

California Levee Vegetation Research Program

Habitat Associations of Burrowing Mammals along Levees in the Sacramento Valley, California



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INTRODUCTION

Earthen levees are important for the protection of human safety and property from floods. Earthen levees rely on tightly compacted soil in order to withstand the water pressure of the body of water contained on one side of the embankment (Federal Emergency Management Agency 2005). Soil-excavating activities of mammals, especially burrowing behavior, can alter the internal and external geometry of earthen levees (Bayoumi and Meguid 2011). Hence, burrowing mammals are considered threats to levee integrity, and their burrowing activities have been implicated as a cause of numerous levee failures (Dixon 1922, Fitzgerald and Marsh 1986, Hegdal and Harbour 1991, Federal Emergency Management Agency 2005, Bayoumi and Meguid 2011).

Burrowing activities by mammals can compromise levee integrity via tunnel formation and soil displacement. Perhaps the most significant impact is alteration of the hydraulic characteristics of the levee; burrows can become conduits for water during rises in water level. Even burrows that only partially penetrate a levee can contribute to an increased seepage volume, a decreased seepage path, and potentially “piping”, the internal erosion of embankment materials that can lead to rapid levee failure (Federal Emergency Management Agency 2005, Bayoumi and Meguid 2011). Further, burrows create voids of space within the levee that can collapse over time, weakening the structural integrity of the levee (Federal Emergency Management Agency 2005, Bayoumi and Meguid 2011). Finally, soil disturbance around the burrow opening can promote erosion that alters the profile of the levee (Federal Emergency Management Agency 2005, Bayoumi and Meguid 2011).

The suitability of levees as habitat for burrowing mammals may be influenced by the composition and structure of vegetation growing on levees (Klitz 1982, Daar et al. 1984, US Army Corps of Engineers 2009, Bayoumi and Meguid 2011). Because dense vegetation on levees may be a hindrance to levee maintenance and function, levee vegetation often is reduced by the removal of woody vegetation or the application of grazing, mowing, burning, or

herbicides to grassland vegetation (Daar et al. 1984, Fitzgerald and Marsh 1986, Shields and Gray 1992, Federal Emergency Management Agency 2005, US Army Corps of Engineers 2009). Vegetation can provide important habitat resources for mammals, such as food or cover; hence, vegetation management on levees might result in decreased (Hegdal and Barbour 1991, Bayoumi and Meguid 2011) or increased (Daar et al. 1984) habitat quality for burrowing mammals, with important implications for levee function. In particular, the conversion of woodland habitat to grassland by removal of trees and shrubs, which is recommended for most levees in the United States (US Army Corps of Engineers 2009), may be especially important because of its major effect on habitat structure. Information on habitat associations of burrowing mammals on levees is needed to understand the consequences of vegetation management for burrowing mammals, but this topic has received little study.

Levees along the Sacramento River and its tributaries, near Sacramento, California, are managed by numerous different agencies that employ various vegetation management practices, resulting in a variety of habitat types. Many levees are managed for grassland vegetation, primarily ruderal annual grasses and forbs common to California's Mediterranean climate, but some support shrub and woodland vegetation. Further, portions of some levees are denuded of vegetation and surfaced with gravel, asphalt, or riprap, or left as exposed soil. Several species of burrowing mammals live on levees in the area, and some, especially the California ground squirrel (*Otospermophilus beecheyi*), are considered threats to levee integrity (Daar et al. 1984, Fitzgerald and Marsh 1986). Our objective was to evaluate the habitat associations of burrowing mammals along levees in the Sacramento Valley, California, with an emphasis on the California ground squirrel, in order to assess the effects of levee vegetation management on these species.

METHODS

Study area

The study was conducted along portions of 12 levees within Colusa, Sacramento, Yolo, and Yuba counties of the Sacramento Valley (Fig. 1). Common habitat types on levees were grassland (e.g., ripgut brome, *Bromus diandrus*; Italian ryegrass, *Lolium multiflorum*; and wild oat, *Avena fatua*), shrub (e.g., California blackberry, *Rubus ursinus*; western poison oak, *Toxicodendron diversilobum*; and willow, *Salix* spp.), and woodland (e.g., valley oak, *Quercus lobata*; western sycamore, *Platanus racemosa*; California black walnut, *Juglans californica*; Fremont's cottonwood, *Populus fremontii*; and willow). Levees were bordered mostly by row crops, orchards, vineyards, urban and rural residential areas, and riparian habitat.

