Ordeñana. 2012). Current methods employed to reduce the abundance of California ground squirrels include trapping, shooting, exclusion, fumigation, filling of burrows, natural predation, habitat modification, and use of rodenticides (Hoffer et al. 1969, Peardon 1974, Prolux et al., 2009, Salmon and Gorenzel 2010). Rodenticides are currently one of the most popular, effective, and economical control methods employed to control ground squirrel populations (Prolux et al. 2009, Salmon and Gorenzel 2010). Although there is the potential for ground squirrels to avoid and acquire tolerance to rodenticides (Barnett and Spencer 1949, Proulx and Walsh 2007, Proulx et al. 2009, Prolux et al. 2009), they are generally easy to administer, don't require extensive labor, and are economically viable (Prolux et al. 2009, Salmon and Gorenzel 2010). However, rodenticides can have unintended direct or secondary effects to non-target wildlife species, and proposed legislation may significantly restrict the use of these agents (Quinn et al. 2018). Non-target wildlife species are affected by rodenticides by directly consuming poisoned baits or consuming animals poisoned by rodenticides (McDonald et al. 1998, Stone et al. 1999, Riley et al. 2003, Stone et al. 2003, Riley et al. 2007, McMillin et al. 2008, Walker et al. 2008, Elmeros et al. 2011, Serieys et al. 2015, Serieys et al. 2018). Poisoning of humans has also been documented (Eisemann and Petersen 2002), and pets may also be at risk. Due to public concern, changing perspectives, and proposed legislation, many land management agencies in coastal California have reduced or eliminated the use of rodenticides for alternative methods including exclusion and natural predation (e.g., building perches and nest boxes for raptors). Results from these natural predation methods are generally anecdotal or qualitative in nature and may be shown to be highly ineffective. Therefore, an alternative control method that is effective, socially acceptable, economically feasible, and easy to employ is desired.

Trapping ground squirrels is usually utilized to remove them from localized areas or where other techniques are undesirable or not feasible. Trapping ground squirrels is generally considered labor-intensive (Salmon and Schmidt 1984), but it poses no poisoning threat to non-target wildlife. Recent technological advances in rodent traps provide an opportunity to test newly designed, self-resetting traps to reduce California ground squirrel abundance. A self-resetting trap may provide land management agencies an alternative method of controlling California ground squirrel abundance that is economically feasible, reduces the labor required to implement trapping programs, and prevents effects to other wildlife populations through non-target poisoning. Proulx and Feldstein (1994) considered there was a need for improved, more efficient, trapping devices; therefore, the main purpose of this study was to test the effectiveness of a self-repeating trap to reduce California ground squirrel abundance. Additional objectives of this study were to determine if the traps are biased in the size, sex, and life stage of ground squirrels that are removed and provided the opportunity to investigate the number and diversity of non-target rodent species affected by self-resetting traps.

METHODS

Study Area

Naval Base Ventura County (NBVC) Point Mugu is an 1,817-ha naval base located in the Oxnard Plain and Santa Paula Valley in Ventura County within the Southern California Coast Ecoregion (U.S. Navy 2013, Figure 1). The primary mission of NBVC Point Mugu is to support the Naval Air Warfare Center Weapons Division, which provides research, development, acquisition, testing, evaluation, and training of naval weapons systems. NBVC Point Mugu is bordered by the Transverse Mountain Range to the north, by the Santa Monica Mountains to the east and south, and by the Pacific Ocean to the south and west. Elevations at NBVC Point Mugu range from sea level to approximately 3.4 m above mean sea level. The climate is characterized by hot and sub-humid spring-months, and summer-months with the majority of annual precipitation occurring during late-fall and winter (U.S. Navy 2013). The climate at NBVC is heavily influenced by marine air.

