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DISTRIBUTION AND ABUNDANCE OF HARVEST MICE AND DEER MICE ON SANTA CRUZ ISLAND IN RELATION TO FERAL ANIMAL REMOVAL

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Abstract—Like all of the California Channel Islands, Santa Cruz Island has been strongly impacted by a variety of introduced non-native animal species. On Santa Cruz, non-native sheep (*Ovis aries*) and feral pigs (*Sus scrofa*) formerly occurred in very high numbers. Sheep were removed from 90% of the island by the late 1980s, and from the remaining 10% by 2001. As of 2007, a control program has eliminated feral pigs as well. We surveyed Santa Cruz Island from 2004 through 2006 to evaluate the distribution and abundance of western harvest mice (*Reithrodontomys megalotis*). The trapping methods that we used also provided data on deer mice (*Peromyscus maniculatus*), and we evaluate the current extent, numbers, and habitat occurrence of both species. Harvest mice were formerly known only from Prisoners Harbor and a few isolated locations in the island's Central Valley. Our surveys found them at sites across nearly the entire island, and their abundance is higher at sites for which there are comparative data. Deer mice also appear to have increased in abundance compared to previous surveys. We predict further increases in both deer mice and harvest mice as island habitats continue to recover from the effects of non-native ungulates. Changes may be conspicuous in herbaceous vegetation types that recover rapidly, but will take longer in communities like oak woodlands that regenerate more slowly.

INTRODUCTION

Compared to the adjacent mainland, there are very few small mammal species on the southern California Channel Islands. On five of the eight islands, the only native small mammal is the deer mouse (*Peromyscus maniculatus*). The western harvest mouse (*Reithrodontomys megalotis*) is the only other native rodent and is found on three islands—San Clemente, Santa Catalina, and Santa Cruz (von Bloeker 1967). The San Clemente harvest mice are thought to have been inadvertently introduced in hay bales shipped to the island in the late 1930s, and have always had a limited distribution (von Bloeker 1967). Populations on Santa Catalina and Santa Cruz are believed to be native, and distinct island-endemic subspecies have been proposed for the two islands. Pearson (1951) described *Reithrodontomys megalotis santacruzae* based on its longer body, longer tail, and grayer, "less richly colored" dorsum compared to *R. m. longicaudus* from the California mainland. Genetic, morphologic, and allozyme studies also indicate the San Clemente Island population is a recent arrival and that the Santa Catalina and Santa Cruz populations have been isolated for longer periods, but they do not provide strong support for subspecies recognition (Ashley 1989; Collins and George 1990). Collins and George (1990) suggest that harvest mice probably reached both Santa Catalina and Santa Cruz during Holocene times by inadvertent transport on Native American canoes traveling between the mainland and the islands.

Studies in other areas have noted both lower diversity and abundance of small mammals in grazed versus ungrazed areas (Rosenstock 1996; Steen et al. 2005). These effects may be especially pronounced for murid rodents such as harvest mice and deer mice (Jones et al. 2003). Harvest mice typically live in dense grass and herbaceous vegetation, where they build above-ground nests and feed on seeds and invertebrates (Webster and Jones 1982). Heavy grazing, trailing and flattening of vegetation, and rooting and churning of the soil by sheep, pigs, and other non-native ungulates on Santa Cruz Island (e.g., Klinger et al. 2002) have

probably reduced and degraded suitable areas for harvest mouse foraging, escape cover, and nests. Because of their relatively vulnerable above-ground nests, there may also be direct predation by pigs, particularly on dependent young mice. Changes associated with feral animals may have reduced both the overall distribution and the local abundance of harvest mice on Santa Cruz, and their absence or low numbers seems to reflect this.

On Santa Cruz Island, harvest mice were long thought to be limited to the marsh area at Prisoners Harbor on the north shore of the island (Pearson 1951). However, Bills (1969) trapped a single harvest mouse on a sagebrush-covered hillside in the eastern Central Valley. Collins and George (1990) also found harvest mice in the eastern end of the Central Valley. This area is approximately 3 km straight-line distance from the Prisoners Harbor marsh. Little other information has been published on the population biology or ecology of the harvest mouse on Santa Cruz Island. Because of its evident rarity, the harvest mouse is of particular concern to the land managers of Santa Cruz Island, as feral animal removal efforts have been completed and habitat restoration projects are being undertaken. Here we present information on the overall distribution, abundance, population trends, and habitat associations of the western harvest mouse on Santa Cruz Island, based on three years of field surveys and a review of other published and unpublished small mammal surveys on the island.

METHODS

Work on this project consisted of: 1) intensive trapping in the Prisoners Harbor area; 2) extensive surveys around the island, starting with other locations known to have harvest mouse detections (Central Valley/Valley anchorage area), then expanding to other potential sites across the island; and 3) review of published and unpublished data and reports. The field component examined distribution of harvest mice both at a broad, island-wide scale, and at a microhabitat scale at Prisoners Harbor. We also recorded data on habitat associations of the mice on the island, and evaluated relative abundance and other aspects of the ecology of harvest mice on Santa Cruz Island. We reviewed all published literature and unpublished information on harvest mice and their occurrence and ecology on the island. Unpublished reports and data were found primarily at Channel Islands National Park, the University of California Field Station on Santa Cruz Island, and in field notes housed at regional museums. We also reviewed specimen data at museums with important Channel Islands holdings, including the Los Angeles County Museum of Natural History, the Museum of Vertebrate Zoology at the University of California, Berkeley, the San Diego Natural History Museum, and the Santa Barbara Museum of Natural History.