Several species of burrowing rodents live in the Sacramento Valley. California ground squirrels are common and occur on levees, and the threat of their burrowing activities to levees is well known (Daar et al. 1984, Fitzgerald and Marsh 1986, Bayoumi and Meguid 2011). Botta's pocket gophers (*Thomomys bottae*) also are common on levees; gophers have been reported to burrow completely through irrigation ditch embankments (Dixon 1922), and their burrowing activities can displace large volumes of soil (Smallwood and Morrison 1999). Beavers (*Castor canadensis*) and muskrats (*Ondatra zibethicus*) are semi-aquatic mammals that excavate burrows on the water side of levees, with entrances located underwater (Bayoumi and Meguid 2011). California voles (*Microtus californicus*) forage on the surface, constructing extensive above-ground "runways" through dense grassland vegetation, but excavate shallow (<15 centimeter) underground burrows for nests or utilize existing gopher burrows (Cudworth and Koprowski 2010).

Several species of carnivores live in the Sacramento Valley that may excavate soil in levees. Most species forage on the surface, such as coyotes (*Canis latrans*), gray foxes (*Urocyon cinereoargenteus*), red foxes (*Vulpes vulpes*), striped skunks (*Mephitis mephitis*), and

raccoons (*Procyon lotor*), but these species may excavate underground dens for reproduction during the breeding season. One carnivore, the badger (*Taxidea taxus*), is a semi-fossorial species that catches its prey primarily by excavating the burrows of burrow-dwelling rodents such as ground squirrels and gophers.

Data collection

We determined the occurrence of burrowing mammals indirectly, by identifying and counting burrow openings. Our sampling unit was a levee “segment”, a 50-meter portion of a levee measured along the longitudinal axis of the levee. We performed burrow surveys on 166 levee segments between November 2009 and June 2010. Levee segments were located using a stratified-random approach. Because ground squirrels are considered a major threat to levee integrity, we targeted those levee districts that had documented evidence of activity by California ground squirrels, using a database generated by W. D. Meyersohn, California Department of Water Resources (personal communication). Further, we targeted those levee reaches that supported a variety of habitat types, as indicated by aerial photographs or visual inspection. Once a suitable levee reach had been identified, we located our first segment a random distance from the start of the reach, ranging from 500 meters to 1000 meters, then located subsequent segments in succession a random distance apart ranging from 500 meters to 1000 meters. We located segments ≥ 500 meters apart to facilitate independence of observations among segments; the radius of California ground squirrel activity is typically ≤ 75 meters (Van Vuren et al. 1997).

Once a levee segment was located, the upstream and downstream boundaries were delineated perpendicular to the longitudinal axis of the levee using a compass and flagging. Water-side and land-side boundaries were established at the toe of the levee toward and away from the river, respectively. The length of all segments was 50 meters, but width varied among segments depending on the height and slope of the levee. We searched each segment systematically for all burrow entrances, and counted all entrances, measured their diameters,

and recorded characteristics of the entrance to aid in identifying the species that excavated the burrow. We recorded burrows separately for the land side and the water side of each levee segment. We assigned California ground squirrels to those burrows that were 6-15 centimeters in diameter; these burrows typically had a compacted spoil pile downslope of the burrow entrance. We assigned California voles to those open burrows that were 4-6 centimeters in diameter and were connected to the surface “runways” characteristic of the species. We assigned Botta’s pocket gophers to those open burrows that were 4-6 centimeters in diameter and not associated with vole “runways”, and to those closed burrows that were plugged with the mound of loose soil that is characteristic of gophers. We assigned carnivores to those burrows that were greater than 15 centimeters in diameter; we sometimes observed California ground squirrels entering burrows, and 15 centimeters was the largest diameter of such burrows.

Habitats associated with each burrow were characterized at three spatial scales. Microhabitat analyses assessed factors associated with burrow placement on the levee slope; macrohabitat analyses assessed factors associated with burrow occurrence and abundance on the levee segment; and landscape analyses assessed the influence of adjacent land use on burrow occurrence and abundance on the levee segment. At the microhabitat scale, we recorded the substrate at the burrow entrance (e.g., soil, gravel, tree root), and we characterized the habitat within a 5-meter radius of the burrow entrance by visually estimating percent cover by habitat type (e.g., grassland, shrub, tree, barren). Also, we visually divided each slope of the levee (land side and water side) into thirds and assigned the location of each burrow on the levee profile to one of four categories: the levee crown, or the upper, middle, or lower third of the levee slope.

For the macrohabitat scale, we characterized habitat types for each levee segment by visually estimating the percent cover of each habitat type across the levee segment. In areas with tree cover, we estimated percent cover of the tree canopy as a separate category, based on a vertical projection of the canopy. Because habitats often differed on opposite sides of a

levee, we recorded macrohabitat types separately for the land side and the water side of each segment. We excluded the road on the levee crown from our macrohabitat categorization because all levees were topped with a road for levee inspection and maintenance, hence that habitat type was constant among segments. For the landscape scale, we estimated the percent cover of land use types adjacent to the toe of the levee on the land side, within 500 meters of the levee segment.