The study plots used in this research were located on recreational fields or adjacent ruderal areas dominated by invasive grasses and native and non-native shrubs generally less than 0.25 m in height (Figure 1). The recreational fields and ruderal areas often contained ornamental trees in relatively low abundances and were intersected by paved and unpaved roads with varying amounts of vehicular traffic. The recreational fields and ruderal areas were periodically mowed throughout the study, maintaining similar heights of grasses and shrubs within all study plots. The periodic mowing of the study plots restricts the height of vegetation, providing a large viewshed suitable for California ground squirrel occupation and burrow complexes (Yensen and Sherman 2003). The recreational fields were irrigated periodically, whereas the ruderal areas were not. The substrate of the study areas was composed of soft, loamy soils with areas of harder substrates often supported by shrub and tree roots and road surfaces that provided structural support for California ground squirrel burrows (Cobos-Roa et al. 2014, Van Vuren and Ordeñana. 2012). This study was conducted between August 5, 2019 and August 27, 2019.

California Ground Squirrel "Mock" and Goodnature A24 Traps

The Goodnature A24 rat+stoat trap (A24 trap) is a self-resetting, kill trap intended for rats and stoats. A24 traps are small, easy to install and deploy, and utilize a small CO_2 canister that deploys a piston to humanely kill an investigating rat or stoat as it attempts to access the bait located above a wire trigger. After each humane kill, the A24 trap resets itself up to 24 times per CO_2 canister. The vertical or angled positioning of the traps allow dispatched rodents to fall out of the trap, leaving the A24 trap available to additional rodents. Dispatched rodents can then be consumed by avian and mammalian predators and scavengers without the risk of secondary poisoning. In the U.S., A24 traps have been successfully used to control invasive rats (*Rattus* spp.) in Hawaiian forests (Shiels et al. 2018, Shiels et al. 2019).

To investigate if California ground squirrels were

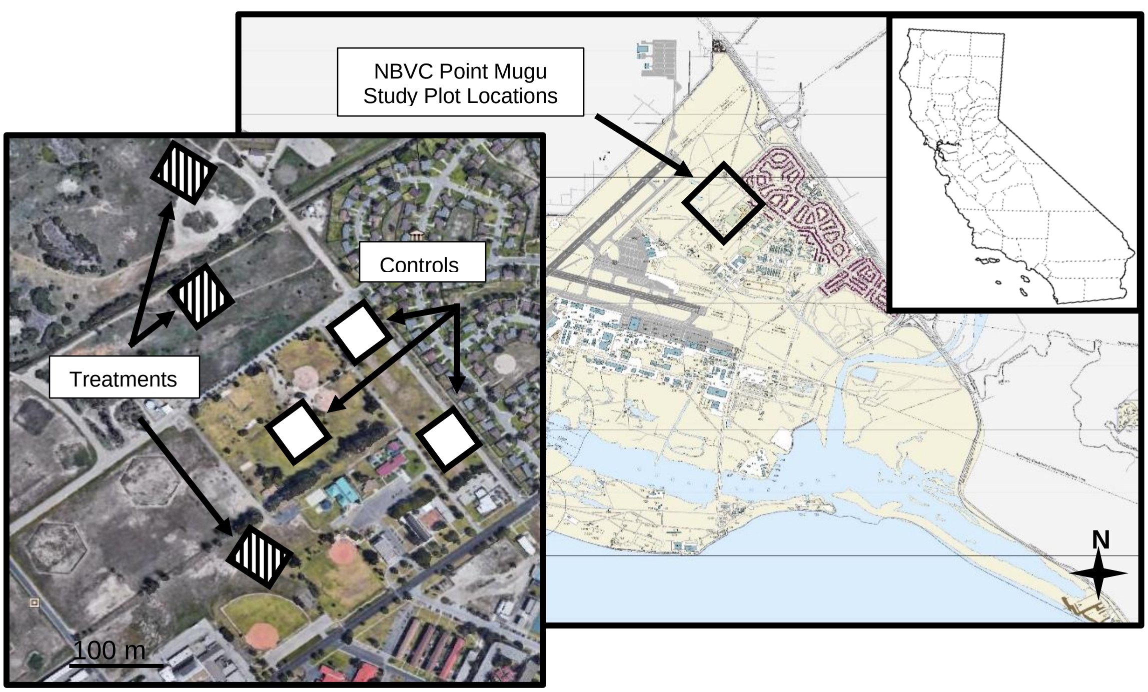

Figure 1. Location of the study area and study plot locations at Naval Base Ventura County (NBVC) Point Mugu, Ventura County, California, 2019.