We used folding aluminum small mammal traps for all field sampling (23 x 9 x 8 cm; H. B. Sherman Co., Tallahassee, FL—use of product name does not imply endorsement by the U.S. Government). Depending on the size of the site we set out from 20 to 100 traps, deployed in transects or grids. Transects typically consisted of 10 stations spaced 10 m apart, with 2 traps per station, for a total of 20 traps. In most cases, the transects were not straight lines, but rather were set out to follow the habitat or feature of interest (e.g., riparian areas along stream courses, or the edge of a marsh area). Grids consisted of 50 to 100 traps, with either 5 rows of 10 traps, or 10 rows of 10 traps, with a spacing of 7 m between traps. We used grids in areas of relatively uniform habitat, and in areas where we were repeating previous trapping efforts. UTM coordinates were recorded with GPS at the beginning and end of transects, or at the corners of grids.

Traps were baited with rolled or crimped oats and placed along the edge of dense vegetation, in small openings in vegetation, or along habitat features that would tend to direct the movements of small mammals (e.g., alongside a fallen log). In some areas, particularly parts of the Prisoners Harbor marsh, we avoided pig trails or areas of extensive pig disturbance. Traps were set in the late afternoon or early evening, and checked early the following morning so that captured animals were in the traps no longer than necessary. On cold evenings, we added cotton batting to the traps for warmth.

We identified trapped animals to species, weighed and measured them, and recorded age and reproductive status. Most sites were only trapped once per trapping session, but at sites that were trapped for two or more nights, mice were marked

with individually numbered ear tags. We followed recommended precautions to minimize exposure to Hantavirus and other mammal-borne diseases. We also noted the general habitat type of each trapping site (e.g., marsh, riparian, grassland, coastal sage scrub), and we recorded detailed habitat notes at each trap station where a harvest mouse was captured, including habitat type, substrate, and species composition and structure of the vegetation. We noted evidence of pig disturbance where it was present. Location information was incorporated into a GIS database.

Trapping effort was recorded as the number of traps set, times the number of nights the traps were open ('trap-nights'). Traps that were noted as non-functional when they were checked (e.g., traps that had closed during the night, or had been robbed without closing), were subtracted from the total number of traps available for that night. Abundance was calculated in terms of capture rate—the number of mice captured, divided by the number of functional traps set in a given area. This calculation of relative abundance is useful for comparison to most other available trapping data for Santa Cruz Island. Previous trapping on the island has consisted of irregular transects or small grids, and the combination of low trap numbers, irregular trap arrangement, and small sample sizes (animals captured) precludes calculating densities with realistic mark-recapture models.

Our fieldwork included 47 sampling sessions, from October 2004 through April 2006. Some sessions were from the same site, or close to the same site, on different dates (Fig. 1; Table 1). Sampling effort totaled 1581 trap-nights (Table 1). Twenty sessions were in the Prisoners Harbor area, with a total of 539 trap-nights. Other areas sampled spanned much of the island, from Scorpion Valley on the east to Black Point Canyon on the west, and from the north side of the island (Prisoners and Scorpion) to the south side (Valley Anchorage and the mouths of Willows and Laguna Canyons; Fig. 1). Habitats trapped included fresh and brackish