Data analysis

For the macrohabitat scale, we evaluated associations between habitat type and both the occurrence and abundance of each species of burrowing mammal. We used bivariate logistic regression to assess the probability of occurrence of each mammal as a function of the percent cover of each habitat type. For each side of each levee segment we assigned a score of 1 (present) if one or more burrows of a given species were identified, or 0 (absent) if no burrows of that species were identified. Separate regressions were performed for the land side and the water side. We used number of burrows per segment as an index of mammal abundance, a relationship that has been validated for California ground squirrels (Owings and Borchert 1975). We used Spearman's rank correlation (r_s) to evaluate associations between mammal abundance and the percent cover of each habitat type. Separate correlations were performed for the land side and the water side.

For the landscape scale, we used bivariate logistic regression to assess the probability of occurrence of each mammal on the land side of the segment as a function of the percent cover of each land use type within a 500-meter radius. We used Spearman's rank correlation to evaluate associations between mammal abundance on the land side of the segment and the percent cover of each land use type within a 500-meter radius. For both the macrohabitat and landscape scales, we restricted our analyses to those habitats or land uses that were identified on or adjacent to $\geq 5\%$ of levee segments. Additionally, False Discovery Rate corrections were

used to control for Type I errors that were associated with simultaneous multiple testing (Benjamini and Hochberg 1995).

For the microhabitat scale, we calculated frequency distributions of burrow locations across the levee profile and among substrates. We characterized the habitat immediately surrounding the burrow entrance by averaging values, across both sides of all 166 segments, for each habitat type within 5 meters of the burrow entrance. To determine if burrowing mammals were selecting particular habitats in which to excavate burrows, we divided percent use of each habitat by percent availability, generating a relative preference index (RPI) in which a value of 1 indicated no preference, a value of >1 indicated preference, and a value of <1 indicated avoidance. Habitat availability was based on percentages of each macrohabitat type on the levee segment; for this analysis we considered the segment as a whole, based on the assumption that burrowing mammals had access to both sides of the levee for selecting a burrow location. Because our goal was to assess choices by mammals among habitats, we used only those levee segments ($N = 131$) that supported at least two macrohabitat types. Habitat use was based on percentages of each microhabitat within a 5-meter radius of the burrow entrance, and we used only those burrows located in the middle portion of the levee slope to ensure that the 5-meter radius was contained entirely within the slope. Statistical analysis of RPI values, while desirable, was precluded by extraordinarily large sample sizes that inflated the chances of a Type I error. Hence, we arbitrarily assigned an RPI value of >1.5 as indicating preference, and a value of <0.67 as indicating avoidance.

RESULTS

Burrowing mammals

We searched 166 levee segments and counted 39,399 burrows attributable to three taxa of burrowing mammals: Botta's pocket gophers ($N = 33,678$), California ground squirrels ($N = 5705$), and carnivores ($N = 16$). Gophers and ground squirrels both were widely distributed,

occurring in 98% and 95% of segments, respectively. Carnivore burrows fell into two diameter classes, 15-28 centimeters (N = 13) and 35-41 centimeters (N = 3), which correspond well to burrow diameters of foxes and coyotes, respectively (Elbroch 2003). Carnivore burrows were too few to include in further analyses. Most gopher burrows were plugged with soil, but some were open and could have been made by California voles. However, although we often found the characteristic “runways” of voles in grassland vegetation, none of the runways led to burrow entrances. We found no evidence of badger activity, as indicated by the massive excavation of soil that is characteristic of badgers as they dig for prey. We also found no evidence of beaver or muskrat burrows, probably because entrances to burrows of these species are normally under water.

Macrohabitat

For California ground squirrels, logistic regression models indicated that tree cover and leaf litter had a negative influence on probability of occurrence, and the effect was significant on both the land side and the water side of the levee (Table 1). We were unable to conduct a similar analysis for Botta's pocket gopher because gophers were absent at too few levee segments, on either the land side or the water side, for a meaningful presence/absence analysis.

Correlation analysis revealed significant negative relationships between number of ground squirrel burrows and tree cover on the land side of the levee, and leaf litter on both sides of the levee (Table 2). In addition, number of squirrel burrows was significantly positively related to shrub cover on the water side, and to grassland on the land side. For gophers, number of burrows was significantly negatively related to both tree cover and leaf litter on both sides of the levee, and to shrub cover on the water side of the levee (Table 2). Number of gopher burrows was significantly positively related to grassland on both sides of the levee.

Landscape

Logistic regression models indicated no significant relationships between ground squirrel occurrence on the land side of the levee and any of the land use types adjacent to the levee (Table 3). We were unable to conduct a similar analysis for pocket gophers because gophers were absent at too few levee segments. Correlation analysis indicated a significant negative relationship between the number of ground squirrel burrows and the extent of urbanization. The number of gopher burrows was significantly negatively related to urbanization, and significantly positively related to row crops and wetlands (Table 4).

Microhabitat

Burrows of both ground squirrels and gophers were found on all portions of the levee profile, but those of ground squirrels tended to be concentrated more on the upper slopes of the levee, and those of gophers more on the lower slopes, with relatively few burrows of either species on the crown (Figure 2). Burrows of both species were almost always excavated in soil (Table 5). A few burrows were excavated in gravel and riprap, and almost none in asphalt or beneath tree roots.