attracted to the A24 traps, baited mock traps with a similar configuration to the A24 traps were deployed for seven days prior to the deployment of A24 traps. The mock traps were made of 90° angled PVC with an inside diameter of 6.35 cm to mimic the size and shape of A24 traps. Mock and A24 traps were secured to 45° angled vehicle chock blocks (20.3 cm length × 10.2 cm width × 15.2 cm height). Mock and A24 traps were deployed in and secured to irrigation boxes (53.3 cm length × 40.6 cm width × 30.5 cm height) to prevent human tampering, allow for the affixation of conspicuous hazard signs, and increase target and non-target carcass recovery. To prevent predators and scavengers displacing or knocking over the irrigation boxes, they were weighed down with various materials. Motion-activated cameras (Stealth Cam model G42NG, GSM Outdoors, Grand Prairie, TX) were deployed in selected irrigation boxes (generally one per treatment study plot) to monitor the rodent species encountering the mock and A24 traps and potential scavengers that entered the irrigation boxes. Mock and A24 traps were baited with commercially available oatmeal coated with a combination of hazelnut spread, peanut butter, and vegetable oil. Bait was replaced when needed in the mock traps (usually daily), and bait condition and A24 trap functioning was checked daily. Four A24 traps were deployed in each of the treatment study plots over nine days for a total of 108 trap-nights before their removal. The A24 traps were deployed for a total of nine days because it appeared that this duration was sufficient to observe a noticeable decrease in California ground squirrel abundances in the treatment plots. Control plots did not contain irrigation boxes or mock or A24 traps and were not provided bait of any type.

Study Plots

To facilitate California ground squirrel abundance estimates, three treatment and three control plots (study plots) were haphazardly located in areas with high abundances of California ground squirrels. Study plots consisted of 80 m × 80 m quadrats with four irrigation boxes outfitted with a single mock or A24 trap depending on the phase of the project (pre-baiting or trapping), spaced 35 m × 35 m within the center of the plots (Figure 2).

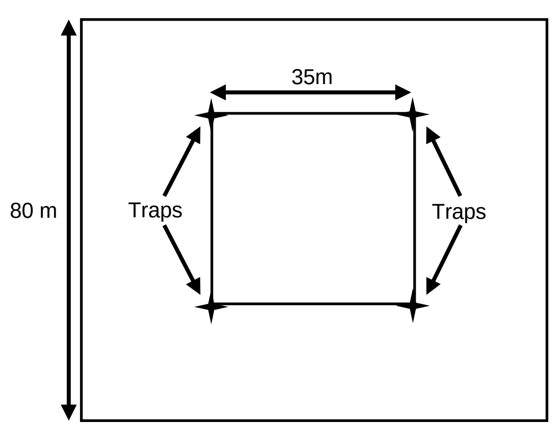

Figure 2. Diagram of California ground squirrel (*Otospermophilus beecheyi*) treatment study plots. Diamond shapes represent the position of the irrigation boxes outfitted with mock or Goodnature A24 traps.

Target and Non-target Carcass Recovery

Once the A24 traps were deployed, rodent carcasses were identified to the species level, safely placed in sealed plastic bags with forceps, and frozen to kill all endoparasites and ectoparasites. To investigate if the A24 traps were biased at removing a particular size, age class or sex of California ground squirrels, morphometric measurements (body length and weight) and life stage (sex and reproductive status) were assessed following thawing of the carcasses. Morphometric estimates and life stage determinations were not performed on non-target rodent carcasses. All partially consumed carcasses that were scavenged were disposed of a non-hazardous solid waste, and all intact carcasses are currently maintained at the University of California at Santa Barbara Vertebrate Museum Satellite Facility.

