THE STRUCTURE OF CALIFORNIA GROUND SQUIRREL BURROWS: CONTROL IMPLICATIONS

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ABSTRACT: The California ground squirrel (*Spermophilus beecheyi*) is responsible for severe crop damage, and burrows can weaken levees and present hazards for livestock and humans. While control efforts using rodenticides have been effective in reducing the number of animals on a given site, repopulation into the old burrow systems commonly occurs. Destroying burrow systems could inhibit reinvasion of a site, although destruction methods attempted have not met with success. A better understanding of burrow structure should lead to better management strategies. We excavated 15 burrows on 3 different terrain types (slopes) and determined that California ground squirrels burrow at relatively the same depth regardless of slope. However, as slope increases, squirrels tend to burrow in a more horizontal direction which likely is a more efficient excavation method. Burrow structure was similar among terrain types, indicating that control strategies would not need to vary among sites.

Key words: California ground squirrel (*Spermophilus beecheyi*), burrow structure, sloping terrain, levee bank.

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The California ground squirrel (*Spermophilus beecheyi*) is considered a serious agricultural pest (Marsh 1987; Gilson and Salmon 1990; Marsh 1994, 1998). The species is responsible for financial losses due to crop destruction (Marsh 1994). Their burrows weaken levees and dams (Grinnell and Dixon 1918, Storer 1938, Marsh 1985), contribute to erosion and gully formation (Longhurst 1957, Marsh 1985), and present physical hazards to livestock (Marsh 1998). Various population control methods are used including shooting, trapping, fumigating and distributing toxic bait (Dana 1962, Clark 1978, Salmon and Schmidt 1984). The implementation of burrow destruction as part of control efforts also has been discussed (Storer 1945, Salmon et al. 1987) but the efficacy of this strategy is not known. Furthermore, it has been proposed that the use of toxic bait followed by burrow destruction may reduce initial ground squirrel populations and slow the rate of reinvasion of the site (Salmon et al. 1987).

The structure of California ground squirrel burrows has been described (Grinnell and Dixon 1918, Linsdale 1946, Fitch 1948), but the relationship between structure and terrain type (i.e., slope) is unknown. Grinnell and Dixon (1918) reported average maximum depths of 96.8 cm (range of 45.7 - 167.6 cm) and an average length of 10.7 m (range 1.5 - 42.1 m). Grinnell and Dixon (1918) also stated that ground squirrels prefer to burrow into hillsides in order to dig in a horizontal direction, which presumably requires less energy than digging straight down, but no data were presented.

Research has shown that many animals living above ground select their direction of travel on sloping terrain in a manner that helps to minimize energy expenditure (Reichman and Aitchison 1981). In addition, Vleck (1981) showed that pocket gophers (*Thomomys bottae*) minimize energy expenditure when creating feeding tunnels by removing excavation debris through lateral tunnels to the soil surface, rather than transporting debris to the entrance of the feeding tunnel. Furthermore, Sealboom et al. (2000) showed that pocket gophers create these lateral tunnels downhill to facilitate dirt removal from the burrow, but overall burrow structure remains parallel to the surface. No research on California ground squirrel burrow structure has been reported that assesses the relationship between burrowing and slope.

STUDY AREA

We selected 3 sites for burrow excavation to study burrow structure and how it is affected by slope. The 3 sites were located at the University of California, Davis, and represented flat, moderately sloped, and steeply sloped (levee bank) terrains. Burrow excavation took place between August and October 2000.

The flat terrain site was in the Experimental Ecosystem; 40 ha of level ground largely free of rocks, trees, and fences. Vegetation consisted primarily of annual grasses. Soil types were Capay silty clay and Yolo loam (Huntington et al. 1981). The moderately sloping ground (18% grade) was in the former bed of Putah Creek. Vegetation consisted of annual grasses and oaks (*Quercus* spp.) with

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large patches of bare ground. The soil type was Reiff loam (Huntington et al. 1981). This area is routinely grazed but was free from livestock at the time of this study. The third site was on the landward bank of a 1200-m^2 concrete-lined reservoir located in an agricultural research field west of the UC Davis campus. We classified the site as steep terrain (53% grade on the landward side) and typical of a small levee bank. This "levee bank" was 1.8 m high with a crown width of 3.1 m. It consisted of disturbed soil of an unknown type, but was probably Yolo loam, which was the surrounding soil type (Huntington et al. 1981). A variety of grasses and forbs were present along the crown and landward side, as well as a few small willows (*Salix* spp.).

