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CALIFORNIA GROUND SQUIRRELS AT CONCORD NAVAL WEAPONS STATION: ALTERNATIVES FOR CONTROL AND THE ECOLOGICAL CONSEQUENCES

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ABSTRACT: This paper presents a methodological approach that was recently developed to determine alternatives for control of California ground squirrels (*Spermophilus beecheyi*) and the resulting ecological consequences at the Concord Naval Weapons Station (CNWS). The U.S. Navy initiated this study upon determining a need to control ground squirrels for safety reasons. The squirrel's ecological role at CNWS was examined by estimating squirrel abundance and distribution throughout CNWS, analyzing predator diets, and determining the squirrel's relationship to the California tiger salamander (*Ambystoma californiense*). In addition, the efficacy of live capture and translocation of squirrels as a possible control method was specifically examined using an experimental approach. Finally, alternative control measures are reviewed and discussed in the context of our results. The emphasis of this paper is on the methods employed and the discussion of alternatives as an example of an ecologically-based approach to control programs. As wide-scale poisoning control programs have recently come under public opposition in the courts and otherwise, studies such as these will serve to direct future management efforts toward control programs that consider several alternatives and their ecological effects.

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INTRODUCTION

The Concord Naval Weapons Station (CNWS), Contra Costa County, California is a military weapons storage facility owned and operated by the U.S. Navy (USN). CNWS is bordered by the City of Concord on the south, and the City of Martinez lies to the west. Open, rolling grasslands with scattered oaks typify the CNWS landscape, which is also broken by an extensive series of ammunition bunkers where weapons are stored. These bunkers are typically concrete structures covered with a protective layer of soil. This layer of soil on each bunker is necessary to minimize and control damage in case of an accidental explosion.

Wildlife of CNWS is typical of central California grasslands. Of particular interest at CNWS is the dense and widely distributed population of California ground squirrels (*Spermophilus beecheyi*). These squirrels burrow underground and create extensive tunnel systems. A major management problem has arisen for the USN because California ground squirrels burrow into the soil covering the ammunition bunkers. Such burrowing reduces the soil depth on top of bunkers to below the minimum specifications required for public safety.

In the past, ground squirrel populations in California have been reduced by periodic poisoning with toxicants such as zinc phosphide, compound 1080, or strychnine; anticoagulants such as Warfarin, Fumarin, Pival, diphacinone, or chlorophacinone; or burrow fumigants such as aluminum phosphide, carbon disulfide, methyl bromide, or gas cartridges (Jacobs 1983, Flint 1985, Clark 1986). Likewise, poisoning has been used to control ground squirrels at CNWS.

The principal ecological consequences of poisoning are the removal of ground squirrels from the biological community and the inadvertent, secondary effects of poisons. Ground squirrels may serve as important prey for raptors and mammalian carnivores. Further, ground squirrel burrows may provide important habitat for the California tiger salamander (*Ambystoma californiense*), a state-listed species of special concern and a candidate for the federal endangered species list. Burrow fumigants may directly kill any animal in the burrow, including tiger salamanders.

Today, as more control program are being questioned by the public or challenged in lawsuits, studies that consider the ecological consequences of control are needed. Information derived from these studies can be used to direct management efforts and increase public awareness of effective control methods.

The USN undertook this study to gather information in order to formulate a management plan aimed at reducing squirrel numbers to levels consistent with public safety, while maintaining the squirrel's role in the ecosystem. Specific objectives were:

1. Determine the distribution and abundance of ground squirrels.
2. Determine the use of ground squirrels by predators as food.
3. Determine the distribution of California tiger salamanders at CNWS and their use of ground squirrel burrows.
4. Explore live-trapping and translocation as a possible control method.
5. Review other alternative methods of control.

METHODS

Data were collected from February 1992 through March 1993. The study site, CNWS, is typified by valley and foothill grassland with scattered oaks. It is crossed by several streams with associated riparian corridors, and has several small ponds, both permanent and ephemeral.

Distribution and abundance of squirrels

Ground squirrel distribution and abundance were determined using a stratified approach. A map of the base was divided into grid squares that were 200 m on each side. The area covered by each grid square was searched for ground squirrel burrows and classified into one of three categories, based on the number of burrows found in each grid square: low (0 to 49 burrows), moderate (50 to 99 burrows), and high (100 or more burrows). Results were coded and mapped, then the number of grid squares assigned to each category was counted. The number of grid squares assigned to each category was multiplied by 4 ha, the area per square, to calculate the total area classified according to each level of burrow density.

Six study sites, 0.4 to 1.7 ha in area, were selected for estimating ground squirrel densities. Five were located in areas of high burrow density because such areas presumably supported the most ground squirrels, thus they held the greatest potential for damage by squirrels. One was located in an area of moderate burrow density. None were located in areas of low burrow density, because insufficient numbers of squirrels could be trapped and marked.