Habitat characteristics within 5 meters of the burrow entrance were similar for ground squirrels and gophers and comprised almost entirely open habitats, with grassland, barren, gravel, and pavement totaling 87-89% of the average composition (Figures 3 and 4). Shrubs averaged only 6-8% composition, and trees and leaf litter were rarely recorded within 5 meters of burrows for either species ($\leq 3\%$ composition).

When comparing habitat characteristics near the burrow entrance to those available at the level of the tree canopy, both ground squirrels and gophers showed a strong avoidance of tree cover (Table 6). When considering availability at the level of the understory, ground squirrels showed a preference for barren areas and shrub cover, and an avoidance of tree boles, leaf litter, riprap, gravel, and pavement (Table 7). Gophers showed avoidance of leaf litter, tree boles, and gravel.

DISCUSSION

Habitat relations of California ground squirrels have received little study, and most of what is known is based on anecdotal observations. The species is considered a common resident of grasslands and open oak woodlands (Owings et al. 1977, Fehmi et al. 2005), is thought to prefer open habitats with good visibility (Klitz 1982, Marsh 1998, Fehmi et al. 2005), and is believed to occur rarely, if ever, in areas of heavy tree or brush growth (Grinnell and Dixon 1918, Evans and Holdenried 1943). However, California ground squirrels sometimes excavate burrows beneath oak tree canopies, perhaps because of the availability of acorns as food (Fitch 1948, Owings and Borchert 1975). California ground squirrels are herbivores that forage above ground and consume leaves, flowers, seeds, and fruits (Fitch 1948, Marsh 1994), foods found in grasslands but also in open woodlands. Ground squirrels dig underground burrows for refuge during the active season, for rearing young, and for hibernation (Yensen and Sherman 2003). Burrows of California ground squirrels may be lengthened progressively over time (Marsh 1985), and burrow systems have been measured as long as 42 meters in aggregate length (Grinnell and Dixon 1918).

Our results showed that tree cover and leaf litter had a strongly negative influence on both the occurrence and abundance of California ground squirrels along levees, as indicated by logistic regression analysis of occurrence and correlation analysis of abundance. The negative effect of tree cover on California ground squirrels probably results from visual occlusion caused by tall woody vegetation. Similarly, Owings and Borchert (1975) found that California ground squirrels were less likely to burrow in visually obstructed locations. Ground squirrels in general prefer burrow locations with good visibility because of a reliance on vigilance to detect predators in time to escape into burrows (Yensen and Sherman 2003). Research on other species of ground squirrels showed that predation risk is higher in visually obstructed habitats (Schooley et al. 1996, Karels and Boonstra 1999, Van Vuren 2001), and accordingly these habitats are avoided (Carey 1985, Blumstein et al. 2006, Avila-Flores et al. 2010). The negative effect of

trees and leaf litter on ground squirrels was consistent except for the relationship between tree cover and squirrel abundance on the water side of the levee; this relationship was negative but not significant. Perhaps some trees on the water side provided a food resource that partially counteracted the negative influence of visual occlusion.

The negative effect of leaf litter probably resulted mostly because this variable was closely associated with tree cover. Although we measured the variables separately, with tree cover as a canopy variable and leaf litter as an understory variable, most locations with leaf litter were beneath tree canopies. However, leaf litter may have had an independent effect by creating a noisy substrate for movement that may have increased the detectability of squirrels to predators. Additionally, the leaf litter was often deep and compacted, potentially interfering with burrowing.

We found significantly positive effects of grassland and shrub cover on ground squirrel abundance, although these effects were not consistent on both sides of the levee. The positive effect of grasslands agrees with prior observations, since grasslands provide food and openness. However, the effect was significant only on the land side of the levee, for uncertain reasons. The positive effect of shrub cover is somewhat surprising, since California ground squirrels are thought to avoid areas of heavy brush growth (Grinnell and Dixon 1918, Evans and Holdenried 1943). However, the effect of shrubs on ground squirrels may be variable. Shrubs may impede visual detection of predators (Schooley et al. 1996), but they may also provide an important food resource; in our study, a common shrub was blackberry, which produces edible fruits. Further, depending on the physical structure of the shrub community, in some situations shrub cover could make a squirrel more difficult for a predator to detect or attack (Schooley et al. 1996, Sharpe and Van Horne 1998). Hence, perhaps the more mesic conditions on the water side of the levee produced a shrub community that provided food or a physical structure favorable for squirrels.