METHODS

A total of 15 ground squirrel burrows were excavated, 5 in each slope category. This was accomplished using a 15-cm trenching shovel and hand trowels. A garden hose was inserted into the burrow opening until resistance was met in order to determine tunnel direction and indicate the burrow floor in the event of a cave-in during excavation. A grid system of plastic ribbon was used to map the burrows (Reynolds and Wakkinen 1987). Wood stakes, 30.5 - 91.4 cm long, were driven into the ground at 4 corners surrounding the excavated burrow to create a square or rectangle. Colored flags marked burrow entrances. Stakes were placed at 30.5-cm intervals along the 4 sides between corner stakes. Ribbon was tied between the stakes at a consistent height above the soil surface creating a grid with 30.5 X 30.5-cm cells. A weighted string was lowered from the ribbon to the burrow floor and the distance measure. The depth of the burrow at each 30.5 X 30.5 cm cell was calculated by subtracting the ribbon height from the total distance. Burrow diameter in each cell was not measured, but spot measurements indicated the diameters were similar to the 10.9 cm reported by Grinnell and Dixon (1918). Coverage area was determined by calculating the area of the square or rectangle required to map the entire burrow.

Burrows were selected for excavation based on their general location, proximity to one another and freedom from obstructions such as rocks or logs. In general, burrows at each site were located near each other. The Experimental Ecosystem was the site of a concurrent radio telemetry study on ground squirrel home ranges. The area had been treated with toxic bait and burrows were selected when radio signals indicated the presence of a squirrel carcass. The burrow opening closest to the signal was chosen and the entire system excavated. This did not always result in carcass recovery as occasionally the burrow we excavated proceeded in the opposite direction from the signal. On the moderately sloping site, 5 active burrows in an unobstructed area were selected for excavation. The levee bank was surveyed to determine where the most burrows were located and the first 5 active burrows in this area were excavated. All burrows were backfilled upon completion of the project.

One-way analysis of variance was used to determine whether mean burrow length, mean burrow depth, mean number of entrances, mean deepest point, mean burrow area, and mean depth below horizontal differed among terrain types. Graphs were generated using IBM Data Explorer software.

RESULTS

The 15 ground squirrel burrows excavated were similar despite the differences in slope of the burrowing site.

Table 1. Average length, depth, coverage area, deepest point and number of entrances for California ground squirrel burrows excavated in Davis, California.

	Mean (SE) Values			
Parameters	Flat Ground	Sloping Ground	Levee Bank	*P*-Value
n	5	5	5	
Length (m)	5.0 (0.9)	6.1 (2.2)	3.5 (1.6)	0.57
Range	2.1 - 6.7	1.2 - 13.4	0.9 - 9.5	
Depth (cm)	42.7 (3.7)	45.8 (4.7)	41.6 (5.4)	0.86
Range	35.7 - 55.5	32.7 - 59.0	29.2 - 54.2	
Deepest (cm)	59.4 (6.6)	72.6 (9.3)	65.5 (12.3)	0.44
Range	45.7 - 83.8	63.5 - 109.2	22.9 - 91.4	
# Entrances	1.4 (0.2)	2.0 (0.8)	2.6 (0.8)	0.46
Range	1.0 - 2.0	1.0 - 5.0	1.0 - 5.0	
Area (m2)	4.8 (1.1)	7.9 (3.4)	2.9 (1.3)	0.30
Range	2.0 - 7.9	0.6 - 18.4	0.6 - 7.5	

While the average burrow length, depth, number of entrances, deepest point and area varied between the sites, the differences were not statistically significant (Table 1).

On flat ground, average burrow length was 5.0 m, and average depth was 43.0 cm. The shortest burrow (2.1m) reached the greatest depth (83.8 cm), while the more extensive burrows tended to be shallower.

On moderately sloping ground, the longest burrows (13.7 and 9.8 m) were dug mainly parallel to the soil surface. The two shortest burrows (2.7 and 1.2 m) were constructed at a steep, downward angle with respect to the surface. One of these burrows had a tunnel that followed a tree root. The burrow of middle length (3.7 m) had two branches: one proceeded uphill, parallel to the surface, while the other followed a downward angle, along the slope of the hill.