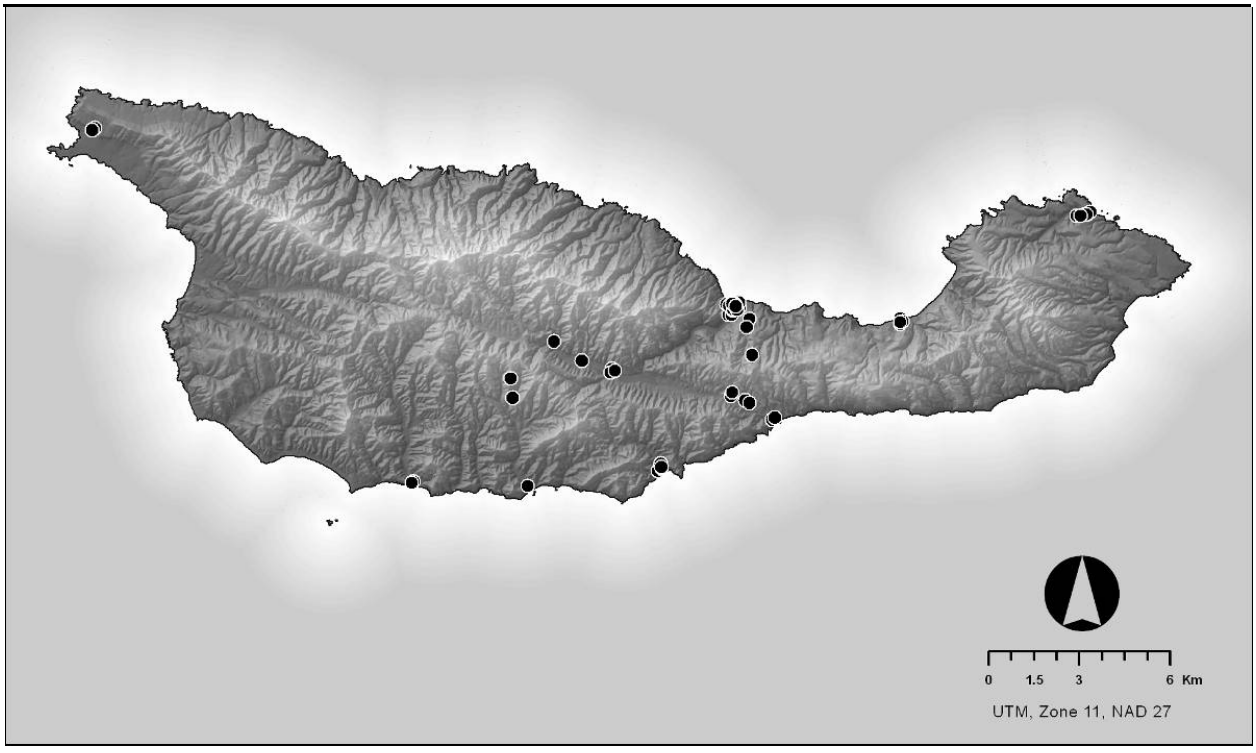

Figure 1. Trapping sites for western harvest mouse (*Reithrodontomys megalotis)* on Santa Cruz Island, California, during a survey conducted in 2004–2006. Multiple sample sites at Prisoners Harbor and Scorpion Valley overlap at this map scale.

Table 1. Trapping effort and capture rates for western harvest mice (*Reithrodontomys megalotis*) and deer mice (*Peromyscus maniculatus*) by date and trap site on Santa Cruz Island, California. Percent capture rates equal the number of individuals captured (harvest mice, deer mice, or total captures) divided by the number of available traps, times 100. In the last row, mean percent capture rate is listed.

			Deer mice		Harvest mice	
Site	Habitat	Traps	Number	%	Number	%
Scorpion Valley	Wet grassland	60	16	26.7	7	11.7
China Harbor	Weedy grassland	38	23	60.5	0	0.0
Valley Anchorage rim	Fennel grassland	17	3	17.6	0	0.0
Valley Anchorage drainage	Chaparral / mixed	18	4	22.2	1	5.6
Lake Pasture (Klinger 78)	Fennel grassland	123	39	31.7	5	4.1
Cañada del Medio, east of airstrip	Fennel grassland	39	6	15.4	0	0.0
Navy Road, just east of Prisoners	Weedy grassland	28	5	17.9	0	0.0
Prisoners Harbor area	Marsh, pasture, riparian	471	120	25.5	33	7.0
Airstrip Coastal Sage Scrub (Klinger 74)	Coastal Sage Scrub	80	15	18.8	1	1.3
Pelican Bay trail	Oak savanna	40	10	25.0	0	0.0
Central Valley (Klinger 23)	Fennel grassland	50	7	14.0	0	0.0
Coches Prietos	Mixed grass / shrub	40	8	20.0	0	0.0
Central Valley near UC Field Station	Mixed grass / shrub	60	0	0.0	0	0.0
Grassland Grid (Klinger 81)	Wet grassland	200	0	0.0	18	9.0
La Cascada—from pool downstream	Mixed grass / shrub	40	8	20.0	0	0.0
Willows Canyon mouth	Mixed grass / shrub	40	17	42.5	1	2.5
Willows Grassland (Klinger 38)	Dry grassland	78	4	5.1	3	3.8
Willows Oak (Klinger 41)	Oak savanna	80	5	6.3	0	0.0
Laguna Canyon mouth	Mixed grass / shrub	40	5	12.5	0	0.0
Black Point Canyon	Mixed grass / shrub	39	10	25.6	0	0.0
Totals:		1581	305	19.3	69	4.4

water marsh, riparian woodland, wet and dry grasslands, coastal sage scrub, and oak savanna.

We specifically targeted harvest mice in our surveys, by searching for and trapping in microhabitats that appeared suitable for this species. This was not the case for most earlier small mammal trapping. For this reason, comparisons with earlier studies may be somewhat misleading. More accurate comparisons can be made where we could re-survey specific sites that were trapped previously. The best data in this respect are those of Klinger (The Nature Conservancy, unpublished), conducted between 1991 and 1995. Klinger established grids of 50 traps in a 5 x 10 configuration at selected sites in a variety of habitats around the island. These sites were all mapped precisely and were sampled in a systematic manner that we could replicate. The data from these surveys are even more valuable because the five-year time span of the work provides a range of potential year-to-year variation in numbers. We relocated Klinger's trapping sites in grassland and fennel – grassland, and also re-trapped other sites where he found harvest mice (oak savanna in Willows Canyon and coastal sage scrub in the eastern Central Valley). We set out the same number of traps in the same configuration at all of these sites.

Comparisons of harvest mouse occurrence among different habitats, and of capture rates between this study and previous surveys, were based on capture rate proportions. We used non-parametric tests (Chi-square goodness of fit and Wilcoxon matched-pairs signed-ranks test, Daniel 1990) with α set at 0.05.

