Chris Kofron

# INTRODUCTION OF CAPTIVE MORRO BAY KANGAROO RATS (*Dipodomys heermanni morroensis*) INTO AN ENCLOSURE ON CRITICAL HABITAT AT MONTANA DE ORO STATE PARK

FINAL REPORT: CALIFORNIA DEPARTMENT OF FISH AND GAME

CONTRACT # FG7568

BY


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MARCH, 1989

# MAJOR FINDINGS AND RECOMMENDATIONS

## Major Findings

1. Construction of a protective enclosure measuring 150 ft X 150 ft (0.212 ha) was completed by the California Conservation Corps on 13 April 1988.

2. The area inside and immediately outside the enclosure was part of a 13 ha parcel of Coastal Dune Scrub habitat (located on Critical Habitat for the Morro Bay kangaroo rat) that had been recovering from an experimental burn conducted in October 1984.

3. Plant cover on the site before the fire was mainly shrubs dominated by California sagebrush, mock heather, California aster, sand almond, and holly-leaf cherry. Plant cover inside the enclosure in 1988 included more herbs and subshrubs than shrubs. Bare sand and herbaceous growth covered 68% of the enclosure while subshrubs and shrubs covered 32%. Dominant shrubs and subshrubs in the enclosure were deerweed, mock heather, California aster, and croton.

4. Prior to the release of Morro Bay kangaroo rats, trapping was conducted in the enclosure from 13 April to 16 May in order to remove potential competitors and predators. California ground squirrels, deer mice, California pocket mice, striped racers, gopher snakes white-crowned sparrows, golden-crowned sparrows, and one house finch had no difficulty entering the enclosure through either the 1/2 in. aviary wire sides or the 1 1/2 in. plastic roof netting. One immature red-tailed hawk broke through the roof netting and was removed by us, uninjured.

5. California ground squirrels were excluded from the enclosure by covering all vertical and horizontal, 6 in. support posts with 8 in. aluminum flashing.

6. Striped racers and gopher snakes were eventually excluded from the enclosure by attaching 20 in. aluminum flashing at ground level around the outer perimeter of the enclosure.

7. Mice and sparrows are still able to enter the enclosure. Apparently mice are able to leave the enclosure with no difficulty, but sparrows are not. Dead sparrows were found inside the enclosure and a dozen or so live birds are usually seen in the enclosure.

8. Three Morro Bay kangaroo rats (1 male and 2 females) were released into artificial burrows inside the enclosure on 27 May 1988. One additional male was released in the same manner on 21 July 1988.

9. Supplemental feed (4 parts hamster chow, 1 part sunflower seeds, 1 part wild bird seed, and 1 part old fashioned rolled oatmeal) was provided in 1 gallon pet feeders and spread liberally on the ground from 27 May to 3 August 1988. Proso millet seeds from the wild bird seed mix and sunflower seeds were regularly taken by the rats in the enclosure. Most of the compressed food pellets in the hamster chow remained on the ground. Mice and birds undoubtedly took a substantial portion of the supplemental feed while it was available. Deerweed was setting seed in August and most of the other plants in the enclosure had produced seeds by mid-October.

10. The 2 females remained in good physical condition inside the enclosure (maximum weight loss = 4 g, maximum weight gain = 5 g) throughout the study period. Neither animal exhibited signs of reproduction during the study period; however this was not surprising because they were released more than a month after the peak breeding season of the wild population at Bayview.

11. We were unable to monitor signs of activity or recapture the first male released with the 2 females in May. He may have been taken by a predator, been killed by one of the females, died in his burrow, escaped, or simply evaded our trapping and burrow monitoring activities.

12. The second male released in July remained in good physical condition inside the enclosure (maximum weight loss = 4 g) during the study period. We are reasonably confident that this was the animal we saw engaged in repeated social interactions (sparring, chasing, and body rubbing at a burrow entrance) with one of the females on 21 July. This male escaped from the enclosure in late October or early November because he was captured outside on 29 November. Since the male escaped before it could be returned to the enclosure, it was presumed to be free-ranging at the end of the study period.

13. A composite map showing the locations of burrow systems, tail drags, and small foraging digs revealed that the Morro Bay kangaroo rats in the enclosure used 74% of the total area inside the enclosure. No statistical difference was found between the proportion of each major ground cover category occurring within the

entire enclosure and the proportion of these cover categories used by Morro Bay kangaroo rats. That is, Morro Bay kangaroo rats in the enclosure showed no distinct preference for any cover category as measured by combined data from their locomotion, foraging and burrowing.

14. In contrast to their general habitat use (#13. above), Morro Bay kangaroo rats in the enclosure showed a statistically significant preference for certain ground cover characteristics in the immediate vicinity of their burrow systems. When the ground cover types located within 61 cm (2 ft) of the 36 burrow systems were ranked from most frequent to least frequent, deerweed ranked first, followed by mock heather, California aster, and open ground. Groundsel, black sage, California sage, coast silver lupine, and coastal buckwheat were least frequently associated with burrow systems.

15. Most burrow systems showed oscillating patterns of activity (ranging from 1-146 days) and inactivity (ranging from 1-40 days). The average number of simultaneously active burrow systems per Morro Bay kangaroo rat in the enclosure was 6 burrow systems / individual in the summer and 10 burrow systems / individual in the fall. Extrapolation of these values to an one hectare area gives 84 active burrow systems / 14 individuals in the summer and 140 active burrow systems / 14 individuals in the fall. If we had to pick a single set of values we would choose those for fall because of the confounding effects of supplemental feeding during most of the summer months.

16. Deer mice were the most abundant small mammal species in the enclosure before Morro Bay kangaroo rats were released in May. A few western harvest mice were present, but their numbers were comparatively low throughout the study period.

17. California pocket mice were not caught in the enclosure before Morro Bay kangaroo rats were released, but they reached extremely high densities in the enclosure after rats were released and this pattern persisted through the last census period in October. A few deer mice were present in the fall, but not as many as were found in the spring, before rats were released. The density of California pocket mice inside the enclosure during the fall (97 individuals / ha) was over 6 times greater than their density in the fall on another study plot located immediately adjacent to the enclosure. Dispersal was one factor contributing to the high density of pocket

mice because 1/3 to 1/2 of the pocket mice caught inside between August and October (after supplemental feeding had been discontinued) were juveniles or subadults. It appears that factors in addition to general dispersal may have been involved in this phenomenon, otherwise we would have found comparable densities in the plot adjacent to the enclosure.

**18.** Different thermal gradients in soil temperature throughout the year produced some interesting patterns in subsurface temperatures collected at 10, 30, and 60 cm. During the summer months (June - August), median soil temperature was warmest at the 10 cm level and coolest at the 60 cm level. Between August and September a thermal turnover occurred such that during the fall and winter months (September - December), median soil temperature was coolest at the 10 cm level and warmest at the 60 cm level. If Morro Bay kangaroo rats burrowed to a depth of about 35 cm or if they adjusted their burrow depths to optimize the seasonal thermal regime in the soil, they would be able to avoid most periods of thermal stress during the year.

**19.** We found no evidence of potential predators (snakes) in the enclosure after 15 July. The tracks of people, domestic dogs and cats, bobcats, raccoons, deer, horses, rabbits, rodents, snakes, and birds were seen around the enclosure and/or around the outer barbless wire fence. The principal investigator was surprised that deer did not jump into the enclosure during the study period. Other than small holes in the roof netting caused by ground squirrels and birds, no other signs of damage or vandalism were seen in 1988. Horse tracks were found in the vicinity of the last burrow entrances known to be used by male # 2702R after he escaped from the enclosure. We hope that this animal was not killed underground by horses walking overhead.

Management Recommendations

1. Continue to pursue the goals of the Recovery plan as vigorously as possible.

2. Plow a 10-15 acre experimental plot at the Pecho site using a ground-breaking "ripper" behind a bulldozer. Pile and burn or chip and haul all plant debris removed by this procedure.

3. Initiate a ground squirrel control program throughout the Critical Habitat area as soon as possible. As more Morro bay kangaroo rats become free-ranging in the area, the risks to the rats from this procedure will increase to a point where it is no longer feasible.

4. Identify and secure (as soon as possible) additional "undeveloped" parcels of land which could be used or restored to a usable condition for subsequent Morro Bay kangaroo rat introductions. Since the private land surrounding Critical Habitat is rapidly being developed, it is essential that a coordinated and cooperative plan be developed to ensure the optimization of available habitat among these parcels.

5. A long-range program of experimental habitat manipulation and/or restoration followed by successive introductions of Morro Bay kangaroo rats should be initiated for the Critical Habitat area as well as other potential sites within the rat's historic range.

6. At least one more enclosure similar to the existing one should be installed on Critical Habitat as soon as possible.

7. Annual ground reconnaissance of Critical Habitat, Essential Habitat, and land adjacent to these areas should be conducted to ensure early detection of adverse impacts to the habitat and/or Morro Bay kangaroo rats on these areas. Close coordination between state, federal, county, and private individuals is mandatory if this effort is to succeed.

8. Elevate the roof netting and support wires on the existing enclosure to a minimum height of 6 1/2 ft as soon as possible. The risk of injury (falls, strains, and cuts) to personnel working inside the enclosure would be dramatically reduced by this procedure.

9. Develop and promote conservation and/or recovery activities for the Morro Bay kangaroo rat through such organizations as the Morro Bay Museum of Natural History, Sierra Club, or any other private or public organization involved in such activities.

Research Recommendations

1. Increase the support to the USFWS captive breeding program in order to accelerate the production of new animals for future introductions.

2. Conduct controlled food discrimination experiments on captive Morro Bay kangaroo rats to provide a more comprehensive understanding of their preference for native plants in their historic range. This information could be incorporated into habitat restoration procedures in the field.

3. Conduct population estimation studies on all wild populations of Morro Bay kangaroo rats. The last estimates made on the wild populations was in 1986.

4. Design a set of field experiments which would assess the utility of several different types of habitat manipulation/restoration actions in enhancing populations of Morro Bay kangaroo rats.

5. Expand the type and intensity of monitoring efforts directed toward newly introduced Morro Bay kangaroo rats while they are inside the enclosure and after they become free-ranging outside.

6. Continue both small mammal population studies and plant community studies on all plots previously monitored at the Pecho and Bayview sites.

7. Determine the genetic variance of both wild and captive Morro Bay kangaroo rats using no-risk genetic "fingerprinting" techniques as soon as possible. Preserve cellular and/or genetic specimens of representative animals in a long-term gene bank for future scientific research.

8. Establish a local "research/recovery center" for Morro Bay kangaroo rats in an attempt to increase the efficiency of implementing all aspects of research, management, and planning directed toward this endangered species.

# INTRODUCTION

Morro Bay kangaroo rats *(Dipodomys heermanni morroensis)* were once common on the stabilized sand dunes south of Morro Bay (Dixon 1918, Grinnell 1922, Stewart 1958, Stewart and Roest 1960). Over the years, both their numbers and their distribution have steadily decreased to a point where about 50 individuals inhabited about 13 ha at the Bayview site in 1986 (Congdon 1971, Congdon and Roest 1975, Roest 1977, Toyoshima 1983, Roest 1984, Gambs 1986a, 1986c, 1986g, Villablanca 1987, and Gambs and Holland 1988). Factors contributing to this decline include: direct loss of habitat, changes in the remaining habitat, predation by cats and dogs, destruction of burrows by vehicle, livestock, and pedestrian traffic, competition with other burrowing rodents, fragmentation of large populations into small sub–populations, and perhaps inbreeding (Roest 1982b, Gambs 1986c, Gambs and Holland 1988).

In response to the negative population growth observed in the subspecies since 1957, the Morro Bay kangaroo rat was listed as an Endangered Species by the U. S. Fish and Wildlife Service in 1970 and the California Department of Fish and Game in 1971. In 1977, the U. S. Fish and Wildlife Service designated the Pecho area as Critical Habitat for the Morro Bay kangaroo rat (Federal Register 42 (155): 40685 - 40690 and 42 (184): 47840 - 47845). In 1978, the State of California (DFG) purchased a 50 acre parcel of land adjacent to Montana de Oro State Park and established the Morro Dunes Ecological Reserve (Lidberg 1982). The U. S. Fish and Wildlife Service completed a Recovery Plan for the Morro Bay kangaroo rat in 1982, which summarized the status of the subspecies and outlined the steps necessary for its recovery. The long–term goal of the Recovery Plan is to establish a population of at least 2,500 animals located on at least two different sites in the vicinity of Los Osos/Baywood Park, CA. The Pecho site represents one of the two sites (above) and most of the efforts to manage the Morro Bay kangaroo rat and it's habitat have been focused there. Although no rats have been trapped at Pecho since 1979, efforts to improve habitat there by manual brush clearing (1983) and prescribed burns (1984, 1985, 1986) have been conducted in anticipation of this and subsequent re–introduction attempts. The present study, therefore, represents one part of a long–term program of research and habitat manipulation aimed at implementing the Recovery Plan for the endangered Morro Bay kangaroo rat.

This study reports on the first attempt to introduce captive Morro Bay kangaroo rats into the field and documents their first year (May to December, 1988) in Coastal Dune Scrub habitat at Pecho which had been burned in 1984. In order to minimize risks from predation, competition, and human disturbance, we released Morro Bay kangaroo rats into a protective enclosure purchased by the U.S. Fish and Wildlife Service and built by the California Conservation Corps.

The present study was funded by California Department of Fish and Game, U.S. Fish and Wildlife Service, California Department of Parks and Recreation, and was conducted in cooperation with California Polytechnic State University, and California Conservation Corps.

Specific tasks attempted/conducted during this project include:

1. Remove all snakes and small mammals from the enclosure.
2. Remove any remaining exotic vegetation from the enclosure.
3. Prepare a cover map of all woody plants in the enclosure.
4. Install burrows and feeding station for rats in the enclosure.
5. Transport and release in the enclosure, 4 Morro Bay kangaroo rats from the Captive Breeding Colony at Cal Poly.
6. Replenish food at feeding stations for the first 1-2 months.
7. Periodically map burrow systems created by rats in the enclosure.
8. Trap, weigh, and assess the condition of rats in the enclosure.
9. When possible, observe rats in the enclosure at night.

10. Record and report evidence of adverse conditions to either the rats or the enclosure. Coordinate communication among agencies when necessary.
11. When possible, maintain visible presence around the enclosure.
12. Summarize progress and submit 5 progress reports to DFG.
13. Summarize data and submit a final report (this document) to DFG.

# METHODS AND MATERIALS

## STUDY AREA

The Pecho site is located West of the village of Los Osos, Ca.; on Sections 14 and 23, T30S, R10E, Morro Bay South Quadrangle; Longitude 120° 52', Latitude 35° 18' (Gambs 1986). The site is roughly bordered by Morro Bay to the North, Pecho Valley Road to the East, Hazard Creek to the South, and the Pacific Ocean to the West (Figure 1). The Morro Bay kangaroo rat enclosure at Pecho is located approximately in the center of a 13 ha area which was burned in October, 1984 (Figure 2). It overlays slightly the southern border of study plot TUVWX.

The present physiography and geology of the Pecho site was determined largely by sea level fluctuations and erosion during the Pleistocene (about 10,000 years ago) which lead to sand dune formation up to an elevation of about 900 ft along the southern side of Los Osos valley. Most of the Pecho area is covered by Baywood Fine Sand which supports a mosaic of Pioneer Coastal Dune, Coastal Dune Scrub, and Chaparral plant communities. Coastal Oak Woodland, located east of the Pecho site, dominates the oldest dunes and is considered to be the climax vegetation for the area (Holland 1986, Holland and Keil 1986, and Gambs and Holland 1988).