Densities were estimated with a mark/observation method adapted from the Lincoln-Peterson mark/recapture procedure widely used in ecological studies of small mammals. At each study site, ground squirrels were live-trapped for six to twelve days until four to twelve different squirrels had been trapped, marked for visual identification with indelible black fur dye, then released at the point of capture. For three to five days thereafter, an observer scanned the study site with binoculars every 10 minutes during a total of 9 to 16 hours of observation and recorded the numbers of dye-marked and unmarked squirrels visible on the study site. The observer was stationed so that squirrels under observation were not disturbed.

The ratio of marked squirrels observed to total squirrels observed was calculated for each 10-minute period, then a weighted average of these ratios was calculated for each study site. The total number of squirrels on each study site was calculated with the following formula:

$$\frac{\text{No. of squirrels marked}}{\text{Total squirrels on site}} = \frac{\text{Marked squirrels observed}}{\text{Total squirrels observed}}$$

Because the number of squirrels marked and the ratio of the number of marked squirrels observed to the total number of squirrels observed are known quantities, the equation can be solved to estimate the total number of squirrels on the study site. Total number of squirrels was then divided by area of the study site to determine density. Densities were estimated in March and April 1992 and December 1992 through February 1993, when juveniles were not present; thus, estimates represent densities of adult and subadult squirrels.

Predator diets

Predator diets were estimated by analyzing the contents of mammal scats and raptor pellets collected throughout the course of the study. Several transects were set up along dirt and paved roads throughout CNWS to collect coyote, *Canis latrans*, and grey fox, *Urocyon cinereoargenteus*, scats. Transects were systematically walked approximately once per week and all scats were collected. Scats were classified into either coyote or fox on the basis of diameter (Danner 1982), and those not classified unambiguously were omitted from analysis. Red-tailed hawks, *Buteo jamaicensis*, were the most common raptor at CNWS (Morrison et al. 1993). Nest sites and perch trees of this species were checked approximately every 10 days for the presence of pellets. All intact pellets found were collected. Prey remains in scats and pellets were identified by comparison with a reference collection, and the percent frequency of occurrence of California ground squirrel remains, among scats or pellets, was determined.

California tiger salamanders

Tiger salamander breeding ponds were located by surveying all streams and ponds at CNWS for salamander larvae from March through June. Sites were visited from one to five times and were sampled extensively by either seine-netting, dip-netting, or both for at least 30 minutes. To determine habitat use, salamanders were captured at a breeding pond using pit-fall traps placed along the inside and outside of a drift fence erected around the pond. Adults were captured during the winter breeding season, while juveniles were captured during their summer metamorphosis and subsequent dispersal from the pond. Individual salamanders, both adult and juvenile, were visually tracked upon their immediate departure from a breeding pond until settlement; the settlement site was described.

Live trapping and translocation

We examined the efficacy of live trapping and translocation of squirrels as a possible control method, by examining several factors: trapping success, homing behavior, and post-translocation survivorship. Trapping success was calculated as the number of adult squirrels caught per trap-day. Homing behavior was studied by translocating radiocollared squirrels various distances from their capture site, and then determining their fates.

RESULTS

Distribution and abundance of squirrels

Burrow densities of ground squirrels were highly variable throughout CNWS. Variation in burrow density was nonrandom; areas of high densities were closely associated with human-made structures such as bunkers, roads, and railroad tracks.

Densities of ground squirrels, based on marking and observation, averaged 32.0 squirrels/ha ($n = 5$, $SD = 16.23$, range = 8.6-52.1, 95% CL = 11.81-48.19) in areas of high burrow density. A total of 660 ha was classified as containing high densities of burrows.

Therefore, we estimate that about 21,000 squirrels live in the 660 ha of high-density squirrel habitat.

We estimated a density of 11.1 squirrels/ha in an area of moderate burrow density. A total of 532 ha were classified as containing moderate burrow densities. Assuming that the one estimate of ground squirrel density is representative, areas of moderate burrow densities supported about 6,000 squirrels.

Predator diets

A total of 109 coyote scats and 26 fox scats was analyzed. California ground squirrels were the most frequent item in coyote scats, occurring in 55% of scats. California voles (*Microtus californicus*) were the most common item in grey fox scats (46% occurrence), followed by California ground squirrels (38% occurrence). California ground squirrel remains were present in 43% of red-tailed hawk pellets.

California tiger salamanders

Five breeding sites for California tiger salamanders were found at CNWS. Tiger salamanders were not found in any pond that contained fish, even such small fish as mosquito fish, *Gambusia affinis*. Breeding sites tended to be ephemeral pools or small ponds with little or no standing vegetation. Upon their first night leaving the breeding pond, approximately one half of the juveniles and more than three quarters of the adult salamanders entered into ground squirrel burrows.