California Ground Squirrel Abundance Surveys

To determine the abundances of California ground squirrels, visual counts utilizing binoculars were used to record the number of squirrels in each study plot in three scans of three minutes, separated by an interval of five minutes between scans (Bourne et al. 2002, Johnson-Nistler et al. 2005). For each survey conducted at each study plot, the highest number of California ground squirrels counted among the three scans was retained as the minimum abundance of squirrels in each study plot (Fagerstone 1983). Surveys were conducted in the three control and three treatment plots for six days before the deployment of the A24 traps in the treatment plots ($n = 36$), and for seven days in the three control and three treatment plots after the A24 traps were removed from the treatment plots ($n = 42$). All surveys were initiated after sunrise and were completed before 1300 hours, and the study plots were randomly assigned the order that they were surveyed on each sampling day. All observers were situated a minimum of 25 m from the border of each study plot. The surveys were conducted under similar environmental conditions to avoid variation in California ground squirrel activity associated with weather.

Statistical Analyses

For each daily abundance estimate in each study plot ($n = 78$), the highest number of California ground squirrels was retained as the minimum abundance of squirrels in each study plot. Due to small sample sizes and to increase the confidence in the results of this study, a non-parametric statistical test was utilized. A Wilcoxon rank-sum test was used to compare the minimum abundances of California ground squirrels in the control and treatment study plots before trapping, and a second Wilcoxon rank-sum test was used after trapping with A24s. The measure of the success of the A24 traps was a statistically significant ($\alpha \leq 0.05$) reduction in the numbers California ground squirrels in the treatment study plots compared to control plots estimated after the deployment of the A24 traps. All data were analyzed and visualized in the program R Studio using relevant statistical packages (The R Foundation for Statistical Computing).

RESULTS

Wilcoxon rank-sum tests determined the minimum estimate of California ground squirrel abundance on control and treatment study plots before the A24s were deployed did not differ from each other (W = 36, P = 0.4; Figure 3), but abundances in the treatment study plots after A24s were deployed significantly decreased when compared to the control study plots (W = 42, P = 0.001; Figure 3). Additionally, the four A24s deployed in each of the three treatment study plots reduced the abundance of California ground squirrels on average by 84.8% over a period of nine days.

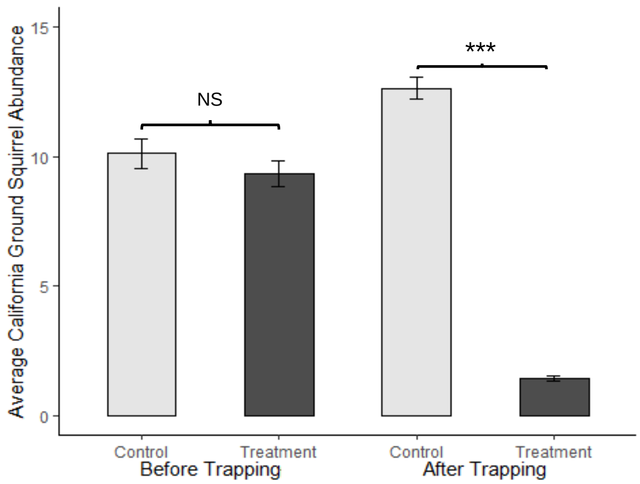

Figure 3. Average abundance of California ground squirrels (*Otospermophilus beecheyi*) in control study plots (light grey bars, n = 3) and treatment study plots (dark grey bars, n = 3) estimated during 6 survey days before trapping and seven survey days after trapping with Goodnature A24 traps at Naval Base Ventura County (NBVC) Point Mugu, Ventura County, California, August 5-27, 2019. Asterisks indicate statistically significant results (W = 42, P = 0.001), and error bars represent standard error (SE).