We found little evidence that adjacent land use influenced ground squirrel occurrence or abundance on levees. The only significant effect was degree of urbanization; the relationship was negative, and may have resulted because burrow sites are limited by the presence of buildings and pavement, and because burrowing animals are often controlled in urban settings. We found the lack of a stronger landscape effect to be somewhat surprising, since land uses such as vineyards and orchards, especially nut crops, provide food resources that are known to attract California ground squirrels (Daar et al. 1984, Marsh 1998). Perhaps adjacent landowners with squirrel infestations responded with control efforts, or perhaps our scale of a 500-meter radius was too large.

Within a levee segment, ground squirrels tended to excavate burrows higher on the levee slope. These elevated sites may improve visibility for detecting predators (Karels and Boonstra 1999). Burrows were almost always excavated in soil and rarely in gravel, riprap, or asphalt, probably because these latter three substrates were more difficult to excavate. Surprisingly, however, burrows were rarely excavated beneath tree roots. California ground squirrels elsewhere often preferentially dig burrows under durable objects such as rocks or logs (Grinnell and Dixon 1918, Linsdale 1946, Fitch 1948, Owings and Borchert 1975), and often burrow beneath tree roots in orchards (Marsh 1998).

Habitat within 5 meters of the burrow influenced burrow site selection; ground squirrels avoided trees, leaf litter, gravel, riprap, and pavement, and preferred barren areas and shrub cover. Avoidance of trees and leaf litter and preference for barren areas likely reflect the importance of unobstructed visibility. Similarly, Daar et al. (1984) found that California ground squirrels preferred barren portions of levees for burrowing. Gravel, riprap, and pavement also provided unobstructed visibility, but these surface treatments on levees were often extensive, thereby separating squirrels from food resources in grasslands. The positive influence of shrub cover on burrow site selection, like similar results for the influence of shrubs in macrohabitat

selection, may result from availability of food resources or a structural configuration that reduces predation risk.

Botta's pocket gophers occur in a wide variety of habitats throughout California (Jones and Baxter 2004). They are a fossorial species that forages primarily underground, eating tubers, roots, foliage, and seeds from a variety of plants (Jones and Baxter 2004), but especially herbaceous species (Gettinger 1984, Hunt 1992, Seabloom and Richards 2003). Gophers excavate extensive burrow systems that include relatively shallow feeding tunnels, which are constructed parallel to the ground surface and provide access to the underground portions of plants, and deeper tunnels to access chambers for nests and food storage (Jones and Baxter 2004). Soil excavated from a new feeding tunnel is deposited either in unused feeding tunnels or on the ground surface, creating the characteristic "gopher mound", and entrances to the burrow system are usually plugged with soil (Jones and Baxter 2004). The tunnel system occupied by one Botta's pocket gopher is as long as 102 meters in aggregate length (Smallwood and Morrison 1999). Botta's pocket gophers disturb approximately 26% of the soil surface annually in California grasslands (Hobbs and Mooney 1991), and their burrowing activities displace an estimated 22 cubic meters of soil per hectare per year (Smallwood and Morrison 1999).

Similar to California ground squirrels, tree cover and leaf litter had a strong negative effect on the abundance of Botta's pocket gophers. However, the underlying cause was probably related to the effect of trees on food availability rather than the effect of habitat structure on predator avoidance, as was the case for ground squirrels, since gophers forage primarily underground. The energetic cost of tunnel excavation by gophers is 360-3400 times as great as the cost of moving an equivalent distance on the ground surface (Vleck 1979), hence gophers probably are constrained to excavating feeding tunnels near food resources. Most of the leaf litter we observed was sufficiently deep to inhibit the growth of herbaceous vegetation, the preferred food of gophers. The importance of food availability is illustrated by

research on northern pocket gophers (*T. talpoides*); removal of herbaceous vegetation via herbicides resulted in a significant reduction in gopher numbers (Sullivan and Hogue 1987). Shrub cover also had a negative influence on gopher abundance and probably for the same reason, a lower density of herbaceous foods in shrubby habitat. However, the effect was significant only on the water side of the levee; perhaps mesic conditions there promoted a dense shrub cover that more effectively excluded herbaceous vegetation than on the land side of the levee. The importance of food availability is further supported by a positive relationship between grassland and gopher abundance.

We found some evidence that adjacent land use influenced gopher abundance on levees. Like ground squirrel abundance, gopher abundance was negatively related to degree of urbanization and perhaps for the same reason; gophers are burrowing mammals that are unwanted in urban settings and often controlled. The presence of wetlands nearby had a positive effect on gopher abundance; wetter soils may provide better quality habitat for gophers (Jones and Baxter 2004), especially during the dry season in California's Mediterranean climate. Row crops also had a positive effect on gopher abundance on levees, perhaps because row crops provide a food source that is irrigated frequently. Row crops often receive annual tillage, which would prevent the build-up of large populations of gophers, but those gophers that had established in row crops may have reacted to tillage by moving to adjacent levees.