The overall effects of the fire on the soils and vegetation within the perimeter of the burn include: increased soil pH (from 5.6 to 6.7); increased soil fertility (as measured by sulfate, chloride, phosphorous, magnesium, calcium, and potassium); removal or suppression of allelopathic soil substances; increased plant species diversity; and a marked change from a plant community dominated by shrubs such as California sagebrush, mock heather, California aster, sand almond, and holly–leaf cherry to a community dominated by herbs and subshrubs such as fiddleneck, little evening–primrose, California goosefoot, cryptantha, and annual golden yarrow (Holland 1986 and Gambs and Holland 1988). Many of the shrubs resprouted soon

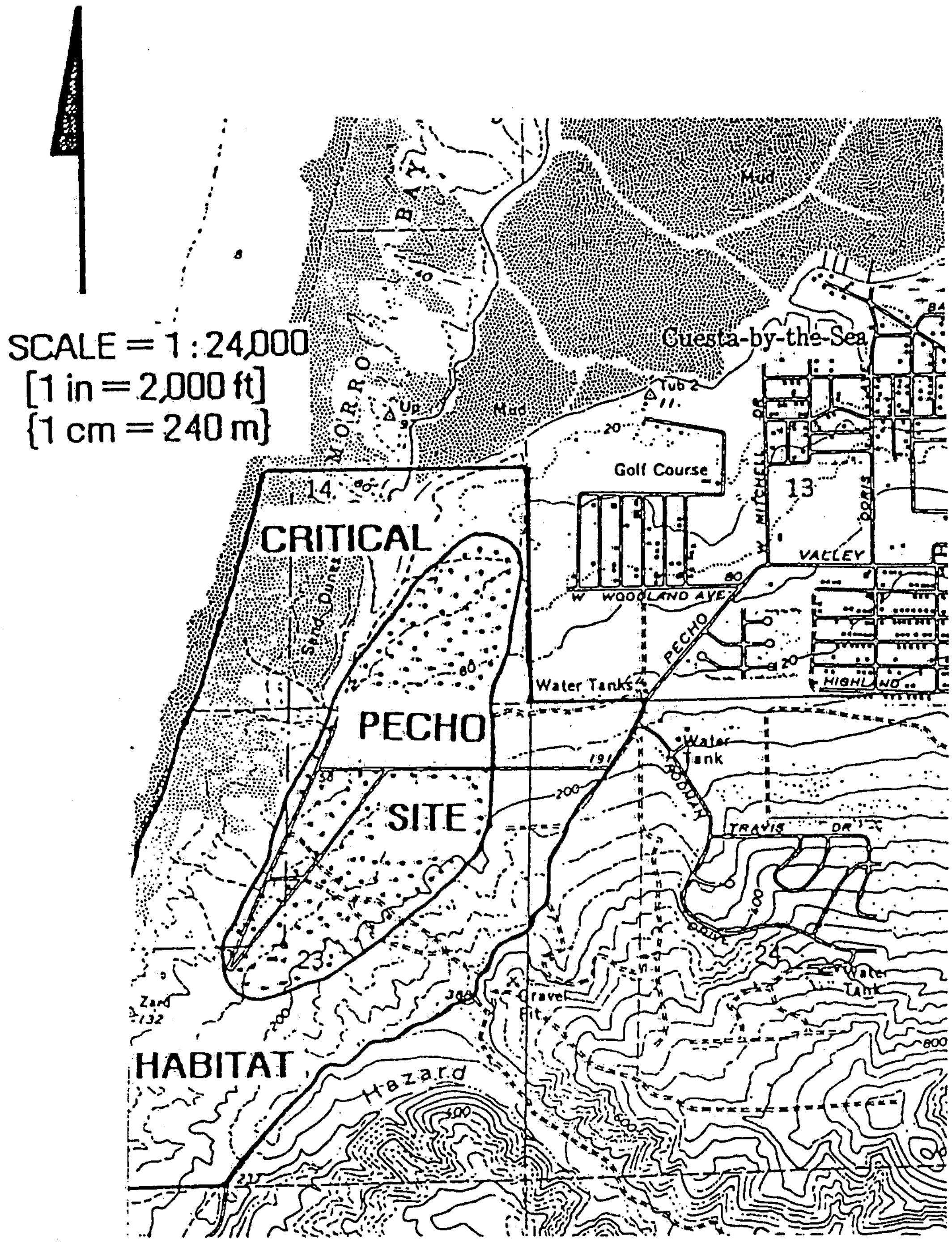



Figure 1. Location of the Pecho study site within the Critical Habitat area of the endangered Morro Bay kangaroo rat.

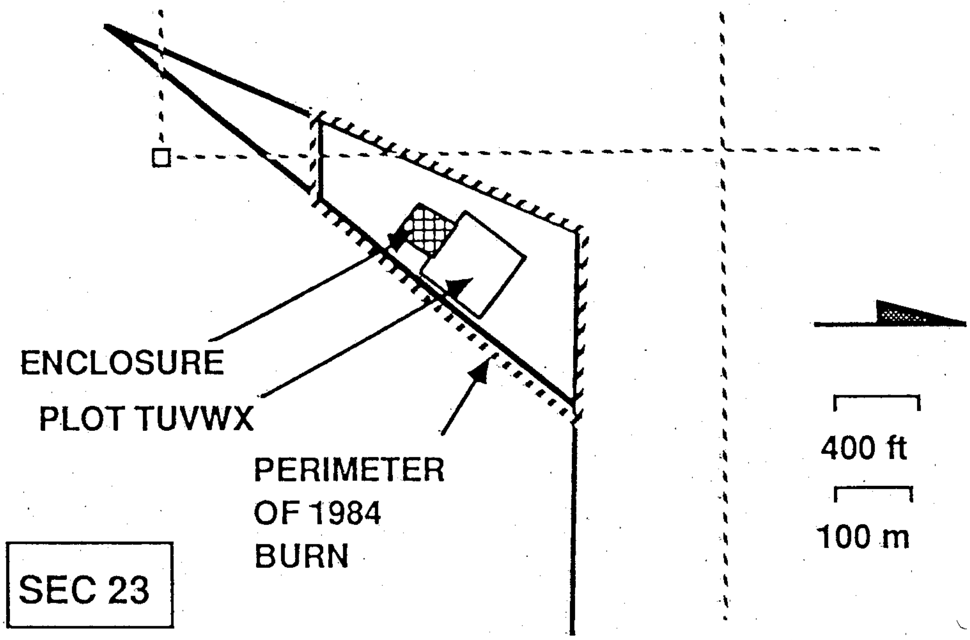



Figure 2. Location of the enclosure within the 1984 prescribed burn area. Note proximity of the enclosure to plot TUVWX.

after the fire; however, the severity of the fire was such that a number of years will be required for the plant community and soil to return to pre–burned conditions. When compared to adjacent, unburned habitat, the vegetation on the burned area was less similar to the vegetation on habitat occupied by Morro Bay kangaroo rats at the Bayview site (Gambs and Holland 1988).

The overall effects of the fire on the small mammal community at Pecho include: reduction in species richness from 5 species (dusky–footed woodrats, California mice, California pocket mice, deer mice, and western harvest mice) to 3 species (California pocket mice, deer mice, and western harvest mice); increased densities of California pocket mice and deer mice; and invasion by California ground squirrels (Gambs 1986b, 1986d, 1986g, and Gambs and Holland 1988). The small mammal community on the burned habitat was somewhat different from that on unburned habitat at Pecho, but not to a level where the small mammal community on the burned habitat could be considered to approach that on habitat occupied by Morro Bay kangaroo rats at the Bayview site (Gambs and Holland 1988).

ENCLOSURE

Originally, the field enclosure to be used to house lab-born Morro Bay kangaroo rats was proposed as a portable structure that could be moved from site to site, much like that used during an earlier, surrogate study with *D. h. arenae* (Gambs 1986f). As the dimensions and details of construction required in sandy soil approached finalization, it became clear that a more substantial support system would be required to ensure a secure structure that would require minimum maintenance.

Construction of the enclosure by the California Conservation Corps was completed on 13 April 1988. An aerial view of the enclosure showing the dimensions and placement of support structures is presented in Fig. 3. A side view of the enclosure showing the placement of fencing, flashing, and plastic netting is

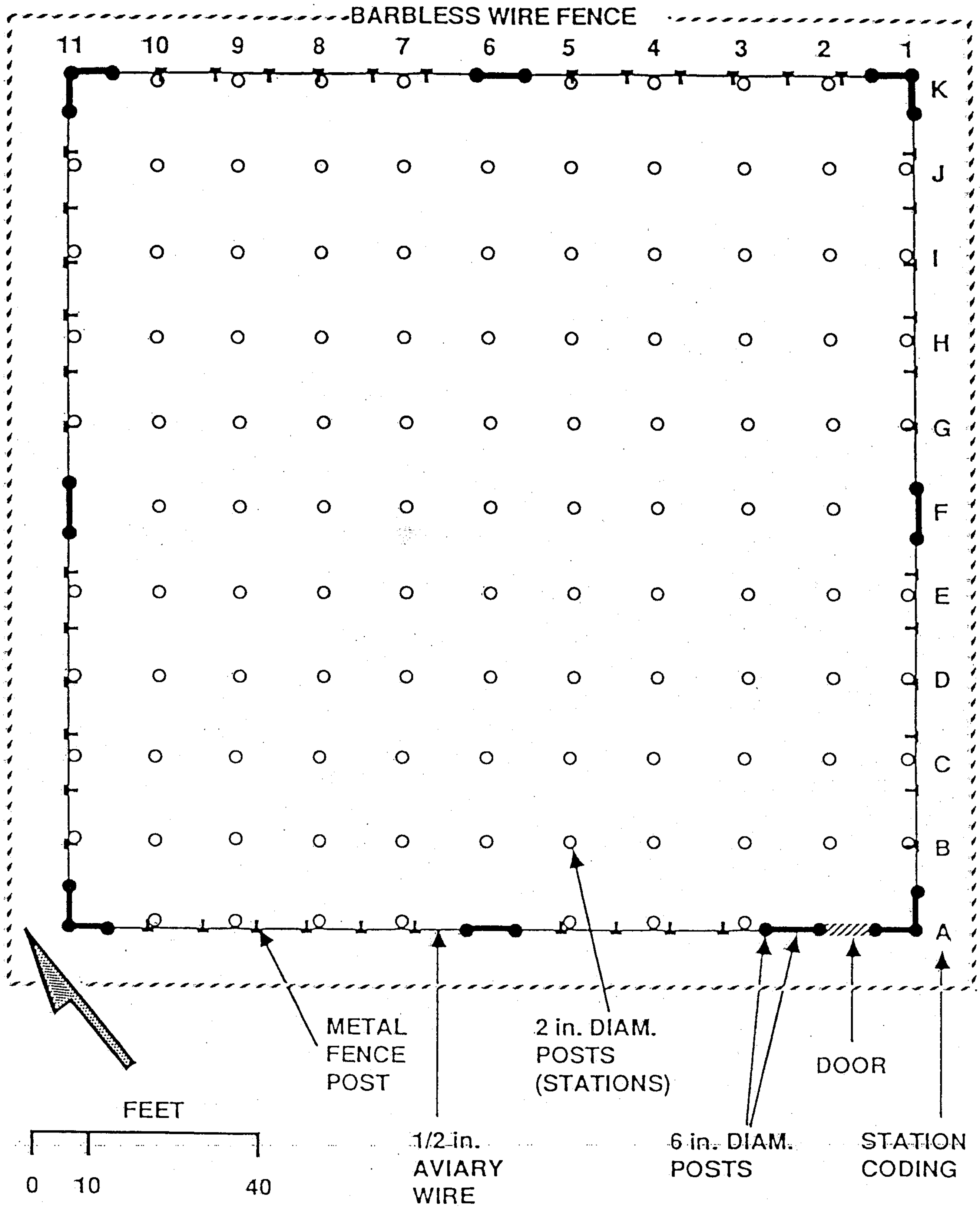



Figure 3. Aerial view of the enclosure showing materials, dimensions, and locations of sample stations.

presented in Fig. 4. All wooden support posts were treated to resist mold, rot, and insects. The distance between the ground and the roof netting ranged from 1.07 m on a small rise to 1.71 m along an old road bed. The average slope over the area of the enclosure was about 9 %.

Station markers were fabricated from 7 in. X 2 3/4 in. pieces of white aluminum flashing, lettered with black paint, and stapled to support posts making an 11 X 11 grid with lines A-K running roughly South to North and lines 1-11 running roughly East to West (Fig. 5). All 121 station markers were installed by 26 April.

By 26 May, 8 in. or 14 in. wide strips of aluminum flashing were nailed over the outside surface of all 6 in. posts to discourage California ground squirrels *(Spermophilus beecheyi)* from entering the enclosure. On 24 June, the California Conservation Corps installed 20 in. wide aluminum flashing at ground level around most of the outside perimeter of the aviary wire fence to discourage snakes from entering the enclosure. An 8 ft gap in this ground-level flashing was covered on 21 July.

All dead wood and conspicuous exotic plants (eg. iceplant - *Carpobrotus* sp.) which would have hindered Morro Bay kangaroo rats or field work were removed from the enclosure by 23 May. New exotic plants were removed from the enclosure as they were found. All discarded plant matter was deposited around the outside of the enclosure.

## VEGETATION

The enclosure was built over a previously burned Coastal Dune Scrub plant community that had been regenerating for 3 1/2 years. Dominant plants before the fire were: California sagebrush, mock heather, California aster, sand almond, and holly–leaf cherry. Living and dead parts of small shrubs, herbs, and litter burned

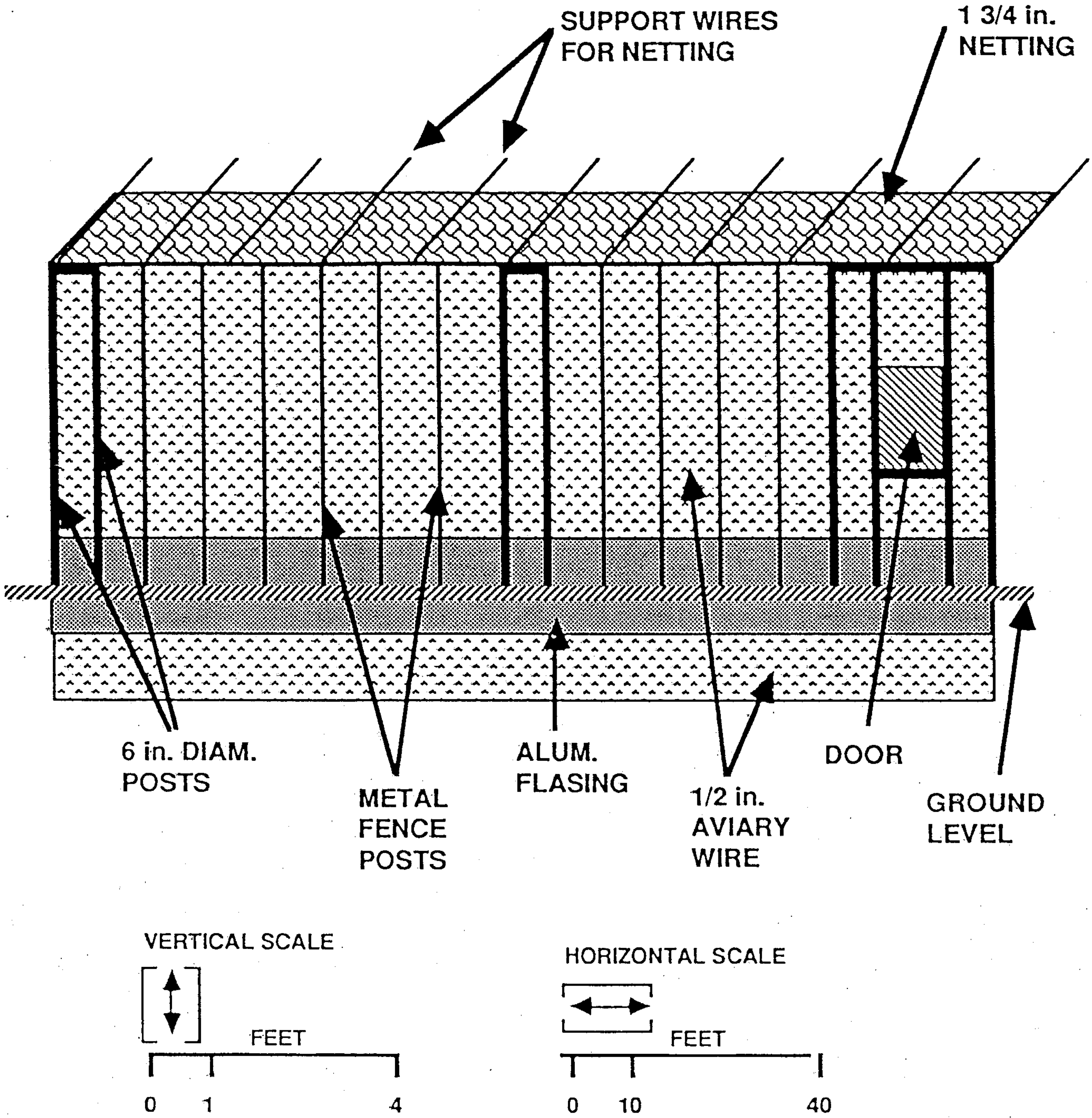



Figure 4. Side view of the enclosure showing construction materials and dimensions. Note the difference in horizontal and vertical scales.