The levee bank burrows were located in the upper half of the levee bank. The most extensive burrow was found closest to the levee crown with 4 of its 5 entrances located approximately 55 cm downslope. From these entrances the burrow went in horizontally. This was also the case for another burrow, where the two entrances were approximately 175 cm down the side of the bank. This burrow proceeded straight in, parallel with the levee crown. The two shortest burrows were each less than 1.0 m long and were dug in a downward direction relative to the soil surface.

To address the question of whether ground squirrels burrow into hillsides in a more horizontal direction, we extended an arbitrary horizontal line from the burrow opening and calculated the average depth below the line (Figure. 1). For burrows on flat terrain, the soil surface was the horizontal line. We then calculated the average depth below the horizontal for all terrain types. In the case of burrows with several openings, the opening farthest downslope was selected in order to avoid influence by other up slope entrances. Average depth (SE) below the horizontal was 43.0 (4.0) cm for flat ground sites, 33.4 (5.7) cm for sloping sites, and 22.6 (6.9) cm for levee bank sites. As slope increased, the average depth below the horizontal decreased, indicating a greater tendency for horizontal burrowing ($p = 0.04$).

We also evaluated the degree of burrowing parallel to the surface regardless of slope. First we excluded burrows less than 3.0 m in length because they tend to follow a steep angle and then dead end. Of the remaining 9 burrows, 8 had burrow segments 120 cm or longer that were parallel to the surface. An average of 54.6% of each of the 9 burrows greater than 3.0 m in length were parallel to the soil surface (range 43.5 - 71.9%).

DISCUSSION

Burrows described by Grinnell and Dixon (1918), Linsdale (1946), and Fitch (1948) were considerably longer and deeper than the ones we excavated. Marsh (1985) stated that ground squirrel burrow systems tend to be expanded in size each successive year, and this could explain the differences between previous studies and our work. At the UC Davis sites, periodic ground squirrel population control was being conducted, whereas little or no control had been performed on sites in previous studies.

The general structure of burrows, including depth and overall complexity were similar on all three terrain types. The impact of slope on burrow depth relative to the burrow entrance indicates a tendency for squirrels to burrow more horizontally on sloped ground possibly using gravity to their advantage. This study also provided evidence that California ground squirrels often create burrows parallel to the surface regardless of the terrain slope. While the reason for this is unknown, a likely explanation is that ground squirrels burrow along soil gradients, such as a hard pan layer, and these often follow the surface topography. Burrowing energetics (e.g., digging uphill and using gravity to help remove debris) also may account for this behavior on sloped terrain. One burrow on the levee that was basically horizontal also followed the soil surface, or levee crown. This is similar to some burrows on flat ground. To address this, additional levee burrows below the crown should be examined.

It is interesting to note that the structures of the burrows excavated were consistent with previous descriptions. Grinnell and Dixon (1918) described the structure of male squirrel burrows as "... short, shallow and simple burrows...," female burrows as more complicated with "... many turns and blind alleys ...," and a colonial burrow as complex with numerous entrances. Furthermore, Fitch (1948) described short, deep emergency burrows that were located along well used runways between burrows. Our 15 burrows provided examples of each of these 4 structures. Of particular interest were the 5 burrows excavated at the UC Davis Experimental Ecosystem; 3 were consistent with the description of female burrows, 1 male, and 1 colonial. The carcasses recovered after control methods were applied were all female. All were recovered from burrows matching the description of female burrows.

CONTROL IMPLICATIONS

Previous research has shown that destroying or rototilling burrow entrances does not significantly reduce the rate of recolonization of California ground squirrel burrows (Salmon et al. 1987). Gilson and Salmon (1990) showed that a tractor equipped with one or more 45 cm ripping blades can be effective in destroying burrow entrances and reducing recolonization after ground squirrel removal has been performed. However, long term efficacy and application of this technique over a variety of terrain types requires further study.