Within a levee segment, gophers showed a slight tendency to prefer burrowing on the lower third of the levee profile, perhaps because soil conditions were moister there than on the more exposed upper slopes. Burrows almost always were excavated in soil, probably because this was the only substrate likely to support grassland vegetation, the preferred food of gophers. Habitat near the burrow influenced burrow site selection; gophers avoided trees, leaf litter, and gravel, probably because of the reduced food availability in these habitats.

MANAGEMENT IMPLICATIONS

Burrowing activities of both California ground squirrels and Botta's pocket gophers are considered serious threats to levee integrity (Dixon 1922, Daar et al. 1984, Fitzgerald and Marsh 1986, Bayoumi and Meguid 2011). Both species have the capacity to construct burrows that penetrate into the levee and facilitate "piping", potentially leading to levee failure. Ground squirrels are more likely to cause this type of damage because most gopher burrows are "feeding tunnels" that are relatively close to the surface (Jones and Baxter 2004). Burrowing activities of both species may threaten levees by creating voids of space that eventually collapse. Again, ground squirrels are probably the bigger threat because their burrows are larger in diameter and are maintained, whereas gopher burrows, especially feeding tunnels, are often backfilled with earth. Finally, burrowing activities of both species may promote soil erosion that alters the levee profile. Gophers may be the bigger threat to levee erosion because of the extensive volumes of soil that they loosen and displace close to the surface.

Current guidelines for management of vegetation on earthen levees and dams call for the removal of woody vegetation, especially trees, and replacement with grassland vegetation (Federal Emergency Management Agency 2005, US Army Corps of Engineers 2009). Our results indicate that trees and associated leaf litter had a strongly negative effect on the occurrence and abundance of ground squirrels, and on the location of their burrowing activities. Trees had a similar negative effect on the abundance of gophers and on the location of their burrowing activities. Consequently, conversion of woodland habitats to grasslands on levees in the Sacramento Valley will probably increase habitat quality for both ground squirrels and gophers, and thereby increase the potential threat that their burrowing activities pose to levee integrity.

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Table 1. Logistic regression models of the effects of levee macrohabitat type on the occurrence of California ground squirrels among 166 levee segments in the Sacramento Valley, California, 2009-2010, showing the chi-squared statistic (χ^2_1), regression coefficient and its associated standard error (*SE*), and probability value (*P*).

Macrohabitat	Levee side	χ^2_1	Coefficient	<i>SE</i>	<i>P</i>
Tree cover	Land	19.69	-0.026	0.006	0.001
	Water	5.43	-0.013	0.006	0.049
Leaf litter	Land	8.54	-0.026	0.009	0.009
	Water	11.59	-0.032	0.009	0.003
Shrub	Land	0.97	0.020	0.021	0.406
	Water	3.73	0.035	0.018	0.067
Grassland	Land	2.12	0.009	0.006	0.243
	Water	3.77	0.010	0.005	0.087
Barren	Land	0.23	0.006	0.014	0.635
	Water	0.25	-0.008	0.015	0.618

Table 2. Correlation analysis of associations between macrohabitat type and the number of burrows of California ground squirrels and Botta's pocket gophers among 166 levee segments in the Sacramento Valley, California, 2009-2010, showing the Spearman rank correlation coefficient (r_s) and probability value (P).

Macrohabitat	Levee side	Ground squirrel r_s	Ground squirrel P	Gopher r_s	Gopher P
Tree cover	Land	-0.331	0.001	-0.468	0.0002
	Water	-0.078	0.529	-0.411	0.0002
Leaf litter	Land	-0.357	0.0002	-0.361	0.0005
	Water	-0.250	0.003	-0.366	0.0005
Shrub	Land	0.003	0.969	0.095	0.281
	Water	0.287	0.001	-0.212	0.008
Grassland	Land	0.173	0.042	0.235	0.004
	Water	-0.032	0.848	0.407	0.0002
Barren	Land	0.137	0.098	-0.019	0.806
	Water	0.986	0.986	-0.098	0.207

Table 3. Logistic regression models of the effects of adjacent land use type on the occurrence of California ground squirrels among 166 levee segments in the Sacramento Valley, California, 2009-2010, showing the chi-squared statistic (χ^2_1), regression coefficient and its associated standard error (*SE*), and probability value (*P*).

Landscape	Levee side	χ^2_1	Coefficient	<i>SE</i>	<i>P</i>
Orchard	Land	0.08	0.002	0.007	0.773
Vineyard	Land	3.16	-0.009	0.005	0.075
Row crop	Land	3.25	0.009	0.005	0.071
Grassland	Land	0.01	-0.001	0.009	0.905
Wetland	Land	0.73	0.035	0.041	0.392
Urban	Land	2.01	-0.009	0.006	0.157

Table 4. Correlation analysis of associations between adjacent land use type and the number of burrows of California ground squirrels and Botta's pocket gophers among 166 levee segments in the Sacramento Valley, California, 2009-2010, showing the Spearman rank correlation coefficient (r_s) and probability value (P).