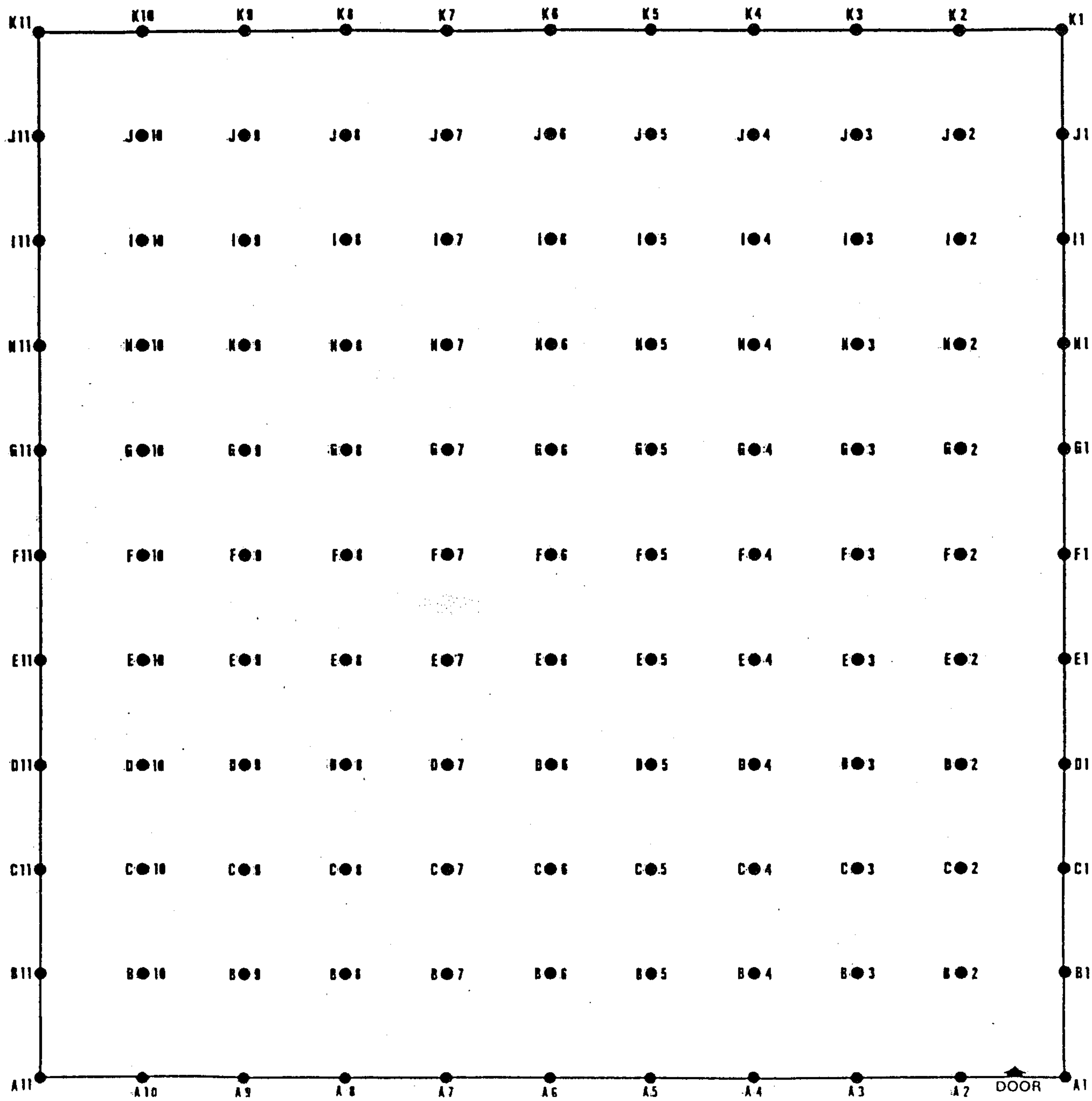



Figure 5. Location of 121 stations in the enclosure. Lines A-K run approximately South to North and lines 1-11 run approximately East to West. Stations are spaced 4.6m (15 ft) apart.

thoroughly during the fire, but the taller shrubs (eg. *Prunus ilicifolia)* resisted the fire and survived. The first year after the fire, much of the open ground created by the fire was covered by herbaceous plants (Holland 1986). Through 1986, the plant community on the burn site was dominated by herbs and subshrubs such as fiddleneck, little evening–primrose, California goosefoot, cryptantha, and annual golden yarrow (Holland 1986 and Gambs and Holland 1988). In 1987, small shrubs and unburned brush had new growth and many of the shrubs that had been killed above ground had new growth at their bases (Nelson 1987). By the time of this study, 3 1/2 years after the burn, the tallest shrubs in the enclosure had reached heights of about 1 meter. However, most shrubs were 1/2 to 3/4 m high and low-growing subshrubs and herbs covered more ground than did the shrubs. Charred stems of shrubs are still conspicuous on the landscape and dead twigs and branches were locally abundant in the southwest corner of the enclosure where the fire did not burn as hot.

To verify plant identification, specimens of the major species of shrubs, subshrubs, and herbs were collected and taken to Dr. Dirk Walters at Cal Poly. Detailed mapping of the 13 most common species began on 5 May and was completed on 15 June. The 13 plant species were given numerical codes for purposes of mapping (below).

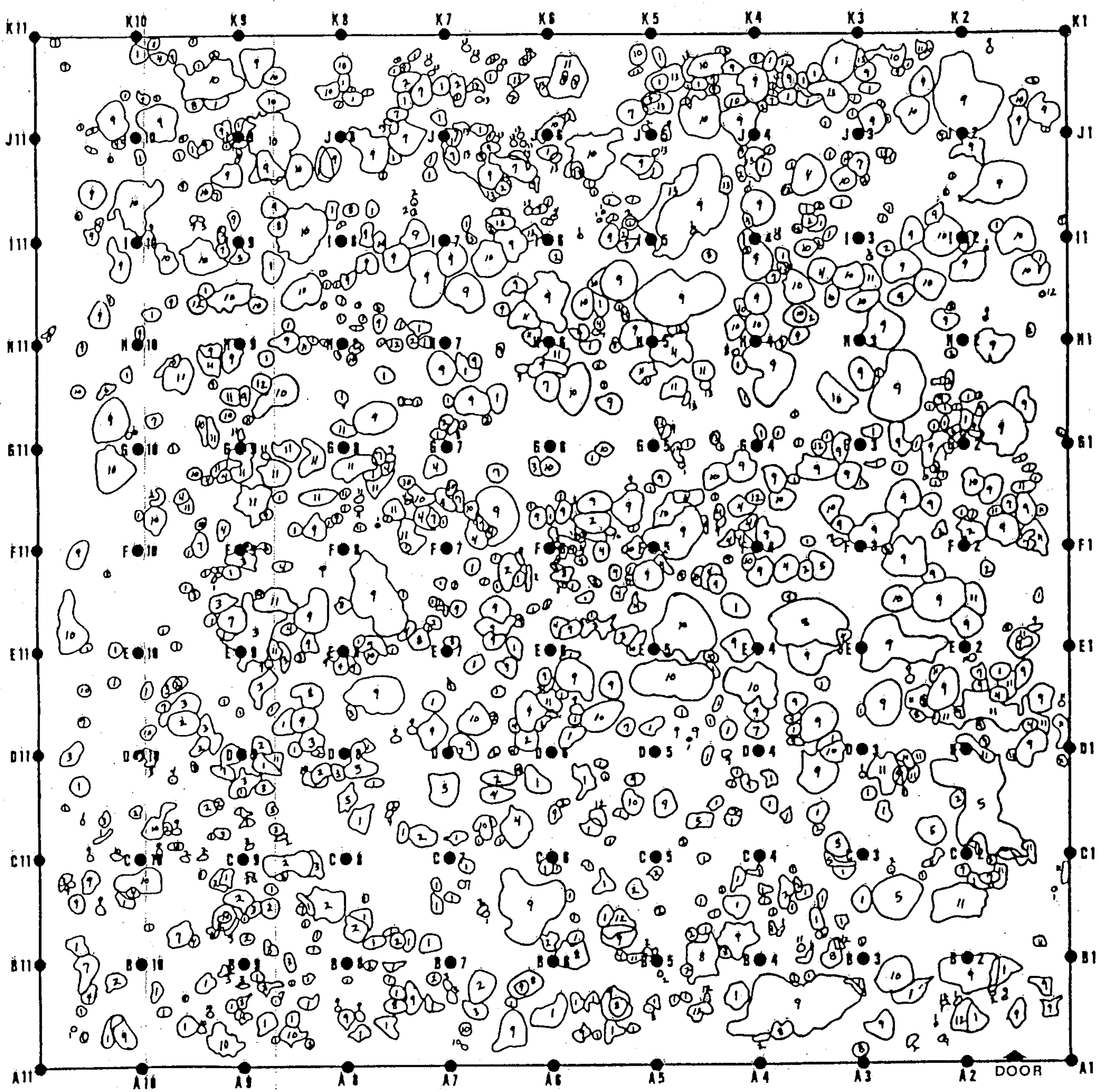
| CODE | SCIENTIFIC NAME | | COMMON NAME |
|---|---|---|---|
| 1 | *Corethrogyne filaginifolia* | - | California aster |
| 2 | *Senecio blochmanii* | - | shrubby groundsel |
| 3 | *Prunus fasciculata* var. *punctata* | - | sand almond |
| 4 | *Eriophyllum confertiflorum* | - | coast golden yarrow |
| 5 | *Salvia mellifera* | - | black sage |
| 6 | *Horkelia cuneata* | - | horkelia |
| 7 | *Artemisia californica* | - | California sagebrush |
| 8 | *Lupinus chamissonis* | - | coastal silver lupine |
| 9 | *Lotus scoparius* | - | deerweed |
| 10 | *Ericameria ericoides* | - | mock heather |

| | | | |
|---|---|---|---|
| 11 | *Croton californicus* | - | croton |
| 12 | *Eriogonum parvifolium* | - | coastal buckwheat |
| 13 | *Toxicodendron diversilobum* | - | poison oak |

To expedite the recording of field observations, this vegetation key, a coded key of animal activities and a checklist of prevailing weather conditions were included on the vegetation field map (Fig. 6).

The cover of each species mapped in the enclosure was determined by measuring each plant on the map using either a LASICO (Model L30), compensating, polar planimeter or a transparent, square grid overlay. A separate vegetation map was made for each species and then each species was shaded after it was measured (Fig. 7). The number of planimeter units or grid squares was totalled for each species and divided by the number of units or squares per $in^2$. Since 1 in on the map is equal to 15 ft in the enclosure, 1 $in^2$ on the map equals 225 $ft^2$ in the enclosure. Using this relationship and the total cover of a species, we were able to determine the $ft^2$, $m^2$, and % cover of each species in the enclosure.

Activity maps (showing tail drags and digs), drawn in the field, were used to determine the total cover which was either used or unused by Morro Bay kangaroo rats. All activity maps were superimposed onto a tracing paper overlay to create a master map of all activity areas. Only those activity maps prepared after the discontinuation of artificial feeding were used in this analysis. Because most of the visible activity (tail drags, digs) occurred on open ground, the perimeter of the active area on the overlay was expanded by 1/4 in (= 3.75 ft on the ground) to incorporate plants adjacent to the active areas (Fig. 8). The cover of unused areas (Fig. 9) was found in a fashion similar to that for the cover of used areas, described above.




N

1 in = 15 ft

DATE: ______ Day ______ Month ______ Year

TIME: START______ END______

OBSERVER: ______________

WEATHER: COLD COOL WARM HOT

CALM BREEZE WINDY

FOG MIST RAIN

CLEAR Pt. CLOUDY OVERCAST

AIR TEMP: ______ °C

SUBSTRATE: DRY DAMP WET

MOONLIGHT: NONE 1/4 1/2 BRIGHT

- ◯ Burrow
- Δ Dig
- ~ Tail drag
- - - Snake track

1 - Corethrogyne filaginifolia
2 - Senecio blochmanii
3 - Prunus fasciculata
4 - Eriophyllum confertiflorum
5 - Salvia mellifera
6 - Horkelia cuneata
7 - Artemisia californica
8 - Lupinus chamissonis
9 - Lotus scoparius
10 - Ericameria ericoides
11 - Croton californicus
12 - Eriogonum parvifolium
13 - Toxicodendron diversilobum

Figure 6.

Vegetation map with species list, checklist of prevailing weather conditions, and coded key of animal activity.

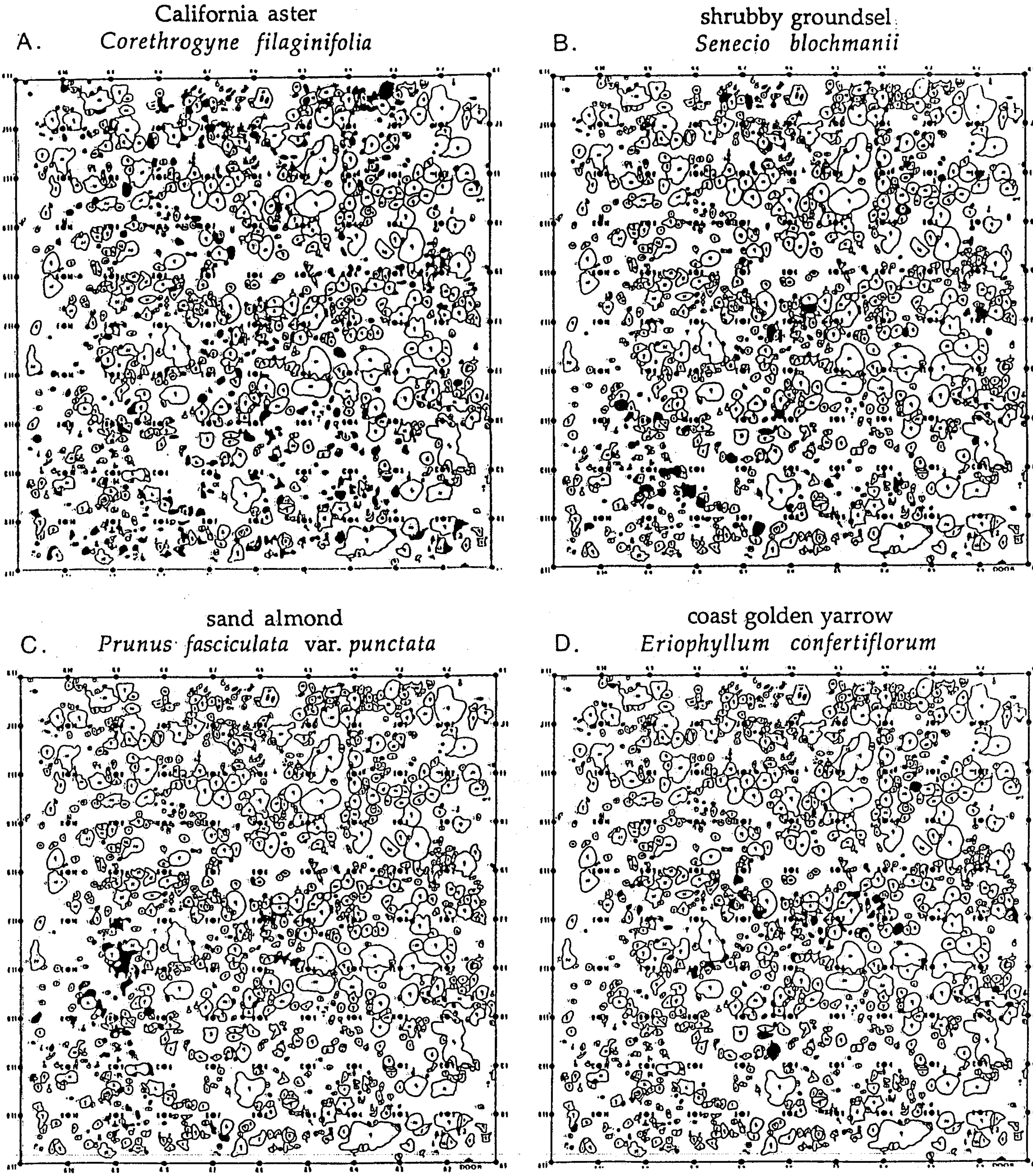
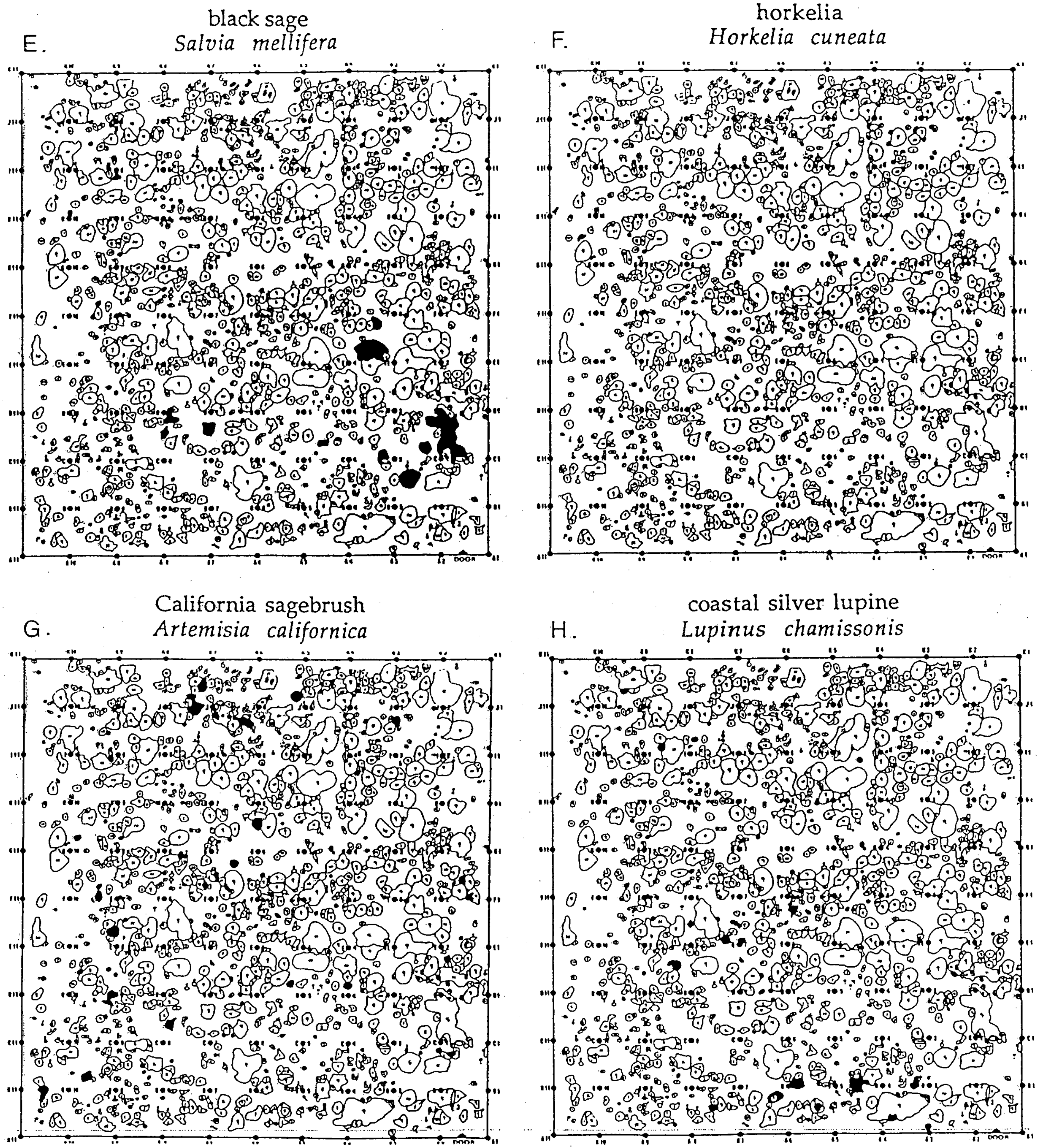