RESULTS

Numbers

We captured a total of 69 harvest mice (overall capture rate of 4.4%) and 305 deer mice (capture rate 19.3%). Numbers of mice caught varied by site and habitat (Table 1). Harvest mouse capture rates varied widely, but ranged up to 22% for some sessions at Prisoners Harbor. The highest overall capture rates for harvest mice were at Prisoners Harbor (7.0%, averaged over varied habitats) and in grass and marshland at Scorpion Valley (11.7%). Capture rates for deer mice were consistently higher at almost all sites, ranging up to 60% in some locations.

We conducted field sampling every other month of the year, with one gap—we did not sample in the month of February. Beginning in October 2004, we sampled in October, December, April, June, and August (2005), then again in April 2006. This nearly year-round schedule provided information on timing of reproduction in harvest mice on the island. Both males and females were reproductively active in April. Four of seven females caught in April were lactating and a single female caught in October was also lactating or had been recently. Two subadults and one juvenile were caught in April and a single subadult was caught in June. Evidence of reproduction or young was not seen in other months.

Distribution

We found harvest mice at eight of our sampling sites on Santa Cruz Island (Fig. 2; Table 1). In addition to Prisoners Harbor, these sites ranged from Scorpion Valley (the easternmost site), the Valley Anchorage area, to the mouth of Willows Canyon. Harvest mice have also been found in the Black Point area at the west end of the island (G. Roemer, personal communication). Locations at Scorpion Valley, Valley Anchorage, the west end of the Central Valley, Willows Canyon, and the Black Point area are previously unreported locations for harvest mice on Santa Cruz Island.

Deer mice were nearly ubiquitous in all sampling areas. We only failed to capture deer mice during two sampling sessions; in December 2004 in the Central Valley near the University of California field station and in April 2006 in the Central Valley (Table 1).

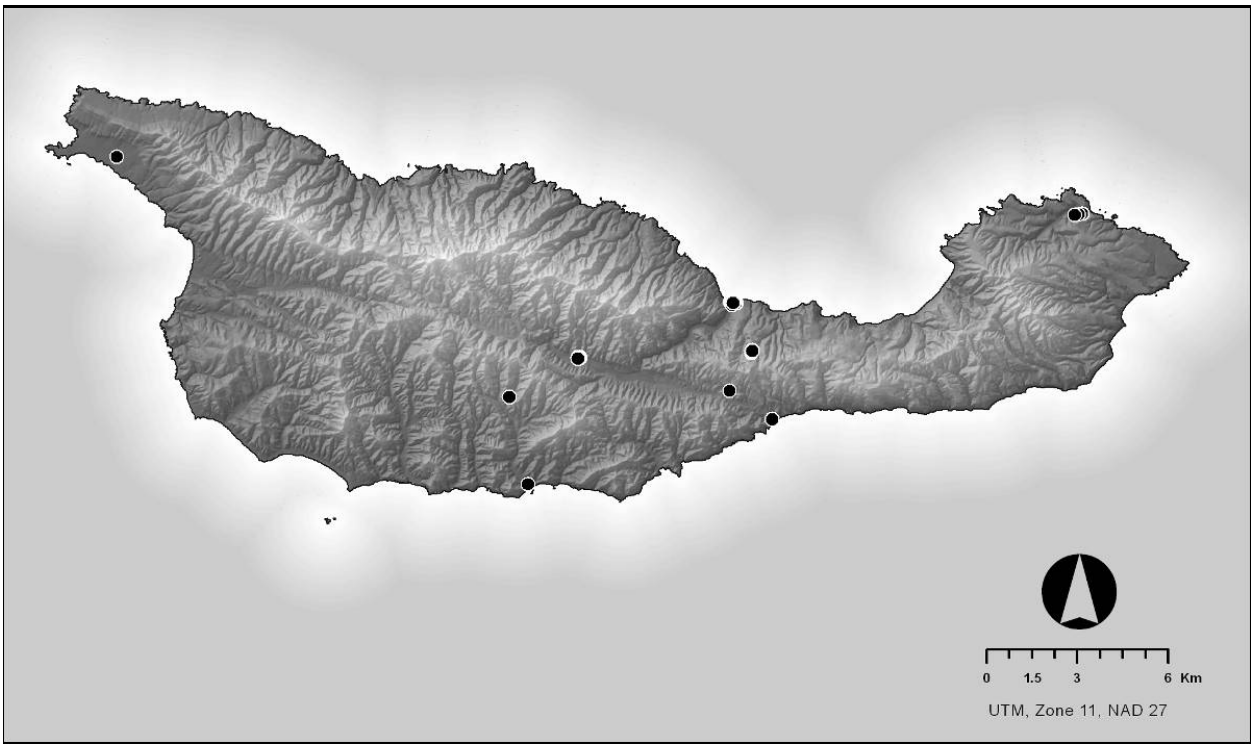

Figure 2. Capture locations of western harvest mouse (*Reithrodontomys megalotis*) on Santa Cruz Island, California, during surveys conducted from 2004 through 2006. In some places (Prisoners Harbor and Scorpion Valley), multiple captures are not shown at this map scale.