Landscape	Levee side	Ground squirrel r_s	Ground squirrel P	Gopher r_s	Gopher P
Orchard	Land	0.094	0.343	0.011	0.884
Vineyard	Land	-0.098	0.414	-0.149	0.084
Row crop	Land	0.115	0.418	0.212	0.018
Grassland	Land	0.043	0.582	-0.054	0.586
Wetland	Land	0.050	0.628	0.179	0.043
Urban	Land	-0.230	0.017	-0.340	0.001

Table 5. Characteristics of substrate at the entrances of burrows of California ground squirrels and Botta's pocket gophers among 166 levee segments in the Sacramento Valley, California, 2009-2010.

Species		Soil	Tree root	Riprap	Gravel	Asphalt	Total
Ground squirrel	N	5388	1	55	258	3	5705
	%	94	<0.1	<0.1	5	<0.1	
Gopher	N	32029	1	5	1638	5	33678
	%	95	<0.1	<0.1	5	<0.1	

Table 6. Comparison of use versus availability of microhabitat types at the canopy level for California ground squirrels and Botta's pocket gophers on 131 levee segments in the Sacramento Valley, California, 2009-2010. A relative preference index (RPI) was calculated by dividing percent use by percent availability.

	Availability	Ground squirrel		Gopher	
		Use	RPI	Use	RPI
Tree cover	22.3%	4.3%	0.2	2.2%	0.1
Open	77.7%	95.7%	1.2	97.8%	1.3

Table 7. Comparison of use versus availability of microhabitat types at the understory level for California ground squirrels and Botta's pocket gophers on 131 levee segments in the Sacramento Valley, California, 2009-2010. A relative preference index (RPI) was calculated by dividing percent use by percent availability.

Habitat	Availability	Ground Squirrel		Gopher	
		Use	RPI	Use	RPI
Tree bole	2.1%	0.1%	0.1	0.4%	0.2
Leaf litter	8.3%	1.3%	0.2	1.0%	0.1
Shrub	10.5%	16.1%	1.5	12.0%	1.1
Grassland	63.2%	63.1%	1.0	70.0%	1.1
Barren	8.5%	17.9%	2.1	11.3%	1.3
Riprap	3.3%	0.7%	0.2	2.7%	0.8
Gravel	2.6%	0.5%	0.2	0.9%	0.4
Pavement	1.5%	0.4%	0.3	1.7%	1.1

Figure 1. Locations of 166 levee segments surveyed for occurrence of burrowing mammals in the Sacramento Valley, California, 2009-2010.