Figure 7. Locations of mapped plant species in the enclosure. Shrubs of species indicated are darkened.

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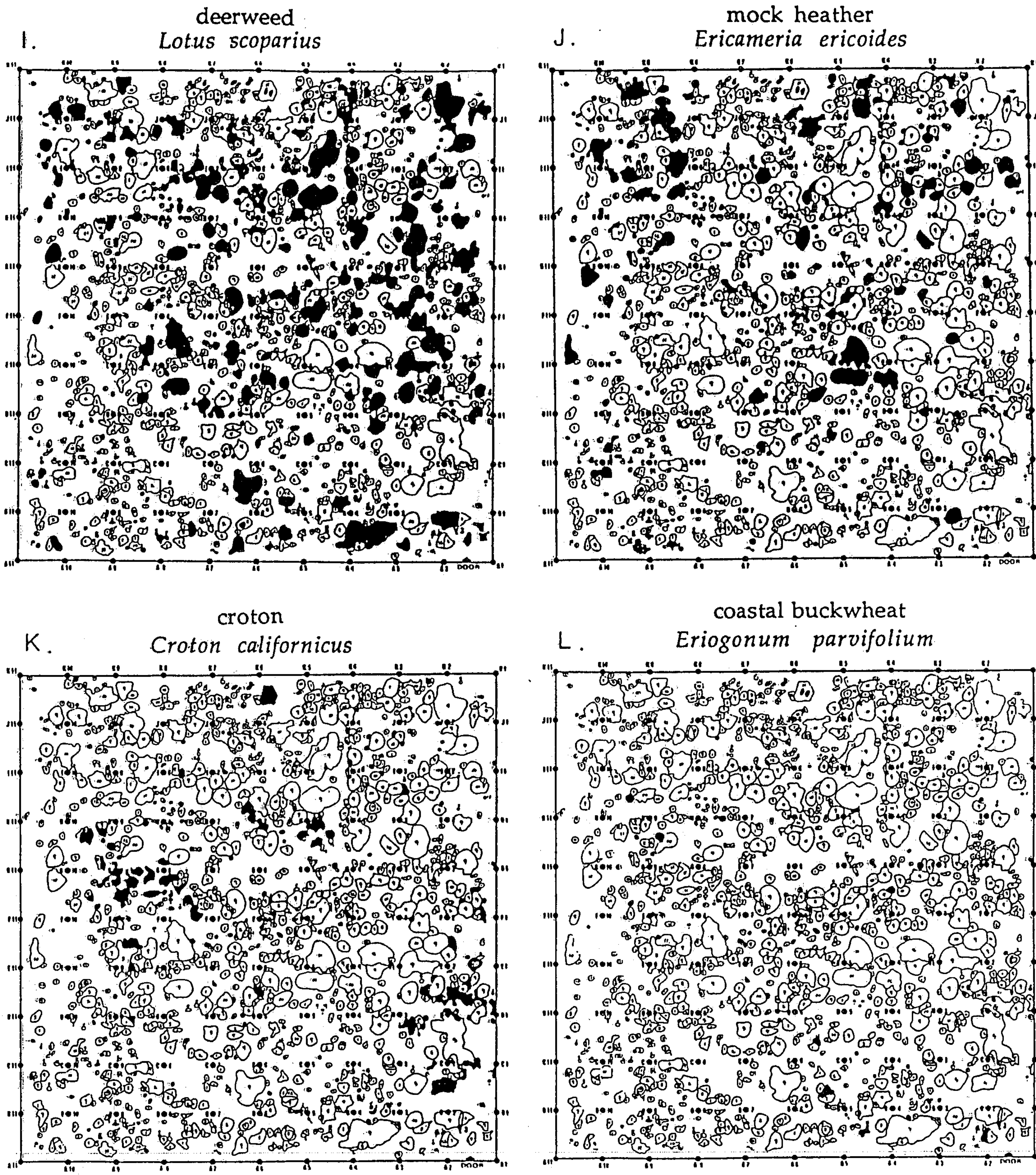


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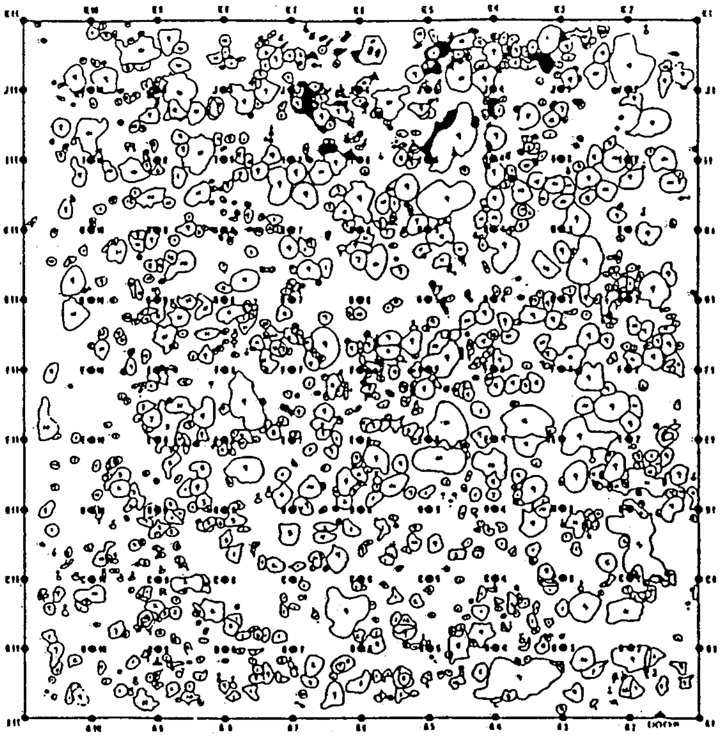
poison oak

M. *Toxicodendron diversilobum*



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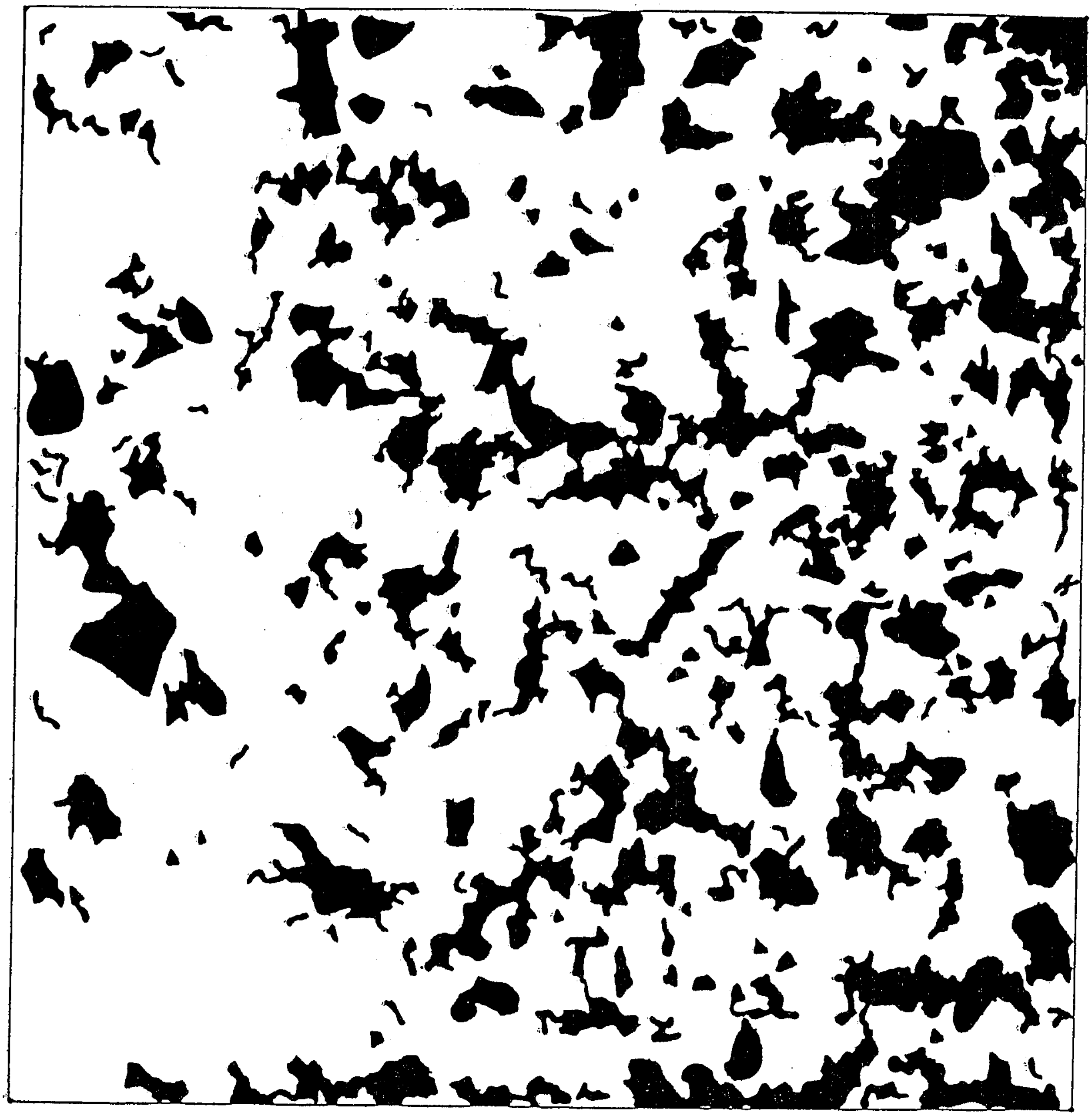


Figure 8. Master map of areas used by Morro Bay kangaroo rats (darkened), based upon presence of tail drags, digs, and burrow systems. This map represents a composite of seperate maps drawn after supplemental feeding had been discontinued.

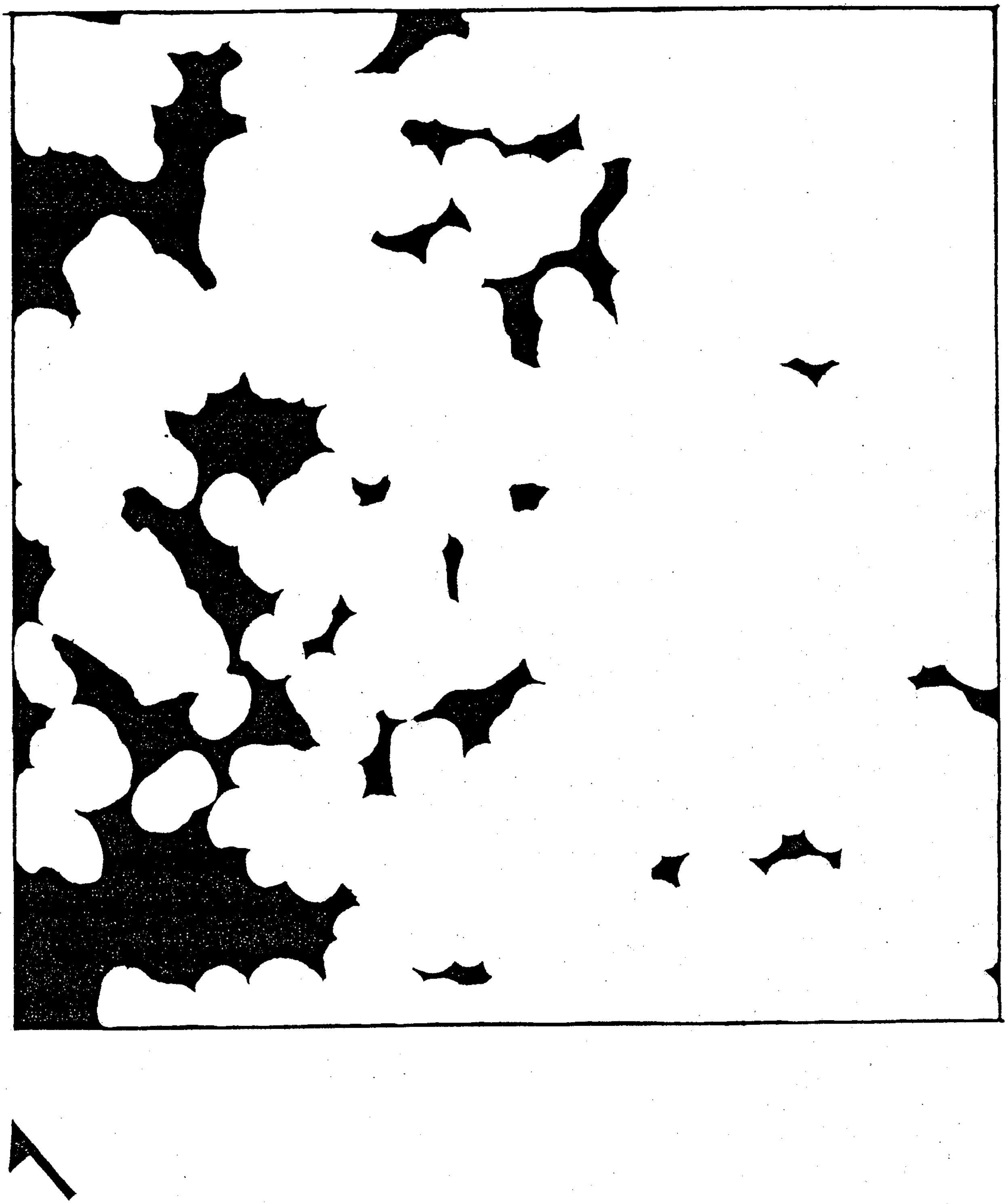


Figure 9. Areas within the enclosure that were not used (darkened) by Morro Bay kangaroo rats after supplemental feeding had been discontinued.

SOIL

The soil of the Pecho area is a Sandy Loam with Baywood Fine sand. "The historic and potential range of Morro Bay kangaroo rats occurs almost entirely within this soil type..." (Gambs and Holland 1988).

SOIL TEMPERATURE

In order to document the magnitude of temperature fluctuation in the soil over the possible range of burrow depths, a Weathertronics (Model 4030) remote, three-point, recording thermograph was installed with the 3 probes buried at depths of 10 cm, 30 cm, and 60 cm. The thermograph was installed at station F6 on 2 May and, after calibration adjustments, was run continuously beginning on 23 May.