Live trapping and translocation

Trap success was extremely low. It varied monthly but never exceeded 0.08 squirrels per trap day. The relationship between translocation distance and homing ability showed a general pattern of a decrease in percentage of squirrels successfully homing as distance increased. From 1500 meters and beyond no squirrels returned home. Squirrels that did not return home had relatively high survivorship; at least two thirds survived.

DISCUSSION

Distribution and abundance of squirrels

From visual comparison of areas of high squirrel burrow density with the distribution of structures at CNWS, it is obvious that there is a concentration of California ground squirrels and their burrows around structures. This is not surprising as this species often prefers disturbed areas with low, weedy vegetation, exposed soil, and elevated structures to sit on (Fetch 1948, Evans and Holdenried 1943, Owings et al. 1977). Bunkers, road embankments, and railroad grades all have some exposed soil and often low weedy vegetation.

Concord Naval Weapons Station supports perhaps 30,000 ground squirrels, assuming that areas of low burrow density, where squirrel density was not estimated, support a few thousand squirrels.

Thus, the construction of ammunition bunkers, along with requisite roads and railroads for access, apparently has created high-quality habitat for California ground squirrels. Ground squirrels have responded by reaching relatively high densities on and near bunkers. A control program aimed at density reduction would require removal or destruction of thousands of squirrels from the high density habitat. Such control actions would have to be periodically repeated to keep the squirrel population from increasing unless the habitat was modified to be less attractive to squirrels. A cattle grazing program, used by the USN for fire control, may improve habitat quality in the ammunition bunker areas. The USN safety requirements for ammunition bunkers, which include firebreaks around each bunker and restrict vegetation height on each bunker to 20 cm or less (Doug Pomeroy, personal communication), also encourage use by squirrels.

Predator diets

Ground squirrels are an important prey for coyotes, foxes, and red-tailed hawks. Any control program should consider the primary effect of reduced food availability for these species, as well as possible secondary effects (e.g., nontarget poisoning). We would expect the coyotes, foxes, and raptors to shift to alternate prey if squirrel numbers were severely reduced, but the most common anticipated alternate prey, voles and mice, usually weigh less than 50 grams as compared to 600 to 1000 grams for a California ground squirrel. Therefore, a program that substantially reduces ground squirrel numbers would result in a substantial reduction in the availability of prey for these predators.

California tiger salamanders

Squirrel burrows provide primary habitat for adult California tiger salamanders. Ground squirrel control may reduce the density of burrows around salamander breeding ponds, thereby reducing habitat for tiger salamanders. A control program should incorporate buffer zones around salamander breeding ponds and should also be mindful of the seasonal periods of increased above-ground activity for salamanders, namely the winter breeding season and summer metamorphosis period.

Alternatives for control

Live trapping and translocation. Ground squirrels might be trapped and relocated, but such an effort would be labor-intensive. We had difficulty trapping California ground squirrels; trap success might by improved by intensive pre-baiting, but labor costs would increase accordingly.

Trapping California ground squirrels is constrained by the fact that they are in hibernation and aestivation much of the year; further, their diets during the active season change from green herbaceous vegetation in late winter and spring to seeds during summer, so bait must be changed accordingly (Flint 1985). Squirrels must be translocated at least 1500 m from the site of capture, because squirrels can find their way home from lesser distances. Much of CNWS contains ammunition bunkers where ground squirrels are undesirable, thus locating suitable sites for release of translocated squirrels may be difficult. Translocating ground squirrels off of the CNWS is currently prohibited by California state law.

Local depopulation of squirrels through relocation will have local ecological consequences. For example, habitat suitability for California tiger salamanders will be reduced, and prey availability for predators with small home ranges will be reduced. Large-scale consequences, however, will be less severe because survival of relocated squirrels is relatively high. Thus, for predators with large home ranges, such as raptors and coyotes, relocation of squirrels may involve moving potential prey from one part of the predator's home range to another.

Poisoning. Several concerns about poisoning exist; some are of lesser consequence than others. Poisoning may leave carcasses available for scavenging by carnivores, thus exposing them to the risk of secondary poisoning (Sullivan 1988). Secondary poisoning can occur, but risk varies according to toxicant; for example, risks may be substantial for toxicants such as compound 1080 and strychnine (Schitoskey 1975, Hegdal et al. 1986, Marsh et al. 1987) but appear to be low for zinc phosphide and chlorophacinone (Bell and Dimmick 1975, Schitoskey 1975, Hill and Carpenter 1982, Matschke et al. 1992). Fumigant poisons should be avoided because they would likely kill all organisms in the burrows, including tiger salamanders, and some are phytotoxic and may kill adjacent plants (Flint 1985).