Habitat

We captured harvest mice in habitats ranging from *Scirpus* marsh to dry weedy grassland edges and coastal sage scrub. In most cases the microhabitat at trap sites where we caught harvest mice was comprised of dense herbaceous vegetation. Capture rates differed significantly by habitat type (Chi-square < 0.001, n=60, 7 df). Habitats with higher–than-expected capture rates included: 1) a back-beach/marsh-edge vegetation association, which included willow (*Salix* sp.), mule fat (*Baccharis salicifolia*), California bulrush (*Scirpus californicus*), and herbaceous species such as silver beachbur (*Ambrosia chamissonis*), brome grass (*Bromus* spp.), and rabbitsfoot grass (*Polypogon monspeliensis*); 2) wet grassland, including both native (e.g., saltgrass, *Distichlis spicata*) and non-native species (rabbitsfoot grass, ryegrass, *Lolium* sp., and smilo grass, *Piptatherum miliaceum*); and weedy edge habitats, including species such as wild oats (*Avena* spp.), wild lettuce (*Lactuca* sp.), mugwort (*Artemisia douglasiana*), and other herbaceous species. Habitats with lower than expected capture rates included: non-native pasture (kikuyu grass, *Pennisetum clandestinum*); dry grassland, dominated by wild oats and ripgut brome (*B. diandrus*); and coastal sage scrub, with shrubs including coastal sagebrush (*Artemisia californica*), chamise (*Adenostoma fasciculatum*), and mountain mahogany (*Cercocarpus betuloides*), and herbaceous understory of grasses (wild oats, brome), fennel, wild lettuce, and nightshade. No harvest mice were caught in areas with a closed tree overstory.

Previous Surveys

Since Pearson (1951) first documented the occurrence of western harvest mice on Santa Cruz Island, there have been a number of museum collecting trips to the island as well as several studies of small mammal population dynamics, genetics, and disease (Table 2). All of these studies have generally found few or no harvest mice away from the Prisoners Harbor area. Bills (1969) trapped extensively around the island, accumulating nearly 4000 trap-nights of sampling effort in 9 natural habitats and 2 human-associated habitats. At Prisoners Harbor he caught 11 harvest mice in 839 trap-nights (1.3% capture success). At 37 other sites around the island he only caught 1 other harvest mouse, in coastal sage scrub near the airfield in the east end of the Central Valley. Gill (1980) caught no harvest mice in 281 trap-nights at four locations, including 70 trap-nights at Prisoners Harbor.

From 1991 through 1996, R. Klinger (unpublished data) conducted annual trapping at 10 sites in 5 different habitats. During this period he caught only 10 harvest mice in over 8000 trap-nights (0.12% capture success). Five of these were in fennel grassland in Lake Pasture, 1 was in oak savanna in upper Willows Canyon, 2 were in coastal sage scrub in Willows Canyon, and 2 were in coastal sage scrub on the north side of the Central Valley airfield. This last location was in the area where Bills (1969) and Collins and George (1990) had each captured a single harvest mouse. Graham and Chomel (1997) used two trap webs with 200 traps each to sample the main ranch area and the east part of the Central Valley. They caught a single harvest mouse at the east valley site in 1200 trap-nights (0.08% capture success).

Comparison of our grid-trapping results in 2005 and 2006 with Klinger's results from 1991 through 1995 (all years combined) shows a large increase in capture rates of harvest mice (Table 3). Overall capture rate for harvest mice in the earlier surveys was under 0.3%, compared to 4.7% for the later surveys. No harvest mice were captured at Willows grassland and the Central Valley grassland in the 1990s, but these two sites had some of the highest capture rates in 2005–2006. Even with the relatively small number of sites where we could make such direct comparisons, capture rates were significantly greater in 2005–2006 (Wilcoxon matched-pairs signed-ranks test, $n = 5$, $T = 0$, $p = 0.0313$).

We did not make detailed comparisons of deer mice numbers between our surveys and earlier studies. In general, however, deer mice appear to have increased as well. Over all of his trapping sites, Klinger had a capture rate of 11% for deer mice compared to our overall capture rate of 19.3%.

DISCUSSION

Trapping

Harvest mice occur in low numbers at most sites, and we probably failed to detect them at some trap locations where they may have occurred. In areas where we had limited trapping effort (e.g., 40

Table 2. Harvest mouse captures in past small mammal trapping on Santa Cruz Island, California. Listed are date, observer, location of trapping, number of traps set, and trapping results. "Trap effort" is the number of traps set times the number of nights of trapping; "number" is the number of harvest mice caught; and "capture rate" is the number of mice captured, divided by trap effort, times 100.