Eight intact and four partially consumed California ground squirrel carcasses were recovered during nine days of A24 trap deployment. Three adult female, three adult male, and two juvenile female California ground squirrel carcasses were recovered (Table 1). It appears that the A24 traps are not biased in the weight, length, sex, or life stages of adult female and male and juvenile female California ground squirrels removed in the study plots, but no juvenile male California ground squirrel carcasses were recovered. California ground squirrels were visually observed removing the carcasses of other California ground squirrels from the irrigation boxes, exposing them to potentially higher rates of scavenging than if the carcasses remained in the irrigation boxes. Additionally, Virginia opossum (*Didelphis virginiana*) were observed scavenging California ground squirrel carcasses inside (n = 1) and outside (n = 1) the irrigation boxes, and turkey vultures (*Cathartes aura*) were observed scavenging California ground squirrel carcasses outside of the irrigation boxes (n = 2). Partially consumed California ground squirrel carcasses were not included in the morphometric analyses, and the stage of consumption of the carcasses prevented sex and life stage determinations. It is likely that additional California ground squirrel carcasses were scavenged by additional mesopredators including racoon (*Procyon lotor*) and coyote (*Canis latrans*) due to the presence of tracks of both of these species in the treatment study plots, and specifically, adjacent to the irrigation boxes but the rate at which these scavenging events occurred could not be determined.

During the deployment of the A24 traps for nine days a total of 19 deer mouse (*Peromyscus maniculatus*) and three western harvest mouse (*Reithrodontomys megalotis*) carcasses were recovered from inside the irrigation boxes. It is likely that more deer mice, western harvest mice, and potentially other native and non-native rodents were removed by the A24 traps due to issues similar to those for California ground squirrel carcass recovery.

DISCUSSION

The A24 traps used in this study were clearly able to reduce the abundance of California ground squirrels in the treatment study plots compared to control study plots. On average, ground squirrel abundance was reduced by 84.8% over a period of nine days of deployment. To be an effective means of control, all ground squirrel control methods should consistently control 70% of the individuals in a population, and the A24 traps outperformed this goal (Barnes 1973, Capp 1976, Fagerstone et al. 1981, Proulx 2002). The results of the current study support that A24 traps are an effective and efficient control method for ground squirrels and may motivate further studies testing the effectiveness of these traps in habitat-specific trapping arrays in a multitude of habitats supporting this species. The potential reduction in the use of rodenticides by deploying A24 traps as an alternative control method will hopefully fulfill the goal of reducing ground squirrel abundance and reduce the realized and unrealized impacts to non-target wildlife caused by these agents (Serieys et al. 2015, Proulx and Feldstein 1994). Changing public perceptions and proposed legislation restricting the use of rodenticides provides the opportunity for A24 traps to be incorporated into integrated pest management programs

Table 1. Life stage, sex, number of carcasses recovered, mean weight, and mean body length (not including tail) of intact (whole) California ground squirrel (*Otospermophilus beecheyi*) carcasses recovered, August 12-20, 2019. Note there were no juvenile males impacted by the A24s or carcasses found.

Life Stage	Sex	Number	Mean Weight (g)	Mean Length (cm)
Adult	Female	3	450 g (range: 430-484.5 g)	24.5 cm (range: 23.0-26.0 cm)
Adult	Male	3	493.5 g (range: 461.4-530.0 g)	24.0 cm (range: 23.5-4.5 cm)
Juvenile	Female	2	65.1 g (range: 353.5-76.7 g)	22.3 cm (range: 22.0-22.3 cm)

as a new control method for California ground squirrels (Quinn et al. 2018).

Due to the short duration of A24 trap deployment, it remains unknown if these traps could reduce ground squirrel abundances to effectively-zero levels, curbing further damage caused by this species. Unfortunately, damaging rodent control is not a single effort but may be indefinite depending on the effectiveness of the method employed (Duron et al. 2017). Control and eradication campaigns for multiple harmful wildlife species indicate that as density declines the remaining individuals become more difficult to control (Gosling and Baker 1989, Veitch 2001); however, this has not been investigated in California ground squirrels.