Any program to depopulate ground squirrels on and near bunkers will be complicated by the tendency of squirrels in adjacent areas to recolonize recently vacated habitat (Stroud 1982). Bunkers provide high quality habitat for ground squirrels; although ground squirrels are particularly abundant at CNWS around bunkers, squirrels live in other areas of the Station as well. Thus, a program of lethal depopulation around bunkers should incorporate buffer zones to slow the rate of recolonization from surrounding areas (Kalinowski and deCalesta 1981, Stroud 1982).

Habitat Manipulation. Habitat preference by California ground squirrels is not well known, but they seem to prefer disturbed areas with relatively short herbaceous vegetation near physical structures such as stumps, rocks, or fence posts. Habitat manipulation to control California ground squirrels is not straightforward; experimental planting of tall vegetation did not reduce habitat suitability (Fitzgerald and Marsh 1986). Nonetheless, several aspects of habitat configuration and structure might be manipulated to reduce habitat suitability, thus ground squirrel densities.

Squirrels might be excluded from bunkers using wire mesh fencing, with the lower edge buried in the ground. California ground squirrels, however, are excellent at both burrowing and climbing, and eventually such enclosures would be breached. Heavy-gauge wire mesh laid on the ground surface, however, might reduce burrowing by squirrels.

Ground squirrels depend on burrows for shelter and do not dig new burrows quickly. Thus, destruction of burrows following a density-reduction program might slow reinvasion by squirrels from adjacent areas. A recent experiment showed that destroying ground squirrel burrows with a ripping blade set to a depth of 45 cm slowed recolonization significantly (Gilson and Salmon 1990). Blade depth, however, is important; an earlier study showed that ripping burrows to a depth of 30 cm had no effect on recolonization rate (Salmon et al. 1987).

Habitat suitability might be reduced by planting dense, low-growing vegetation, such as shrubs, on and near bunkers. Ground squirrels will dig burrows in shrubs, but usually only if open, disturbed areas are nearby.

Predator Supplementation. The ability of predators to control numbers of vertebrate prey is poorly understood. Many prey populations can reproduce faster than predators can eat them. In general, predators have a substantial role in controlling prey numbers only under special circumstances, such as when other factors drastically reduce prey numbers and alternate prey are scarce (Newsome 1990, Pech et al. 1992).

Increasing predator numbers is problematic because most vertebrate predators are territorial, at least to some extent, and all territories may already be filled. Existing populations of predators, however, such as rattlesnakes (*Crotalus viridis*), coyotes, and gray foxes, may be promoted by affording them protection from persecution.

The threat of predation can alter local distribution of prey; house mice (*Mus domesticus*) shifted to dense vegetation when mammalian predators were present (Dickman 1992). Raptor presence can be improved through the installation of artificial perches (Askham 1990). Thus, ground squirrel use of bunkers might be decreased by the installation of perches to promote raptor activity there, but many perch sites already exist.

Spay and Neuter. Surgical sterilization of ground squirrels is a possible means of reducing the rate of reproduction of squirrels living on bunkers, but the approach poses several problems. Ground squirrels may be difficult to live-trap. Further, sterilization will reduce or even prevent reproduction, but sterilized adults will remain residents on bunkers, with concomitant damage due to burrowing, until they die and are replaced through immigration. Prevention of reproduction will remove young-of-the-year as an age class; ground squirrel densities will be reduced somewhat, but there will be significant ecological consequences. Young-of-the-year are often important prey of predators; rattlesnakes in particular probably feed on this age class.

No Action. California ground squirrels are native to California. As a medium-sized prey species that can be eaten by an array of carnivores, and as a creator of burrow systems, they play an especially important ecological role in biological communities. Burrowing by ground squirrels redistributes soil on bunkers, thereby threatening public safety, but the ecological and other costs of substantially reducing ground squirrel densities may exceed the costs of periodically replacing soil that has been redistributed by ground squirrels. These ecological roles of the ground squirrels should be carefully considered in evaluating any proposal to reduce the squirrel population at CNWS.

Integrated Management. A combination of methods might prove effective in controlling ground squirrel damage to bunkers. Squirrels might first be removed from bunkers, either through careful poisoning, lethal trapping, or trapping and removal, with care taken to establish a buffer zone to reduce rate of recolonization. Then, suitability of bunkers as ground squirrel habitat might be reduced by either of two approaches. Each bunker might be covered with heavy-gauge wire mesh laid flush to the ground. Or, the bunker might be revegetated with dense, low-growing shrubs that reduce habitat suitability for squirrels. Such revegetation probably would require fencing to exclude cattle and may require some irrigation. For either approach, suitability for ground squirrels might be further reduced by establishing perches for raptors.

CONCLUSION

Ground squirrels are clearly a public safety problem at CNWS. Previous control efforts utilizing large-scale poisoning have been problematic. This study served to examine the ecological role of the ground squirrel and the effects of various control methods. Information gathered will be used to assist the USN to develop an integrated approach to ground squirrel control.

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