Bills (1969) – Survey period 1968–1969			
Habitat/Location	Trap effort	Number	Capture rate
Chaparral	624	0	0.00
Outcrop	384	0	0.00
Marsh	839	11	1.31
Riparian	733	0	0.00
Grassland	370	0	0.00
Meadow	105	0	0.00
Sagebrush	180	1	0.56
Pines	360	0	0.00
Buildings	144	0	0.00
Dump	48	0	0.00
Grazed slopes	122	0	0.00
Total:	3909	12	0.31
Gill (1973/unpublished notes) – Survey period fall 1973			
Beach / Riparian – Coches	30	0	0.00
Stream / Riparian – Central Valley	148	0	0.00
Prisoners Harbor	70	0	0.00
Buildings / Stanton Ranch	33	0	0.00
Total:	281	0	0.00
Klinger/The Nature Conservancy (unpublished) – Survey period 1991–1995			
Chaparral – Portezuela (plot 84)	750	0	0.00
Chaparral – Willows Canyon (plot 95)	900	0	0.00
Coastal Sage – Valle del Medio (plot 74)	750	2	0.27
Coastal Sage – Willows Canyon (plot 36)	900	2	0.22
Fennel Grassland – Lake Pasture (plot 78)	750	5	0.67
Fennel Grassland – Central Valley (plot 23)	750	0	0.00
Grassland – Valle del Medio (plot 81)	900	0	0.00
Grassland –Willows Canyon (plot 38)	750	0	0.00
Oak Woodland – Willows Canyon (plot 41)	900	1	0.11
Oak Woodland – Matanzas (plot 20)	900	0	0.00
Total:	8250	10	0.12
Mayfield et al. (2000) – Survey period July 1994–March 1995			
Habitat / Location	Trap Effort	Number	Capt rate
Chaparral	1176	0	0.00
Coastal Sage Scrub	1176	0	0.00
Grassland	1176	0	0.00
Fennel Grassland	1176	0	0.00
Oak Woodland	1176	0	0.00
Total:	5880	0	0.00
Graham and Chomel (1997) – Survey period March 1996			
Ranch	600	0	0.00
East Valley	600	1	0.17
Total:	1200	1	0.08

Table 3. Capture rate of harvest mice from six sampling grids on Santa Cruz Island, from 1991 through 1995 (R. Klinger data, from The Nature Conservancy), compared to the same grids in 2005 and 2006. Effort = number of trap-nights, capture rate = number of mice divided by effort, times 100.

	1991–1995			2005–2006		
Location (Grid)	No. mice	Trapping effort	Capture rate	No. mice	Trapping effort	Capture rate
Willows Grassland (38)	0	300	0.00	2	49	4.08
Willows Oak (41)	1	600	0.17	1	109	0.92
Central Valley fennel – grass (23)	0	450	0.00	0	50	0.00
Central Valley Coastal Sage (74)	2	750	0.27	1	80	1.25
Central Valley Grassland (81)	0	150	0.00	18	200	9.00
Lake Pasture fennel / grass (78)	5	750	0.67	5	86	5.81
Total:	8	3000	0.27	27	574	4.70

traps for one night), our failure to find harvest mice does not prove their absence and additional trapping effort would be needed to better ascertain whether harvest mice are present in those areas. Our data show the general extent of distribution on the island, but not the finer details of their occurrence.

Distribution and Numbers

The distribution of harvest mice on Santa Cruz Island is much wider than previously documented. Harvest mice occur from Scorpion Harbor on the east to the Black Point area at the west end of the island, and from the south shore (Willows Canyon and Valley Anchorage) to the north shore (Prisoners Harbor and Scorpion Valley). Based on our trapping, it appears that the species occurs across most or all of the island where there are sufficient areas of suitable habitat. In spite of the number of small mammal studies on Santa Cruz Island, there have been no previous extensive surveys that specifically targeted harvest mouse microhabitat. For this reason, our results probably do not indicate a large expansion in the range of the species. The disjunct distribution of harvest mice across the island suggests that they have been widely distributed in low numbers for some time, but have gone undetected. This evidently relictual pattern of occurrence probably reflects isolation of suitable harvest mouse habitat into restricted pockets. The patchy, but island-wide distribution also supports the long-term presence (i.e., pre-European times) of the species on Santa Cruz Island as suggested by Collins and George (1990).

The design of most of the earlier trapping studies does not allow calculation of population densities. However, we can estimate population trends by comparing relative abundance over time on the basis of capture rate. In 2004–2006, our capture rates of harvest mice were higher than had ever been reported on Santa Cruz Island, averaging 4.4% at individual sites. This is in contrast with earlier surveys, in which all capture rates for harvest mice were less than 1%. Thus, although distribution of harvest mice has probably not increased, our trapping results do indicate an increase in numbers.

Habitat

von Bloeker (1967) described the Prisoners Harbor location where he originally found harvest mice as being similar to harvest mouse habitat on the mainland, consisting of "patches of grass and forbs around springs and small streams, and … marshy areas dominated by growths of tules, bulrushes, and willows." At Prisoners Harbor, we frequently caught harvest mice at the edge of grass/herbaceous habitats and patches of willow and mule fat, but only rarely deep within patches of shrubs. None were captured under continuous tree or dense shrub canopy. We found a small number of harvest mice in the non-native kikuyu grass that blankets large areas in and around the historic corrals near the harbor. However, these occurrences were almost all along edges, where there was a mix of kikuyu and other native and non-native herbaceous plants.

Based on our trapping, harvest mice in the Prisoners Harbor area appear to be nearly or completely restricted to the marsh, parts of the

pasture in and around the corrals, and the back beach area at the harbor mouth, an area of roughly 1 ha (Fig. 3). We did not catch any harvest mice along the forested stream channel that traces the east edge of the Prisoners Harbor valley mouth. We also trapped the beaches and bluffs to the east and west of Prisoners Harbor (on either side of the black outline in Fig. 3, and beyond) and approximately 500 m up the drainage to the south (beyond the area shown in the photo).