MORRO BAY KANGAROO RAT INTRODUCTION

Three artificial burrows were created in the enclosure on 26 May, in preparation for the introduction of 3 animals from the captive breeding colony. A 50 mm diameter soil auger was used to create the burrows which were about 80 cm deep and sloped downward at about a 35° angle. All 3 artificial burrows were placed adjacent to deerweed plants, with the entrances facing toward open ground.

Three Morro Bay kangaroo rats ( Male # 2601R, Female # 2602L, and Female # 2603L) were removed from the Captive Breeding Colony at Cal Poly, San Luis Obispo, and released into the artificial burrows A, B, and C by 10 AM On 27 May 1988. On 21 July, artificial burrow L was created in the same manner as previously described, again at the edge of a deerweed shrub facing open ground. Morro Bay kangaroo rat Male #2702R was removed from the Captive Breeding Colony the same day and introduced into artificial burrow L at 8:15 PM. Refer to Fig. 10 for release dates and sites of all Morro Bay kangaroo rats introduced into the enclosure in 1988.

Male #2601R (previously #331M) was introduced into artificial burrow A. This animal had a thin, complete hip stripe. He was bred and born in the Captive Breeding Colony at Cal Poly from a cross between female #2173F (captured at the Bayview site) and male #315M (captured at the Jr. High School at Los Osos). At the time of his release, Male # 2601R was 2 years old and weighed 72 grams.

Female #2602L (previously #316F) was introduced into artificial burrow B. This animal had an incomplete hip stripe. She was born in the Captive Breeding Colony from female #374F (originally #501) shortly after #374F was brought into captivity from the Bayview site. At the time of her release, Female #2602L was 4 years old and weighed 58 grams.

Female #2603L (previously #2173F) was introduced into artificial burrow C. This animal had an incomplete hip stripe. She was brought into captivity from the Bayview site as an adult in 1986. She is the mother of male #2601R, released into burrow A. At the time of release, Female #2603L was at least 3 years old and weighed 63 grams.

Male # 2702R (previously # 329M) was introduced into artificial burrow L. This animal had a hip stripe which was 50% complete and 50% faint but present. He was born in the Captive Breeding Colony from a cross between female #1542F (captured at the Bayview site) and male #1540M (captured at the Bayview site). At the time of release, Male # 2702R was 2 years old and weighed 91.9 grams.

SUPPLEMENTAL FEEDING

One-gallon, pet feeders were placed near artificial burrows A, B, and C, but not burrow L. Additional feed was scattered liberally near all burrows and at other sites recieving high use by rats every 3 -5 days during June and July. The supplemental

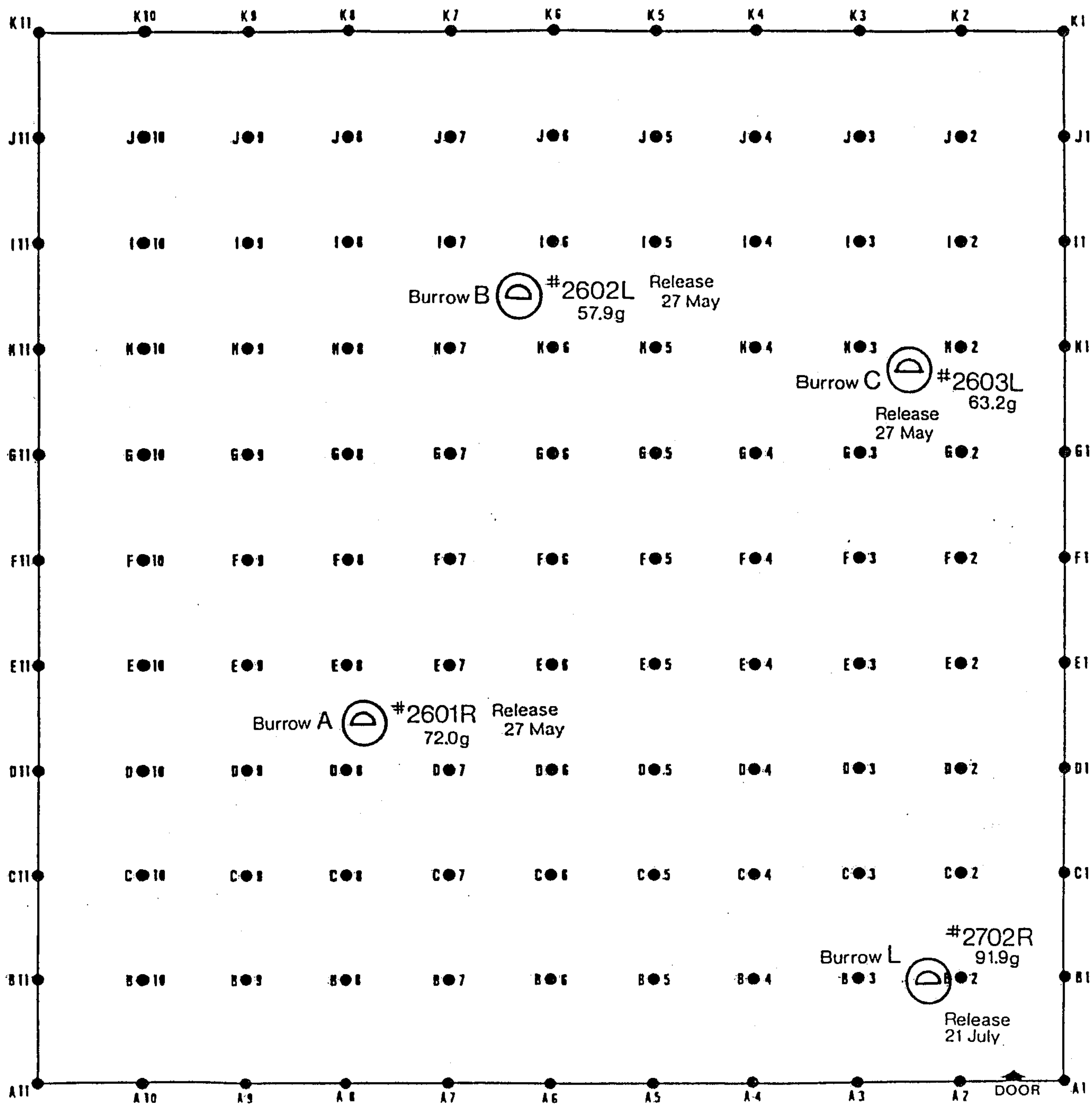



Figure 10. Date and site of release of 4 Morro Bay kangaroo rats in the enclosure. Body weight at the time of release is shown below the identification number of each animal. Refer to text for details on the sex and history of each individual.

feed mix consisted of 4 parts hamster chow (rat/mouse): 1 part sunflower seeds: 1 part wild bird seed: 1 part old-fashioned, rolled oatmeal. The large amount of available food in the enclosure may have contributed to our limited ability to recapture rats during early trapping efforts. In order to begin "weaning" rats away from supplemental feed, the three feeders were removed on 25 July and no feed mix was distributed in the enclosure after 3 August.

TRAPPING METHODS

All field work was conducted under provisions of U. S. Fish and Wildlife Service, Region One, blanket Endangered and Threatened Species Permit No. PRT-702631, subpermit No. GAMBRD-1; State of California Department of Fish and Game Scientific Collector's Permit; and a Memorandum of Understanding by and between California Polytechnic State University and California Department of Fish and Game.

Folding, aluminum, Sherman XLK live traps and/or folding Tomahawk No. 201 live traps were used to trap small mammals and ground squirrels. A small ball of cotton was placed in each trap to prevent hypothermia. No cotton was used in the Tomahawk traps, but 2 wooden shingles (9 cm x 45.7 cm = 3.5 in x 18 in) were placed on top of each trap to provide protection for captured animals. A small handful of bait was divided between the inside of the trap and the ground just outside the door. Several different baits were used to trap Morro Bay kangaroo rats; Quaker, old-fashioned rolled oats, rolled oats with walnut halves, supplemental feed mix, wild bird seed with apple chunks, sunflower seeds with apple chunks, rolled oats with pear chunks, rolled oats with rolled Planters cocktail peanuts and diced apple, and rolled oats with diced apples. After experiencing limited success catching Morro Bay kangaroo rats with Sherman traps, 1 Tomahawk #201 trap was added to each trapping station for the later trapping dates.

Before Morro Bay kangaroo rats were introduced into the enclosure, 2 trapping sessions were conducted on 20-29 April and 10-20 May. Three trapping sessions (2 - 10 Jun., 9 - 19 Aug., and 21 Sep. - 13 Oct.) were conducted inside the enclosure after rats had become established. Table 1 provides a synopsis of trapping sessions, including dates, trap type, number of traps, trapping stations, and bait used.

FIELD DATA

The following data were recorded for each small mammal at the time of capture:

1. Date of capture
2. General weather; cloud cover, fog, moisture, wind, temperature.
3. Identification to species
4. Sex
5. Age class and signs of molting
6. General reproductive condition
7. Tag number

Body weight was recorded after the May trapping session and location of capture (trap station) was recorded after the June trapping session. California ground squirrels were not ear tagged or sexed because of the limited time available to conduct this portion of the study. Data collected from Morro Bay kangaroo rats included the standard field data as well as general appearance and condition, direction of escape after release, and the burrow they entered after release.

INDIVIDUAL MARKING

Each new small mammal caught in the enclosure (except California ground squirrels) was marked with a numbered, stainless-steel, fingerling tag (Salt Lake Stamp Co.) clamped to one of it's ears. The tag number recorded for each individual

**Table 1.** Synopsis of trapping efforts in 1988. SHER = Sherman XLK live traps, TOM = Tomahawk #210 live traps, FUNN = 15 cm diameter X 40 cm long, wire mesh, funnel traps. Trap Stations C,E;2,4,6,8,10 = stations C2, C4, C6, C8, C10, E2, E4, E6, E8, E10. WLNTS = walnut halves; WL BRD SD = wild bird seed; APL CHNKS = 1-2 $cm^3$ apple chunks; DCD APL = .5 $cm^3$ apple pieces; SUNFL SD = sunflower seeds; ROLD PNTS = Planters, rolled, salted, cocktail peanuts; OATS = Quaker, old fashioned, rolled oats

| DATE (1988) | TRAP TYPE | NUMBER TRAPS | TRAP STATION | BAIT |
|---|---|---|---|---|
| 4/20-22 | SHER | 20 | C,E;2,4,6,8,10 | OATS |
| 4/26-29 | SHER | 20 | G,I;2,4,6,8,10 | OATS |
| 4/28-5/26 | TOM | 5 | GR. SQUIRREL BURROWS | OATS |
| 5/9-26 | FUNN | 4 | 1 MIDWAY EACH SIDE | -- |
| 5/10 | SHER | 20 | B,D,F,H,J;3,5,7,9 | OATS |
| 5/17-20 | SHER | 20 | " " | OATS |
| 3 MORRO BAY KANGAROO RATS RELEASED 27 MAY 1988 | | | | |
| 6/2-3 | SHER | 20 | ACT. AREAS, MBKR BURROWS | OATS |
| 6/6-10 | SHER | 20 | " " " " | OATS + WLNTS |
| 6/1-3 | TOM | 5 | OUTSIDE FENCES | FEED MIX |
| 6/21-23 | TOM | 5 | " " | FEED MIX |
| 1 MORRO BAY KANGAROO RAT RELEASED 21 JULY 1988 | | | | |
| 8/9-12 | SHER | 60 | B,D,F,H,J;1,3,5,7,9,11 ENTIRE ENCLOSURE | LN'S B,D: WLD BRD SD + APL CHNKS LINES F,H,J: SUNFL SD + APL CHNKS |
| 8/15-19 | SHER | 60 | " " | OATS + PEAR |
| 9/21-23 | SHER | 60 | B,D,F,H,J;1,3,5,7,9,11 | OATS |
| 9/26-29 | SHER | 60 | " " | OATS |
| 9/30 | SHER | 60 | " " | OATS + ROLD PNTS + DCD APL |
| 10/4-6 | SHER | 60 | B,D,F,H,J;1,3,5,7,9,11 | " " |
| | TOM | 30 | " " | OATS + DCD APL |
| 10/11-13 | SHER | 60 | " " | CONTENTS + OATS |
| | TOM | 30 | " " | " " |

included a four-digit number followed by an L or R, indicating the ear carrying the tag. Captive Morro Bay kangaroo rats from the breeding colony were given new ear tags before they were released into the enclosure.

REMOVAL OF POTENTIAL COMPETITORS AND PREDATORS

The original plan called for the removal of small mammals, other than Morro Bay kangaroo rats, from the enclosure to reduce interspecific competition. On 20-22 April, all mice caught inside were released up to 100 yards away from the fence of the enclosure. Several of these mice were recaptured inside the enclosure and two were observed as they crawled through the aviary wire fence. Because the aviary wire alone was an ineffective barrier to mice, all mice caught inside were simply released at the site of capture. Mice caught inside were again released outside the enclosure on 9-12 August, after flashing was installed around the base of the enclosure. Several of these animals also were recaptured inside and, following these results, mice caught inside were released at the site of capture for the remainder of the study.

Since California ground squirrels in the enclosure were expected to behaviorally and ecologically dominate Morro Bay kangaroo rats (Gambs and Holland 1988), 5, #201, Tomahawk, folding live traps were set near ground squirrel burrows from 28 Apr. to 26 May. All California ground squirrels caught inside were removed from the enclosure.

Four funnel traps, obtained from the U. S. Fish and Wildlife Service, were used to capture and remove snakes from the enclosure before Morro Bay kangaroo rats were introduced. One funnel trap was placed midway along each side of the enclosure, next to the aviary wire fence.

## TRAPPING INTENSITY, EASE OF CAPTURE, AND RELATIVE ABUNDANCE

The trapping intensity of any trapping session is expressed as the number of trap nights (TN), which is equal to the total number of traps set minus the number of tripped traps and traps containing other animals (e. g. birds, California ground squirrels, lizards).

Ease of capture is expressed as the ratio of trapping intensity to the number of individuals captured (TN/CAP). As an example, if a trapping session consisted of 225 TN and 9 deer mice were captured, then the ease of capture for deer mice during this session would be 225/9, or 25 TN/CAP.

Relative abundance is expressed as the number of animals that would be expected to be caught per 100 TN (#/100 TN), given the actual number of animals caught and the actual number of trap nights exerted during the trapping session. As an example, if the trapping session consisted of 225 TN and 9 deer mice were captured, then the relative abundance for deer mice during this session would be (100/225 TN) X 9 animals, or 4 deer mice/100 TN.

## POPULATION ESTIMATION

Capture and recapture data for each trapping session were used to calculate population estimates according to the Schnabel method (Davis and Winstead 1980). The first time an individual was caught during each separate trapping session it was counted as a new capture. Each subsequent capture of this animal was counted as a recapture during that particular trapping session.

## DENSITY ESTIMATION

Density, expressed as the number of animals per hectare (ha), was calculated using the Schnabel population estimates and an assumed area "trapped". The Schnabel population estimates quantify the number of animals on the trapped area, not on 1 ha. Therefore, the density of a species in the enclosure during any trapping session = (1 ha / area trapped in that session) X the population estimate for that species during that session. Each station in the enclosure was assumed to "trap" an area equal to the distance between stations (9.2 m X 9.2 m area = 84.64$m^2$). The April trapping session consisted of 10 stations giving an assumed area trapped = 10 X 84.64 $m^2$ = 846.4 $m^2$ = 0.085 ha. The May trapping session consisted of 20 stations giving an assumed area trapped = 1,692.8 $m^2$ = 0.17 ha. Population and density estimates could not be done for the June traping session because the traps were clustered around active rat areas and not uniformely spaced in the enclosure. For the August and September-October trapping sessions, traps were spaced evenly throughout the enclosure so the assumed area trapped equals the area of the enclosure, 0.212 ha.

## FIELD OBSERVATIONS

The soil in the enclosure was searched for signs of kangaroo rat activity once every 2 - 4 days after Morro Bay kangaroo rats were released in late May. The locations of open and/or active burrow entrances, small digs on the surface, and tail drags were recorded in a field notebook (during daytime visits) until 5 May. A burrow was considered to be active if either recent digging activity was evident, regardless of whether or not entrances were open, or the entrance was not obstructed with dead plant litter. The number of entrances/burrow system varied from 1-7 or more. Often, new entrances would appear relatively close (2 - 4.5 m, 7 - 15 ft) to existing burrows. In these cases, the new entrances were considered to be seperate burrows if they appeared to develop independent of (not visibly interconnected with) other neighboring burrows. Despite our attempts to classify discrete burrow systems, it is quite possible that some of the flagged burrows were interconnected. Field observations on signs of activity were recorded in a field notebook until 5 July. Beginning on 6 July, signs of activity were recorded directly on vegetation maps. Four different field signs were recorded on these maps as follows:

1. Burrow entrance open and/or showing signs of recent use
2. Small, shallow dig in the soil surface
3. Shallow tail drag in the soil surface
4. Undulating snake track in the soil surface

Beginning on 1 September, only burrowing activity was recorded on the daytime observation maps because we felt we had collected sufficient, redundant data on tail drags and digs and no signs of snakes were evident. All other observations (ie. other animals in the enclosure, other signs of animal activity outside the enclosure, and general condition of the enclosure) were recorded in a field notebook.