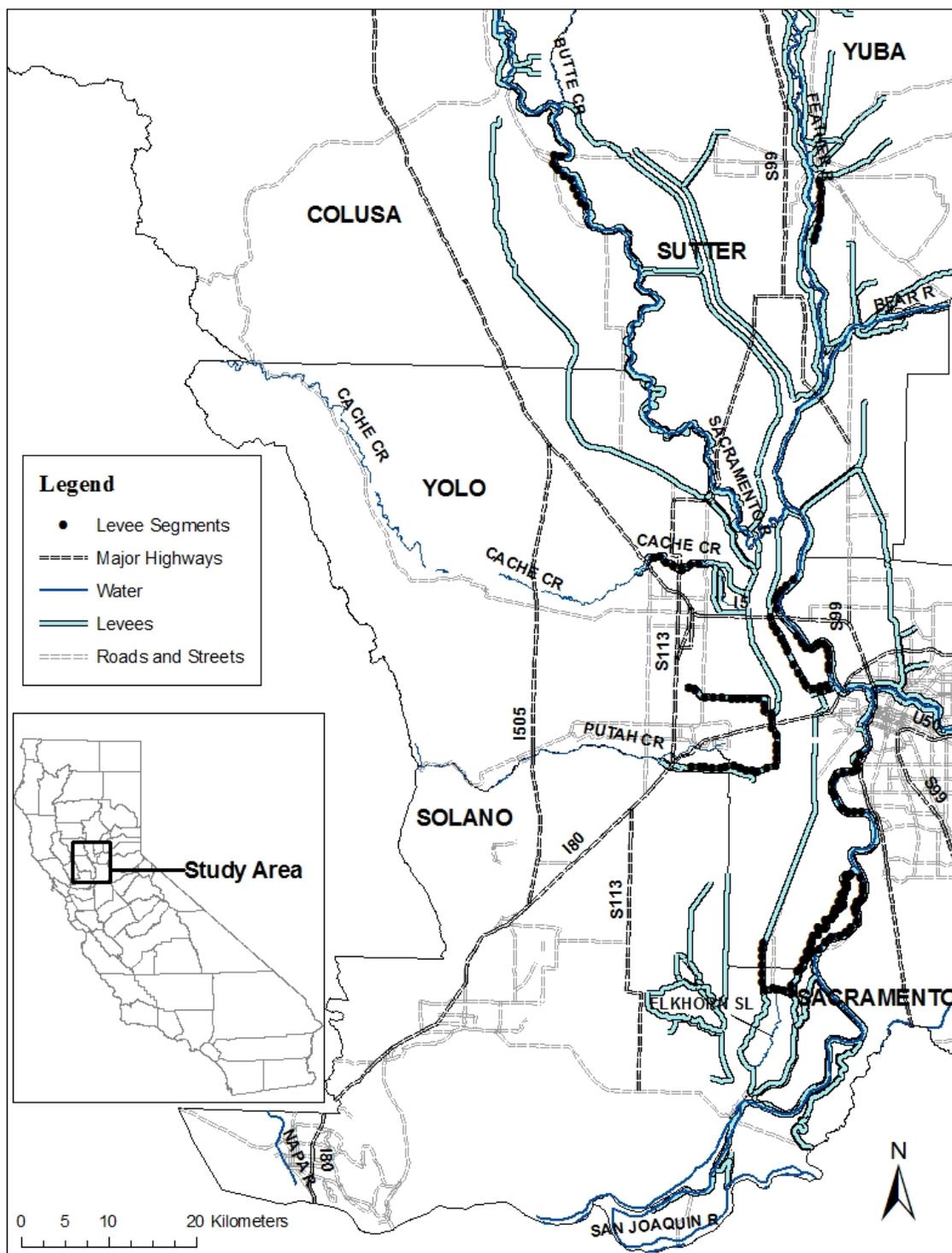


Figure 2. Distributions of burrows of California ground squirrels and Botta's pocket gophers across the levee profile among 166 levee segments in the Sacramento Valley, California, 2009-2010.

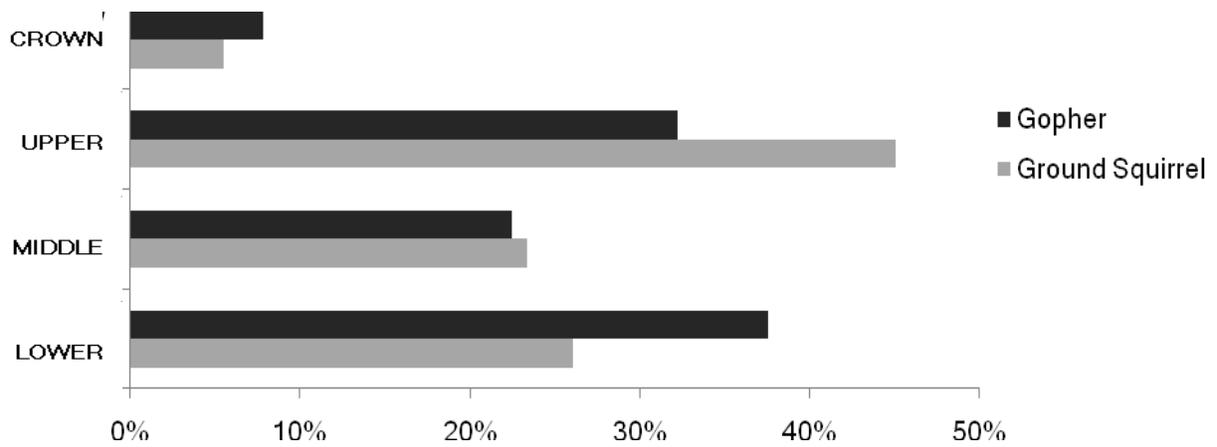


Figure 3. Average microhabitat composition within 5 meters of the burrow entrances of California ground squirrels on 166 levee segments in the Sacramento Valley, California, 2009-2010.

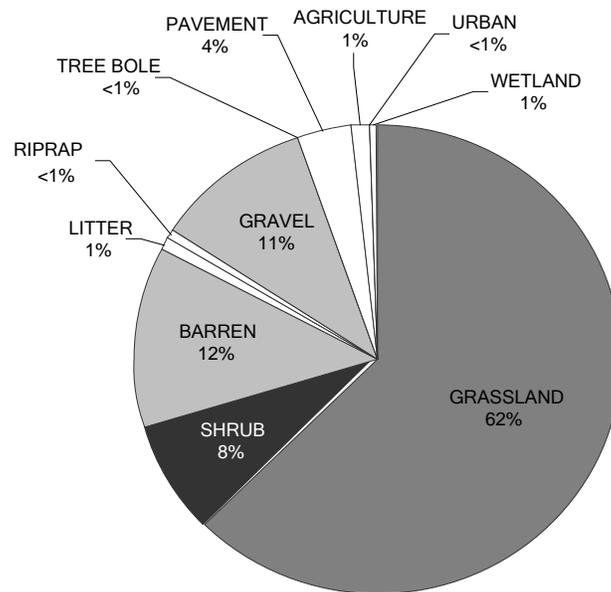


Figure 4. Average microhabitat composition within 5 meters of the burrow entrances of Botta's pocket gophers on levees in the Sacramento Valley, California, 2009-2010.