Two seemingly unusual habitats at Prisoners that supported numbers of harvest mice were: 1) drier grass and herbaceous habitat in the archaeological exclosure east of the Prisoners Harbor wetland; and 2) the margin between beach sand and the wetland habitat behind the beach. The occurrence of harvest mice within the archaeological exclosure may be influenced by protection offered by the surrounding fence—both for the vegetation and for the mice. The back-beach habitat is different than most areas where we captured harvest mice, with a more extensive shrub canopy (mule fat and willow) and open understory with scattered grasses and such species as silver beachbur. Most of this habitat is adjacent to the Prisoners Harbor wetland and the mice may be using the wetland/beach edge.

Lower Scorpion Valley had one of the highest harvest mouse capture rates of any area on the island. The lower part of Scorpion has broad areas of tall, dense grass (primarily non-native smilo grass, *Piptatherum miliaceum*) with scattered shrubs. Our trapping at this site indicates that harvest mice occur throughout the extent of this dense, moist, low-lying grassland. Similar habitat occurs at the mouths of some other large drainages around the island, and harvest mice are to be looked for in such areas.

Harvest mice on Santa Cruz Island are also present in some drier upland areas, either in tall, thick grasslands, or in coastal sage scrub with intermixed grass and herbaceous vegetation. In coastal sage scrub, we captured harvest mice in gullies and small canyons that were wetter and had denser vegetation than the surrounding shrub

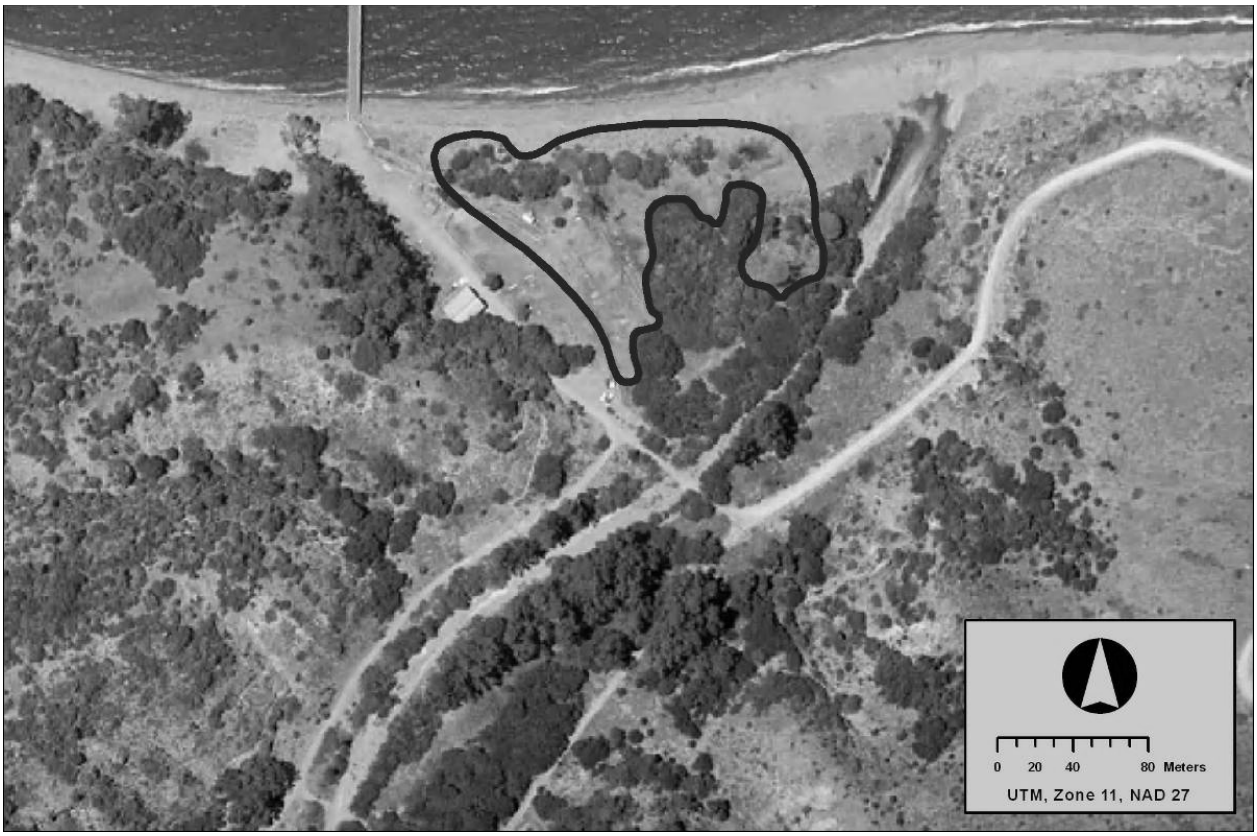

Figure 3. Local distribution of harvest mice at Prisoners Harbor, Santa Cruz Island, California. The broad dark line shows boundary of where harvest mice were captured from 2004 through 2006.

community. Grassland in the west end of the Central Valley where harvest mice occurred had low, boggy areas where ryegrass replaced the wild oats and bromes of drier sites. Such moist microhabitats may be especially important on slopes and hillsides that are otherwise relatively dry and sparsely vegetated.