NIGHTTIME FIELD OBSERVATIONS

Direct observations of Morro Bay kangaroo rats at night, using Baird, General Purpose, Night Vision Goggles (GP/NVG 1), began on 27 June and continued until 21 July. The goggles (owned by the Department of Energy) were loaned to us by EG&G, an environmental consulting firm based in Santa Barbara, CA. All nocturnal field observations were recorded on a microcassette tape recorder and later transcribed onto field notebooks and activity maps. Some new codes for activities seen at night were added to the key of observations included on the base vegetation maps.

ACTIVITY CODES AND DESCRIPTIONS

Seven different activity codes (below) were used to record activity on the nighttime observation maps.

### ⌓ BURROW ENTRANCES

This symbol indicates the location of either an open or an active burrow. Both burrow conditions were included under one category because active burrows could be left open or plugged with fresh sand during the daytime. Burrow entrances ranged from about 3 - 9 cm (1 1/4 - 3 1/2 in) across the flat bottom of the runway by 2.5 - 9 cm (1 - 3 1/2 in) from the bottom to the apex of the arched roof. The smaller entrances generally showed signs of less activity and most of these were probably escape entrances or subsidiary burrow entrances as described by Stewart (1958). One burrow entrance was designaged with one symbol on the acitivity maps. When several burrow entrances were located close to each other, these were designated as multiple openings to a single burrow system.

### ↗ MOVEMENT

Movement of a Morro Bay kangaroo rats includes walking, running, or hopping. An animal was considered to be "walking" when all 4 feet regularly contacted the ground as the animal propelled itself forward (at a slow pace) with its hind legs. Walking generally occurred over short distances (up to 2 ft.) while the animal was foraging.

An animal was considered to be "running" when all 4 feet regularly contacted the ground and it propelled itself forward (at a fast pace) with its hind legs. Running was noted several times at night and we were surprised to see that Morro Bay kangaroo rats could move on all 4 feet at a very rapid speed. Running occurred when an animal was startled or when two animals were engaged in sparring and chasing (eg. 21 July). When startled, the rats usually ran more than 20 ft (5 m) and they usually went out of our sight before stopping.

An animal was considered to be "hopping" when the front legs were held off the ground as the hind legs propelled the body forward, above the substrate, at an intermediate rate of speed. Hopping was the primary mode of movement when an animal travelled between 2 locations without foraging or digging.

Morro Bay kangaroo rats were not always moving while we watched them. Sometimes, they would stand still for several seconds in an upright posture ("sentry") on their mounds. They often remained in one locality for up to 1 1/2 min while they were foraging.

## Δ DIGGING

Digging is defined as digging for food, starting a burrow, or moving large amounts of sand associated with clearing a burrow entrance or reducing the height of a burrow mound. Digging usually involved the use of both front and hind legs, but occasionally rats dug with only the front or the hind legs. Typically, the front legs kicked sand posteriorly with 3 or 4 quick strokes creating a small pile near the animals hind quarters. Then the hind legs kicked with one sharp thrust which threw the sand backwards as far as 1 1/2 m. During intensive bouts of digging, this sequenced pattern would occur 3-5 times in rapid succession. Then the animal would jump aside a few inches, or on top of a burrow mound, and crouch or stand quietly on its hind legs. After 2 - 10 seconds, the rat would jump back to the digging site and repeat the digging process again.

This typical digging pattern was altered for different digging situations. When an animal was reducing the height of a burrow mound, it often used only the hind legs to move sand. The animal started this process from the top of the mound as it faced the burrow entrance. As it slowly moved toward the entrance, it kicked back with its hind legs in rapid succession until it reached the entrance. The front legs were used only for balance, direction, and resistance to forward movement. The animal then jumped back to the top of the mound, remained motionless for a few seconds, and then started digging toward the entrance again. When a rat was digging at a burrow entrance, it sometimes bobbed its head up and down over the edge of the entrance rather than jumping out to remain motionless near the burrow.

Digging for food often involved movement of only the front legs as the animal made shallow digs in the sand. When digging for food, the hind legs were used only for support. Morro Bay kangaroo rats were seen digging for food at supplemental feeding sites, in the open ground, and under deerweed and mock heather plants.

## X FORAGING

Foraging is defined as "investigating" the substrate, but without digging below the surface or moving conspicuous amounts of sand. The hind legs supported the body while the front legs and head were held close to the surface as the animal moved over the substrate. The front feet shuffled through the sand and occasionally food items were brought to the mouth where they were either eaten or stored in the cheek pouches. The rats usually moved over the surface as they foraged by taking 1-3 small, walking steps between foraging bouts. They usually remained within an area having a diameter of about 2 ft before they hopped to a more distant foraging site. Morro Bay kangaroo rats were seen foraging at supplemental feeding sites and under deerweed and shrubby groundsel plants.

## θ EATING

At night, it was impossible to tell what the rats were eating and it was difficult to distinguish between eating and seed storage in the cheek pouches. Thus, if the front feet remained near the face for over 4-5 seconds and/or the jaws could be seen moving rhythmically, the behavior was classified as eating.

## CL CLEANING (GROOMING)

Cleaning behavior was observed only twice, once on 7 July and once on 19 July. On both occasions, the behavior consisted of placing both front feet in front of the face, licking the paws, and then wiping the paws over the head from behind the ears to the nose or from the eyes to the nose.

# RESULTS

## VEGETATION

The spatial distribution of vegetation throughout the Pecho area was described as patchy, "with aggregations of individuals occuring at some sites and not at others" (Gambs and Holland 1988). The vegetation within the enclosure has these same characteristics (Fig. 7). While the more abundant species may be dispersed more or less uniformly throughout the enclosure, other species have a more patchy dispersion pattern. "This patchiness may be due to environmental factors such as enhanced or decreased moisture availability or to variable reproductive successes of original colonizers" (Gambs and Holland 1988). We believe that colonization is probably a major factor in the present study because the enclosure is located on a recently burned area.

The thirteen species of shrubs and subshrubs which were mapped in detail covered 31. 56% of the enclosure. The remainder of the enclosure was covered by either open ground or herbaceous species (Table 2). Deerweed, the dominant shrub, covered more than a 1/3 (12.71%) of all mapped vegetation. Mock heather covered 5.18% of the mapped vegetation followed by: California aster (4.02%), and croton (2.34%). Horkelia, California sagebrush, coast silver lupine, coastal buckwheat, and poison oak each covered less than 1% of the plant cover that was mapped.

All plant cover and bare ground adjacent to burrows, digs, and tail drags of Morro Bay kangaroo rats was summed by species category and designated as used habitat within the enclosure (Fig. 8). The remaining areas in the enclosure were summed and designated as unused habitat (Fig. 9). Nearly all (93.1%) of the total deerweed cover in the enclosure was associated with signs of Morro Bay kangaroo rat use (Table 2 and Fig. 11). In fact, with the exception of sand almond, at least 70%

Table 2. Total $m^2$ and % cover of each shrubby or subshrubby plant species and herbaceous growth or bare sand mapped in the enclosure. The % species cover in the used and unused areas is calculated from the total areal coverage of that species in the enclosure. Plant species are listed from highest to lowest total cover. Refer to the methods for full species names and common names. Numbers in parentheses after each species abbreviation refer to the number codes assigned to each species on the field map of the enclosure (Fig. 6).

| SPECIES (#) | TOTAL COVER | | % OF SPECIES COVER | |
|---|---|---|---|---|
| | $m^2$ | % COVER | USED | NOT USED |
| LOT. SC. (9) | 265.58 | 12.71 | 93.10 | 6.90 |
| ERI. ER. (10) | 108.35 | 5.18 | 84.00 | 16.00 |
| COR. FI. (1) | 84.03 | 4.02 | 88.20 | 11.80 |
| CRO. CA. (11) | 48.89 | 2.34 | 74.90 | 25.10 |
| SEN. BL. (2) | 31.35 | 1.50 | 79.80 | 20.20 |
| SAL. ME. (5) | 25.40 | 1.22 | 96.50 | 3.50 |
| PRU. FA. (3) | 21.37 | 1.02 | 26.20 | 73.80 |
| ERI. CO. (4) | 20.90 | 1.00 | 84.70 | 15.30 |
| ART. CA. (7) | 19.54 | 0.93 | 70.30 | 29.70 |
| TOX. DI. (13) | 16.15 | 0.77 | 83.20 | 16.80 |
| LUP. CH. (8) | 11.60 | 0.55 | 100.00 | 0.00 |
| ERI. PA. (12) | 5.59 | 0.27 | 100.00 | 0.00 |
| HOR. CU. (6) | 0.84 | 0.04 | 81.00 | 19.00 |
| SAND + HERBS | 1430.66 | 68.44 | 69.10 | 30.90 |
| TOTAL = | 2090.25 | | | |

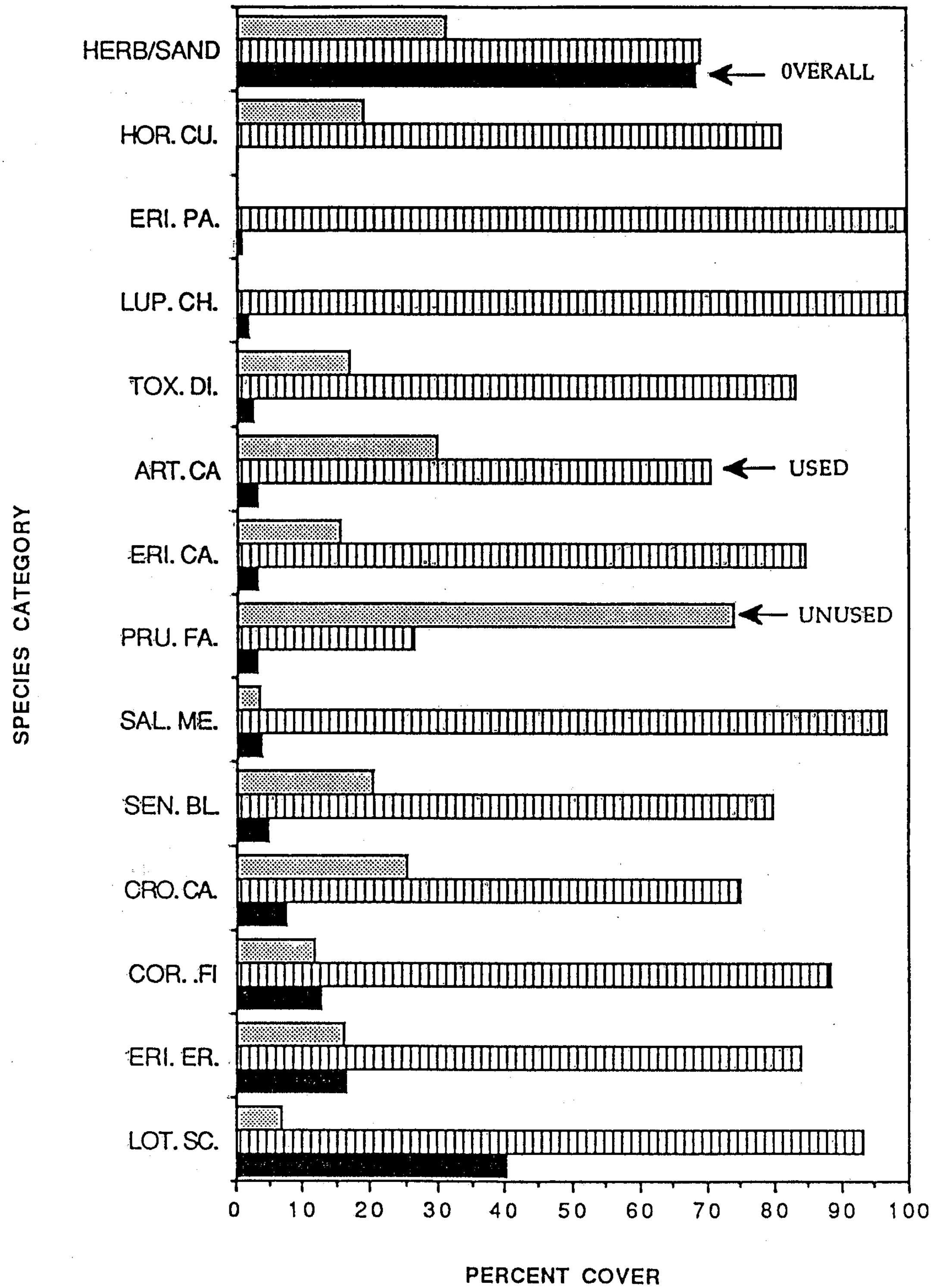



Figure 11. Percent cover of each shrubby or subshrubby plant species and herbaceous growth or bare sand in the enclosure. Overall percent cover (solid bars) is the % of total coverage of each species category within the entire enclosure (refer to Table 2). Used percent cover (hatched bars) is that portion of the overall coverage of a species category which was used by Morro Bay kangaroo rats (ie. had burrows, tail drags, or digs in the immediate vicinity). Unused percent cover (stippled) is that portion of the overall coverage of a species category which was not used by Morro Bay kangaroo rats during the study period. Refer to the methods for full species names and common names of all plant abbreviations.

of the cover of each species category was associated with Morro Bay kangaroo rat use. Only 26.2 % of the sand almond cover was associated with Morro Bay kangaroo rat use. When the actual cover of each species category that was used by Morro Bay kangaroo rats was compared to the amount of each cover category expected to be used (assumes rats randomly used species categories in proportion to the occurrence of species categories in the enclosure), no significant difference was found (Chi Square = 12.62, df = 13, $p > .3$). Although Morro Bay kangaroo rats did not frequent sand almond as much as we expected, their overall use of the major habitat elements in the enclosure was no different from that expected by a random habitat utilization model.

By the end of August, the vegetation inside the enclosure was clearly more productive than the vegetation outside. The visible difference was independently noted by the authors as well as 2 visitors to the site. There appeared to be higher germination rates, more new vegetative growth, and more flowers on plants inside the enclosure. Plant foliage also appeared to be greener inside than outside the enclosure. These differences were probably the result of more favorable growing conditions inside the enclosure produced by a less rigorous microclimate. The wire sides and plastic roof netting of the enclosure served as condensation sites for moisture from the prevailing fog. This water subsequently dripped on the soil and vegetation, increasing water availability to plants inside. This accelerated "fog drip" was typical during the summer and often was sufficient to obscure all signs of animal activity on the sand surface inside the enclosure. In addition, the sides and roof undoubtedly reduced wind velocity over the plants, thereby reducing the rates of evaporation and transpiration. Part of the difference between plant growth inside and plant growth outside the enclosure could be attributed to differences in foraging pressure. Deer, rabbits, and other large herbivores had free access to the surrounding habitat, but not to the forage inside the enclosure.

**Food Sources In The Enclosure**

With the exception of the compressed food pellets in the hamster chow, most components of the supplemental feed mix were taken by either Morro Bay kangaroo rats, other small mammals, or birds in the enclosure. We often found shells of sunflower seeds piled near surface resting sites of Morro Bay kangaroo rats. On one occasion, we found about a cup of 3 varieties of Proso Millet seeds (identified by F. L. Wertman, Registered Seed Technologist, The Central Seed Laboratory, 473 Woodbridge, San Luis Obispo, CA 93401) piled behind the recording thermograph by a Morro Bay kangaroo rat. On another occassion, we caught a Morro Bay kangaroo rat with both cheek pouches filled with Proso Millet. The source of millet seeds was from the wild bird seed component of the supplemental feed mix.

There was an abundance of deerweed seed on the ground in the enclosure in August. California aster, coastal buckwheat, croton, shrubby groundsel, coast golden yarrow, mock heather, California sage, and some herbs were flowering in August and most of these were setting seed by mid-October. It appeared that there would be a large seed crop available during fall and winter to small mammals in the enclosure.

On two occasions (25 August and 26 October), iceplants in the enclosure were found which had been grazed on. On the second occasion, distinct incisor marks, which appeared to be made by rodents, were visible on the leaves. At this point, we do not know which species grazed the plants, but we certainly cannot rule out Morro Bay kangaroo rats.