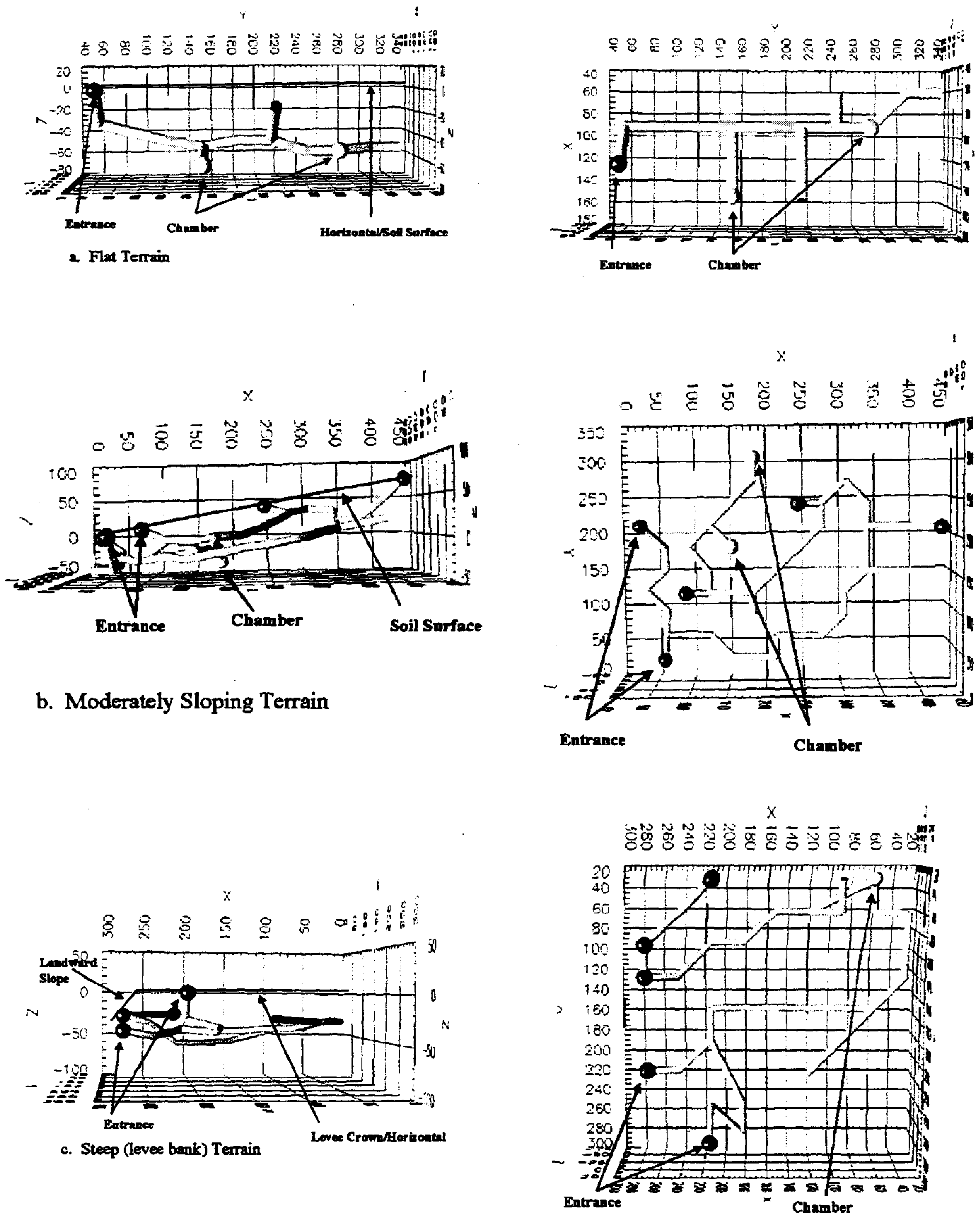

Figure 1: Side and surface/top view of selected California ground squirrel burrows on flat (a), moderately sloping (b), and steep/levee bank (c) terrain, respectively. Side view (left) illustrates burrow structure and depth relative to soil surface and horizontal. Surface/top view (right) illustrates overall length and coverage area. Graphs are positioned to represent length, width and depth from horizontal, perpendicular, and vertical axes, respectively. Axis units in cm.

More thorough burrow destruction may be an effective deterrent to recolonization and this study provides a better understanding of burrow depth and coverage area that may need to be treated. In this study, the number of burrow entrances was not an accurate indicator of burrow length or coverage area. This is particularly important for those conducting squirrel control using fumigants or attempting burrow destruction by ripping soil as the burrow volume or area of treatment cannot be accurately determined based on the number of burrow entrances on the site.

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