Feral Animal Effects

Sheep, pigs, and other non-native animals were introduced onto Santa Cruz Island in the mid- to late-1800s. They subsequently increased to very high numbers, with estimates of sheep numbers in the late 1800s ranging up to 60,000 (Brumbaugh 1980). Their grazing, trailing, and other activity on the island was associated with major changes in the vegetation of Santa Cruz Island (Brumbaugh 1980; Junak et al. 1995). Careful descriptions, photographs, and other data from this time period are relatively few and detailed botanical data are lacking. Because of this, our understanding of vegetation changes that occurred is somewhat general in nature, and patchy in its geographic extent. For Santa Cruz Island and the other Channel Islands, however, it is generally agreed that there was widespread reduction of shrub and tree communities, denudation of ground cover with accompanying erosion, and severe losses of some plant species to the point of extirpation (Dunkle 1950; Coblentz 1980; Hobbs 1980; Peart et al. 1994; Junak et al. 1995).

The Santa Cruz Island Company (landowner of the island at the time) began efforts to reduce the numbers of feral sheep starting in 1939 (Junak et al. 1995). The Nature Conservancy assumed partial management of the island in 1978 and began an intensive removal program for sheep in 1981. Sheep were effectively eliminated from the western 90% of Santa Cruz Island by 1989 (Schuyler 1993). The island vegetation communities have shown marked recovery since that time, with increased vegetation cover, higher germination rates of tree and shrub seedlings, and increased numbers of some rare plant species (Schuyler 1993; L. Laughrin, personal communication). Junak et al. (1995) specifically noted increased vegetative cover and amount of water in coastal marshes at the mouths of canyons after the cessation of sheep grazing, and Klinger et al. (1994, 2002) recorded increased herbaceous cover and decreased bare ground in grassland habitat over the period 1984–1993. Greater cover and density of these marsh and grassland habitats should be particularly important for harvest mice on the island.

Santa Catalina Island is the only other member of the California Channel Islands where harvest mice have a long-established native population. In limited trapping on Santa Catalina Island, Perlmutter (1993) found harvest mice to be nearly as numerous as deer mice. Catalina also has more extensive areas of dense native shrub habitats and tall dense herbaceous vegetation. Although Santa Catalina Island still has non-native grazing animals (notably the managed herd of bison [*Bison bison*]), vegetation on that island may provide an indication of the conditions that Santa Cruz Island will tend toward following the removal of sheep, pigs, and other non-native species.

Although they outnumber harvest mice, numbers of deer mice on Santa Cruz Island are lower than on other islands in the Channel Islands group. Deer mouse populations on some of the other islands, particularly Santa Barbara Island (Drost and Fellers 1991), reach extraordinary levels—much higher than deer mouse densities reported anywhere else in North America. During high population periods on Santa Barbara, capture rates frequently exceed 100% (this can occur when individual traps catch two or three mice). Although we did not concentrate on deer mouse populations for this survey, their relatively low abundance may reflect the persistent effects of sheep, pigs, and other non-native animals on cover, food resources, and other habitat requirements (Mayfield et al. 2000).

Management Considerations

Feral pigs on Santa Cruz Island consumed, trampled, and uprooted herbaceous vegetation and young woody plants on the island. Vegetation surveys have found these effects in essentially all habitats on the island, including the grasslands, marsh, and other habitats where harvest mice occur. Up through the end of fieldwork for this study (April 2006), the wetlands and grassland at Prisoners Harbor showed extensive trailing and trampled vegetation from pigs. The control program by the National Park Service and The Nature Conservancy is now complete, and pigs have been eliminated from Santa Cruz Island. Based on what we know of habitat preferences of harvest mice, and of the effects of pigs on vegetation cover, we predict that

both distribution and numbers of harvest mice should increase. Numbers of deer mice on Santa Cruz are relatively low compared to populations on the other Channel Islands, and we expect this species to increase in numbers as well. In some areas, such as the much-reduced coastal sage scrub community and oak woodlands, vegetation recovery and associated changes in small mammal numbers will probably be gradual. In other areas, such as wetland habitats where vegetation regrowth can be rapid, increases in mouse numbers may occur more quickly. The island has been in the process of vegetation recovery since sheep were removed, and removal of pigs should have additional beneficial effects for the flora and fauna, including the harvest mouse.

Continued monitoring of small mammals on Santa Cruz Island should provide useful information on ecosystem changes that occur following the removal of non-native animals. Harvest mice have been of particular interest and concern because of their low numbers and sparse distribution, but deer mice occur much more broadly and changes in their numbers will potentially provide insights into a wider range of habitats. Both species have a high reproductive potential and are likely to respond quickly to expected changes in vegetation and food resources. Deer mice are also an important prey species for the endangered island fox (*Urocyon littoralis santacruzae*; Moore and Collins 1995). As discussed in this report, there is evidence of increased numbers of both harvest mice and deer mice associated with ongoing vegetation recovery on Santa Cruz Island. The data on small mammal populations collected by The Nature Conservancy (R. Klinger, unpublished) provides a substantial baseline for comparison of future changes, and continued trapping on some or all of the grids on an annual basis would provide an efficient monitoring program with broad habitat coverage. With removal of feral pigs now complete, monitoring over the next four to five years may be particularly important in understanding the response of the island ecosystem.

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