# MORRO BAY KANGAROO RAT CAPTURES

## Female #2602L (released 27 May 1988)

Female #2602L was trapped in Sherman traps 7 different times inside the enclosure, on 9, 11, 16, 19 August and 21, 23, 30 September (Fig. 12). Her weight at the time of release was 58.0 g whereas her weight at the time of these captures ranged from 54.0g to 58.0g. She always appeared to be non-reproductive, healthy, and free of visible external parasites. Female #2602L entered burrow system Q on 2 separate occassions after she was released. On 1 occasion she entered burrow system AA. She either hid under nearby shrubs or ran out of sight after being released from other captures.

## Female #2603L (released 27 May 1988)

Female #2603L was trapped in Tomahawk traps twice inside the enclosure on 11 and 12 October (Fig. 13). Her weight at the time of release was 63.2 g whereas her weight ranged from 65.0g to 68.0g at the time of these captures. Like Female # 2602L, Female # 2603L always appeared to be non-reproductive, healthy, and free of visible external parasites. After her release from the first capture, Female # 2603L stayed under a shrub next to a plugged entrance to burrow system W. After the second capture, she dug her way into burrow system W, using the same plugged entrance.

## Male #2601R (released 27 May 1988)

Male #2601R was never captured after he was introduced to the enclosure. This individual consistently showed the least amount of activity of the 4 rats released in the enclosure. There were fewer signs of activity (burrows, tail drags, and digs) in

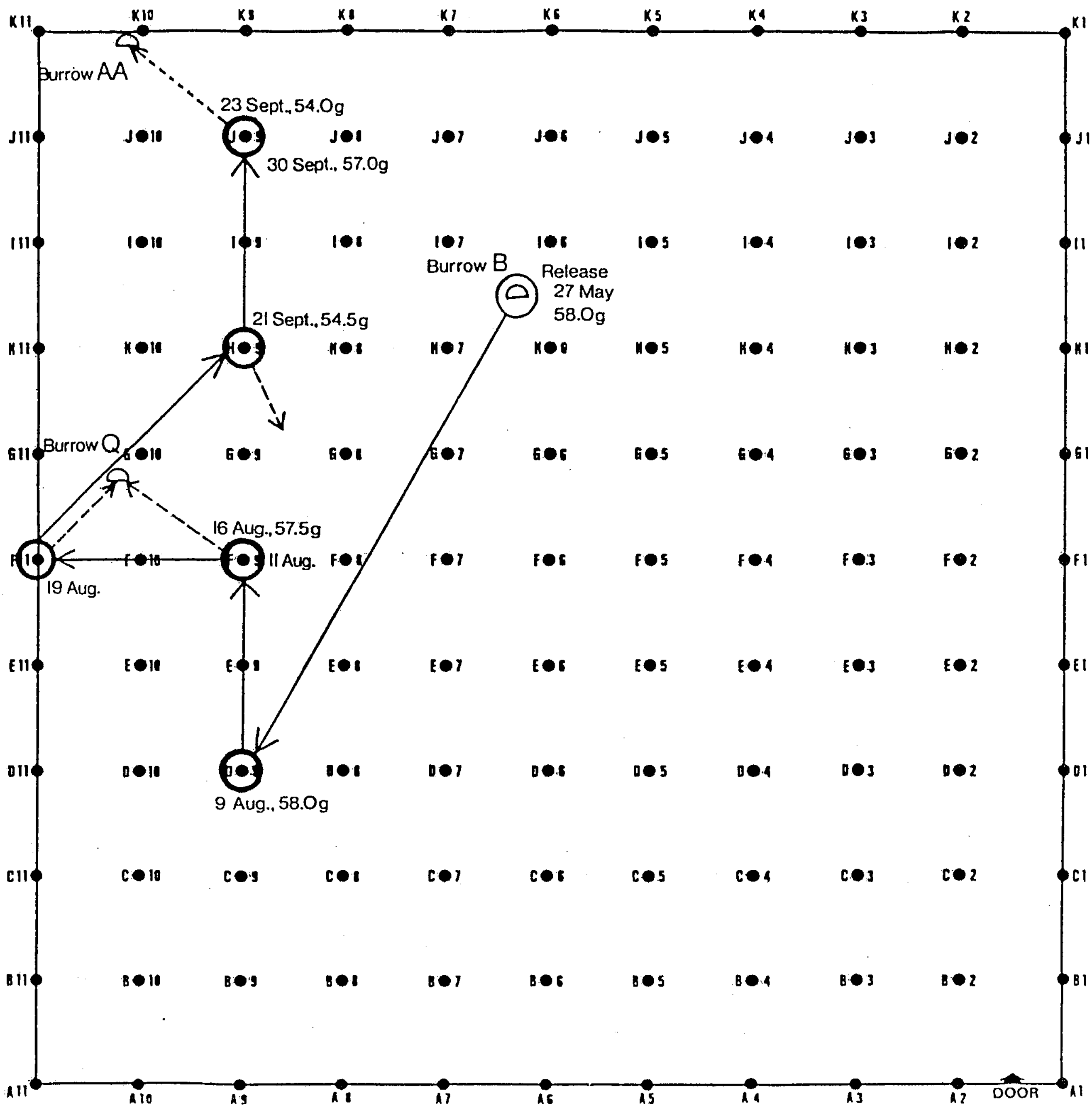



Figure 12. Initial release and subsequent capture sites (heavy circles) of female Morro Bay kangaroo rat #2602L. Date and body weight (if available) at the time of capture are indicated near capture sites. Solid arrows indicate sequence of capture and dashed arrows indicate the animals movement when released after capture. A dashed arrow touching a burrow indicates the animal was seen entering that burrow after release.

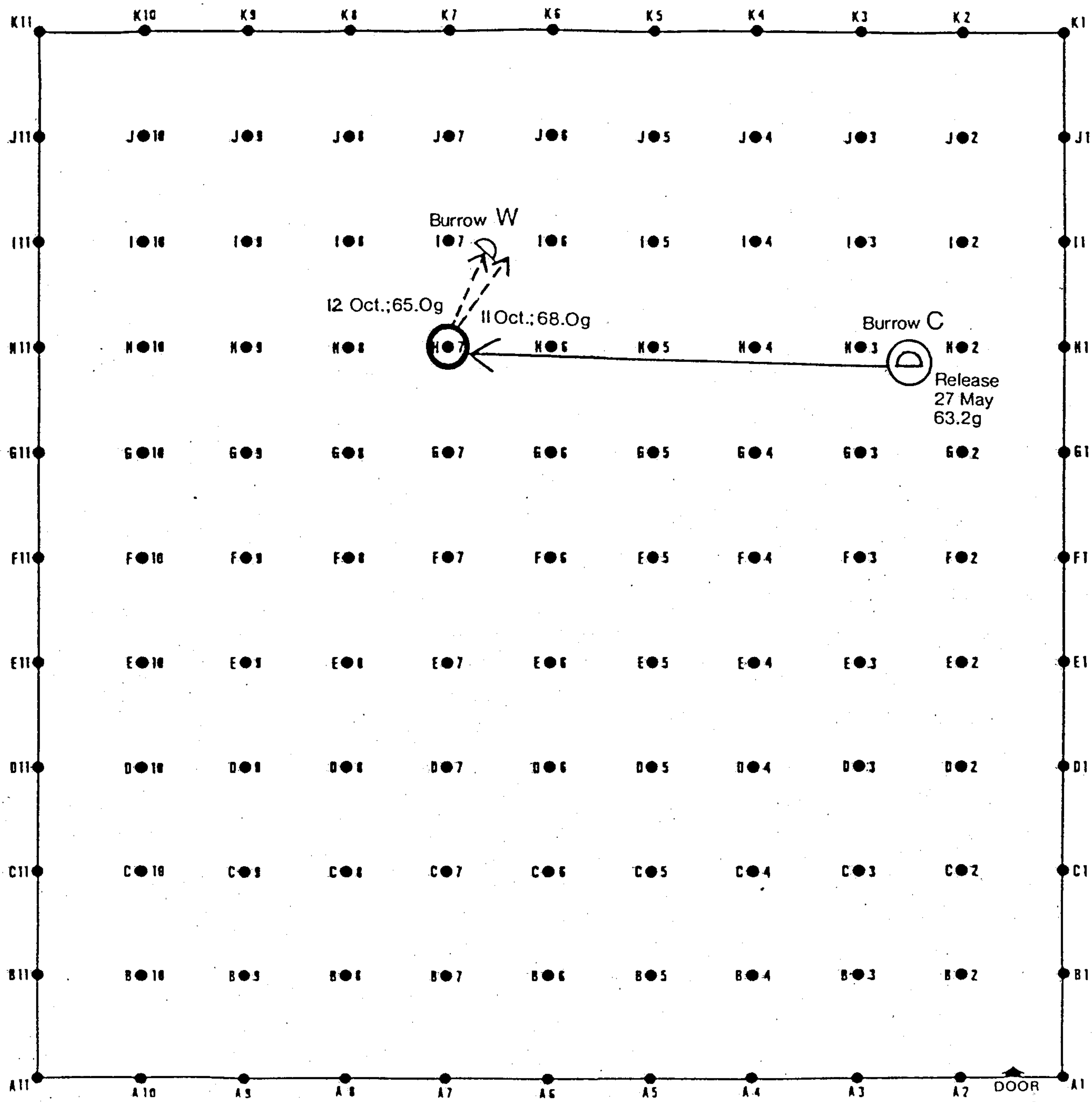



Figure 13. Initial release and subsequent capture sites (heavy circles) of female Morro Bay kangaroo rat #2603L. Date and body weight (if available) at the time of capture are indicated near capture sites. Solid arrows indicate sequence of capture and dashed arrows indicate the animals movement when released after capture. A dashed arrow touching a burrow indicates the animal was seen entering that burrow after release.

the vicinity of burrow A, the artificial burrow where he was released, and there was little evidence that he wandered far from that burrow. Whereas the whereabouts of the other 3 rats became evident through signs of activity, trapping, and observations at night, this animal essentially "disappeared" from our records after burrow A became inactive on 2 July 1988.

Male # 2601R may have died, but if this was the case, his remains are probably in a burrow because no carcass was found on the surface and there was no evidence to indicate that he was taken by a snake or other predator. It is possible that Male # 2601R is still inhabiting the enclosure and we simply have been unable to detect his presence. There are a number of burrows in the enclosure that we have been unable to assign to a specific individual. Our variable trapping success of Morro Bay kangaroo rats in the enclosure suggests that some Morro Bay kangaroo rats are more wary of traps than others and perhaps Male # 2601R is one that refuses to enter traps. Finally, like Male #2702R (below) Male #2601R, may have escaped from the enclosure, although no burrowing activity was seen outside the enclosure. We doubt that he could have burrowed out unnoticed; however if he climbed up the aviary fence and through the roof netting, he could have moved away from the enclosure far enough to preclude our detection of his new burrow.

Male #2702R (released 21 July 1988)

Male #2702R was captured once in a Sherman trap in the enclosure on 29 September (Fig. 14). His weight at the time of release was 91.9 g; whereas his weight at the time of this capture was 88.0 g. He appeared to be non-reproductive, healthy, and free of visible external parasites. Male #2702R hopped to the northeast corner and disappeared out of sight after being released.

On 29 November, Male #2702R was captured in a Sherman trap outside the enclosure, approximately 1.5 m (5 ft) East of station G1. Since he escaped before being weighed and returned to the enclosure, no weight was recorded. He appeared to be

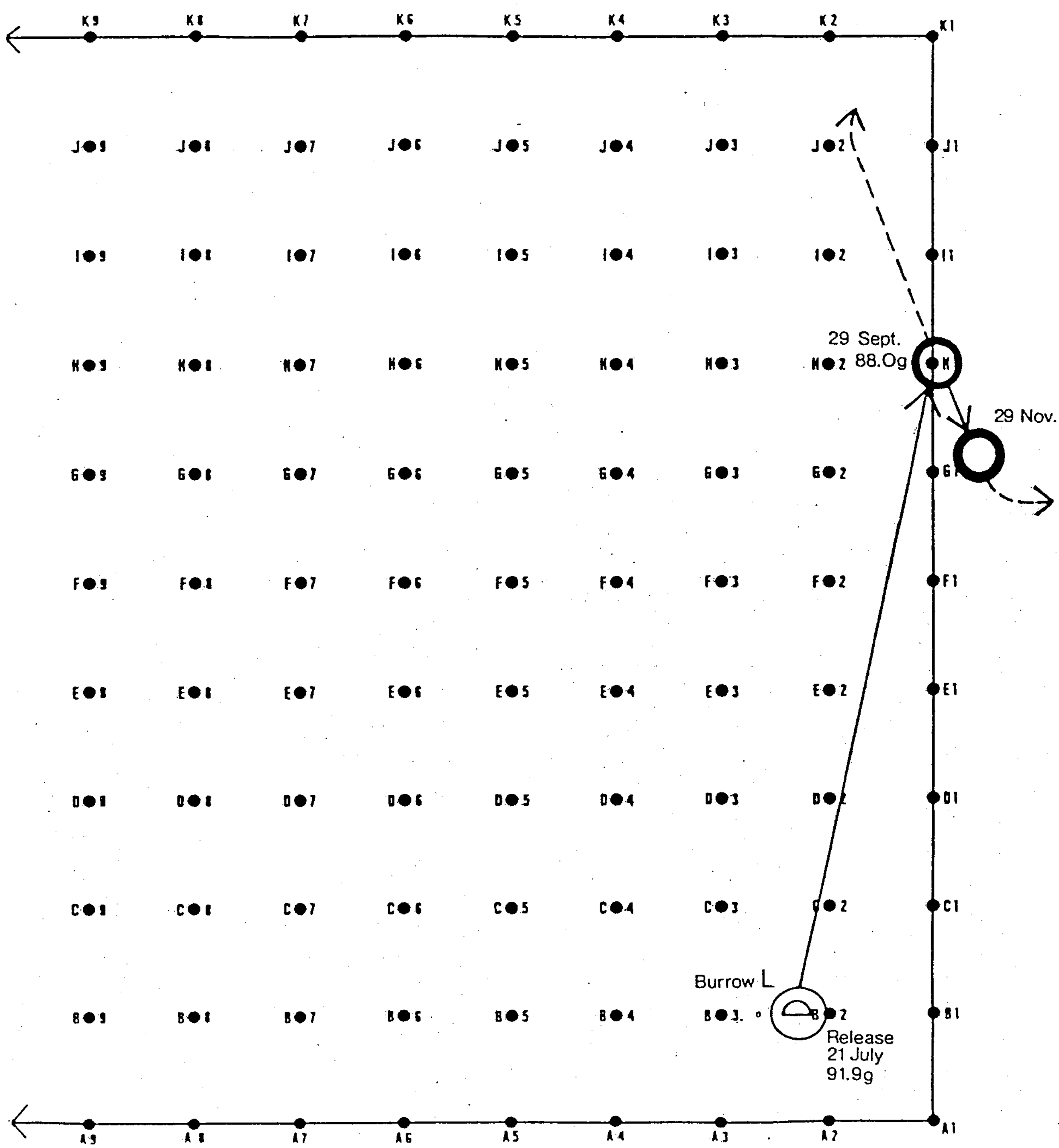



Figure 14. Initial release and subsequent capture sites (heavy circles) of male Morro Bay kangaroo rat #2702R. Date and body weight (if available) at the time of capture are indicated near capture sites. Solid arrows indicate sequence of capture and dashed arrows indicate the animals movement when released after capture. ~~A dashed arrow touching a burrow indicates the~~ animal was seen entering that burrow after release.

non-reproductive, healthy, and free of visible external parasites. As he escaped, he hopped East, past the outer barbless fence, and out of sight in the shrubs. Burrowing activity in the area adjacent to G1 was first seen on 9 November, but 2, subterranean cave-ins were seen there on 20 October. Tail drags and digs were first seen in the area outside the enclosure on 23 November.

There are at least 2 ways that Male #2702R could have escaped from the enclosure. First, he might have climbed up the inner surface of the aviary wire, through the roof net, and then down to the ground outside the enclosure. Several small (4 cm - 7.5 cm diameter) holes in the netting were found at stations E1, D1, and J1 on 9 November which tends to support this hypothesis. Second, he might have burrowed under the aviary wire fence and flashing. The presence of cave-ins seen near G1 on 20 October support this latter hypothesis. Stewart (1958) found that unobstructed Morro Bay kangaroo rat burrows could be as deep as 66 cm (26 in.) below the surface. Since the aviary wire is buried 61 - 92 cm (24 - 36 in.) below the surface, it is quite possible that Male #2702R escaped by burrowing below the wire and flashing. Furthermore, there is no reason to believe that a Morro Bay kangaroo rat could not burrow deeper than 66 cm if it encountered a subterranian obstruction. The burrows inside the enclosure (EE and JJ) which were closest to the burrows outside (Fig. 15) were approximately 4.5 m (15 ft) away from the outside burrows (well within the burrowing range of a Morro Bay kangaroo rat). It is doubtful that a Morro Bay kangaroo rat could get through the aviary wire fence and no holes were found in the fence above ground level.