More ground squirrels are born annually than will survive, and removal of juveniles that would perish anyway would have a negligible effect on the population over the long term (Fitch 1948, Storer 1949, Dana 1962). California ground squirrel carcass recovery indicated that A24 traps are not generally biased in the weight, length, sex, or life stages of California ground squirrels removed, but due to small sample sizes further investigation on this aspect of this study is recommended, especially regarding the lack of juvenile male squirrel carcasses recovered. In this study, the sex ratio of the California ground squirrels was not determined, but it is unlikely that there is considerable sex ratio skewness, especially in the juvenile population. Importantly, the A24 traps successfully reduced the abundance of adults, reducing the number of reproductive individuals in the population resulting in a rapid abundance reduction and potential for long-term reductions in all life stages if there is a reduction in recruitment.

A total of 21 non-target wildlife carcasses were recovered during the deployment of the A24 traps. Two species, deer mouse (n = 19) and western harvest mouse (n = 2), were the species that were recovered. It is likely that more non-target wildlife effects occurred during the deployment of the traps but estimating the number of additional non-target wildlife affected was not possible during the current study. California ground squirrels were observed removing dispatched ground squirrels from the irrigation boxes designed to prevent carcass scavenging and loss, and it remains unknown if small rodents were also scavenged or removed from the irrigation boxes by ground squirrels or other scavengers. Virginia opossum were observed scavenging California ground squirrel carcasses inside and outside of the irrigation boxes (n = 2), and turkey vultures were observed scavenging ground squirrels outside of the irrigation boxes (n = 2). Additionally, racoon and coyote tracks were commonly observed in the treatment study plots, including many instances of high abundances of tracks adjacent to the irrigation boxes outfitted with A24 traps. Due to the mechanism of dispatch that A24 traps employ there was no potential for secondary poisoning in the observed or possible scavengers. However, just as rodenticides are not target-specific, there were at least two other rodent species that were killed by the A24 traps. A24s that are only diurnally active may help reduce the trapping of some nocturnally active (non-target) small mammals.

Prior to the deployment of the A24 traps, the mock traps were pre-baited daily to assess if the California ground squirrels would enter mock traps similar in size and shape to A24 traps and determine what non-target wildlife species exploited the bait. It would be beneficial to investigate what amount of pre-baiting, if any, is necessary to attract California ground squirrels to the A24 traps. If pre-baiting is necessary to attract California ground squirrels to the traps, development of a long-lasting pre-bait would be worthwhile to substantially reduce the cost and time needed for pre-baiting. The relatively high investment cost for each A24 trap ($169.99), suggests that equipment costs may reduce their appeal as the only means of damaging rodent control over single-set traps over short time periods (30-days) (Warburton and Gormley 2015). However, during long term rodent control programs, the cost of using self-resetting traps are comparable, or are cheaper than single-set traps (Carter and Peters 2016, Carter et al. 2016), and labor costs were reduced over the use of single-set traps to control non-native rodents in Hawaii (Franklin 2013). A cost comparison between the use of A24 traps versus rodenticides for California ground squirrel control has not been performed, but such cost estimates may be important to determine what additional costs, if any, are associated with this new control technique.

In the current study, the A24 traps were deployed in irrigation boxes to prevent the scavenging of ground squirrel carcasses, and the outside of the boxes were labeled with conspicuous hazard signs to prevent human tampering. However, Virginia opossum was observed within one of the irrigation boxes and the positioning of the A24 traps at a 45° angle increases the potential that meso-predators and herbivores (e.g., lagomorphs) may investigate the traps with their snouts and/or appendages and may be injured by the traps. Additionally, this research was conducted in a relatively secured area with a low potential for human tampering, but caution should be used if these traps are deployed in areas where human tampering and potential for injury exists. Prior to the large-scale deployment of A24 traps for California ground squirrel control, it is recommended that a secure box be designed to contain the A24 traps to allow the ingress of California ground squirrels, reduce or eliminate injury to scavengers and humans, facilitate the placement of suitable hazard warnings, and allow scavengers to exploit carcasses.

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