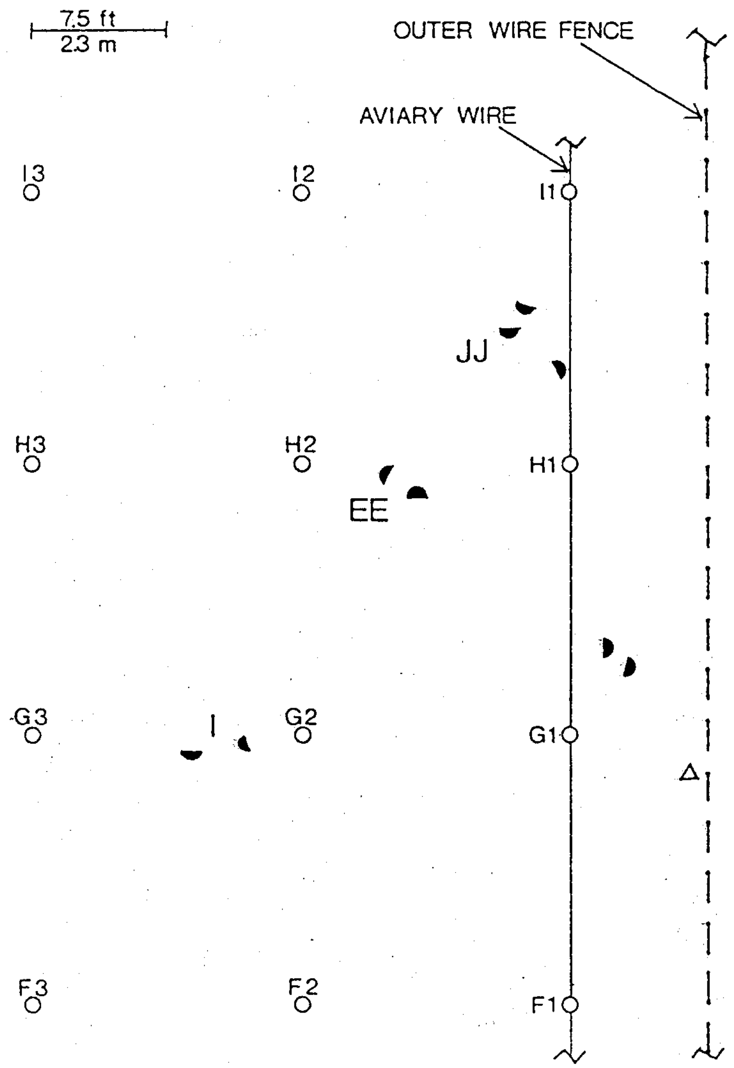



Figure 15. Morro Bay kangaroo rat burrow outside the enclosure (near G1) where male #2702R was captured. The nearest burrows inside the enclosure are also shown (I, EE, JJ).

## NIGHTIME OBSERVATIONS WITH GP/NVG

### Summary of Activities Observed

No Morro Bay kangaroo rats were seen with the goggles on the first 2 nights, but one or more were seen every night thereafter. All 3 forms of movement (described in the methods) were seen with the aid of night vision goggles. On 30 June, a Morro Bay kangaroo rat was seen walking across a dead branch about 12" above ground. This was seen only once and no other evidence was gathered which would indicate that Morro Bay kangaroo rats regularly climb above ground.

Morro Bay kangaroo rats were seen digging at burrows, supplemental feeding areas, on bare ground, and under deerweed and mock heather plants.

Morro Bay kangaroo rats were seen foraging in supplemental feeding areas and under deerweed and shrubby groundsel plants. On 1 occasion, a Morro Bay kangaroo rat was seen standing on its hind legs as it grabbed a deerweed branch with its front feet. On other occasions, the branches of deerweed shrubs were seen to shake vigorously after animals approached them. It appears that Morro Bay kangaroo rats in the enclosure generally forage on the substrate, but may also forage directly on the foliage, flowers, or fruits of some of the plants there.

Grooming (Cleaning) activity was observed on 7 July and on 19 July.

### Activity Patterns

Most of these results were collected from 1 individual Morro Bay kangaroo rat in the northeast corner of the enclosure. Animals were seen in other areas but with less frequency.

Morro Bay kangaroo rats were first seen immediately after dusk and they were seen at all times throughout the night. On 11 July, the same animal (assuming exclusive home range) was first seen at 9:15 pm and then periodically thereafter until the last sighting at 4:35 am, 12 July. This protracted activity period (7.3 hours) is much longer than the 1.8 hours reported by Braun (1985) for the giant kangaroo rat *(Dipodomys ingens).* Actual (observed) above-ground active periods in the giant kangaroo rat ranged from less than 1 minute up to at least 48 minutes; however active periods often ended when an animal disappeared behind shrubs rather than entering a burrow. Actual active periods in giant kangaroo rats were probably longer than observed active periods because of the confounding problems of visibility.

During 140 minutes of observation time on 19 July, one Morro Bay kangaroo rat was active for at least 90 minutes. An estimate of total active time per night was not possible because of limitations on visibility. The duration of time spent above ground by Morro Bay kangaroo rats must be much more than the average 20 minutes/<u>night</u> for giant kangaroo rats reported by Braun (1985) or the average 15 minutes/<u>night</u> for the chisel-toothed kangaroo rat *(Dipodomys microps)* reported by Kenagy (1973). The duration of time spent above ground by Morro Bay kangaroo rats is probably more similar to the average 25 minutes/<u>hour</u> for the bannertail kangaroo rat *(Dipodomys spectabilis).* reported by Schroder (1979)

## Social Interaction

On 30 June, 2 rats were seen simultaneously, but no interactions were observed (refer to Third Progress Report for additional details). Interactions between 2 Morro Bay kangaroo rats may have been observed on 19 July, but the presence of 2 different animals could not be confirmed. On 21 July, 2 rats were seen interacting repeatedly over a period of about one hour.

A large rat (probably a male) and a smaller rat (probably a female) were first seen engaged in what resembled sparring behavior. They ran toward each other and then glanced to opposite sides just before colliding. Then they stopped, turned around, and repeated this behavior sequence. Brief contact was made on some of the sparring passes, but no biting or vigorous kicking actions were observed and no vocalizations were audible to us. The smaller rat was known to occupy the burrows in the area where these interactions took place.

After several (2-8) of these sparring sequences, the larger rat began chasing the smaller rat through the brush at a high rate of speed. At one point during the chase, one of the rats ran into the observer's chair and another jumped onto the observer's boot. We could hear the running sounds of the 2 animals easily as they ran through the brush. After the bout of chasing, the 2 rats stopped 2-4 feet apart, raised up on their hind legs, and faced toward each other for a moment. One rat charged and the other one jumped up on the fence and then fled out of sight with the first rat still in pursuit. The smaller rat then returned to our view and resumed normal foraging and digging activities in the area near its burrows. The large rat approached the small one again and the small rat went down a burrow. The large rat followed the path used by the small rat when it entered its burrow. The large rat stretched its body out on top of the sand mound next to the burrow and rubbed its belly and neck over the surface of the sand. This body rubbing behavior lasted for approximately 30 seconds and then the large rat left the area. The large rat never approached the burrow entrances closely and it did not attempt to enter the burrow entrances in the area where it had been "body rubbing".

The sequence of sparring, chasing, escape, and body rubbing may have been an antagonistic interaction with the large rat (probably male) attempting to take over the smaller rats' (probably female) burrow system or it may have been a courtship interaction with the large rat advertising its presence to the smaller rat.

In addition to the categories of behavior described above, other, less common activities, were observed and recorded. On 30 June, a Morro Bay kangaroo rat was seen walking along a dead branch about 12" above ground. This was seen only once and no other evidence was found in the enclosure that indicated rats regularly climb above ground. Once a Morro Bay kangaroo rat was seen standing on its hind legs as it held a deerweed branch with its front feet. On other occasions, deerweed branches were seen shaking vigorously after Morro Bay kangaroo rats approached them. It appears that Morro Bay kangaroo rats in the enclosure generally foraged on the substrate, but they also may forage directly on the foliage, flowers, or fruits of some of the plants there.

## BURROWING ACTIVITY

By 1 December, 36 Morro Bay kangaroo rat burrow systems, including the 4 artificial burrows, had been identified and flagged in the enclosure. Burrow systems were designated chronologically A-Z and AA-JJ (Fig. 16). The first new kangaroo rat burrows were detected on 31 May, four days after the initial release, and burrows continued to appear throughout 1988 (Fig. 17). The last burrow system flagged in 1988 (JJ) became active on 2 November. Most of the 36 burrow systems exhibited alternating periods of activity ranging from 1 - 146 days and periods of inactivity ranging from 1 - 40 days (Fig. 17). There is no apparent pattern to the temporal activity. Only burrow systems J, EE, and II remained continuously active from the time they appeared until 1 December.

Eleven of the 17 identified burrow systems (C, D, E, F, G, H, I, J, K, N, O; 10 of the 13 made by Morro Bay kangaroo rats) which first appeared in June, July, and August occur in the northeast corner of the enclosure from lines E-K and 1-5 (shaded burrows in Fig. 16). Since burrow C became inactive 1 week after the appearence of burrows D, E, and F, it was assumed that the animal initially released into burrow C (Female #2603L) moved into the abandoned California ground squirrel burrow (burrow system D) and also created burrow systems E and F. Female #2603L also is most likely responsible for the other burrow systems which appeared in the northeast corner before September G, H, I, J, K, N, O).

Only 2 Morro Bay kangaroo rat burrow systems were identified West of line 6

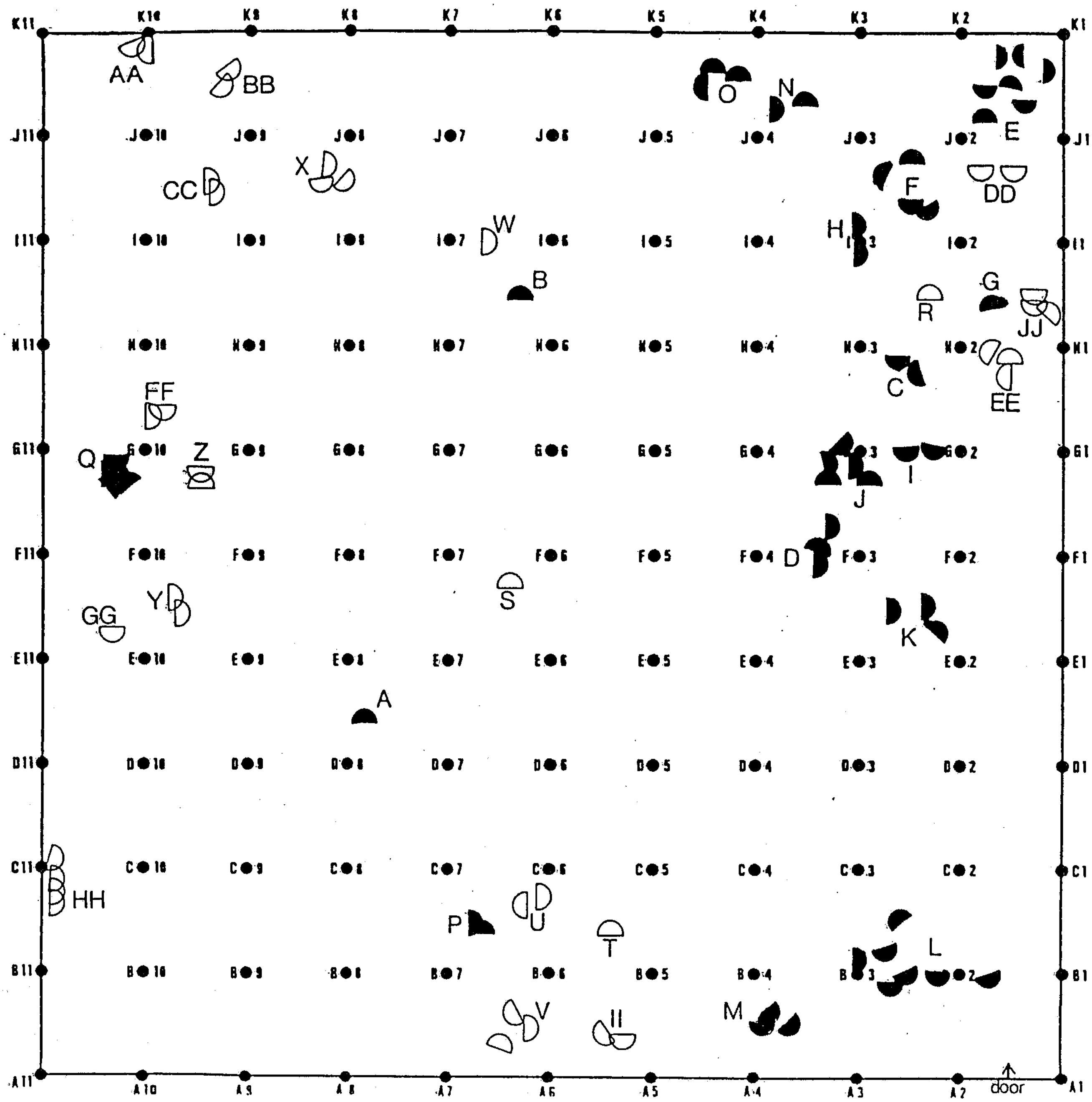
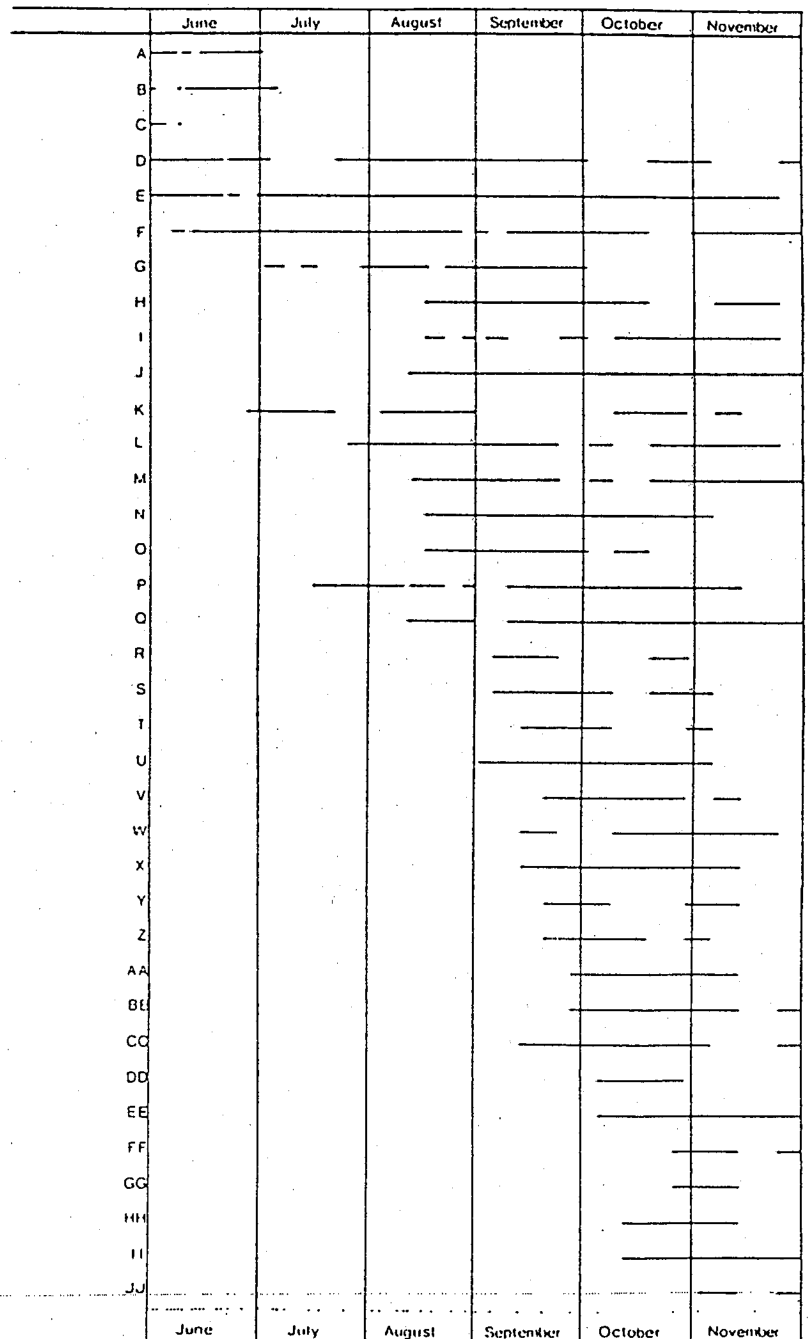



Figure 16. The 36 confirmed Morro Bay kangaroo rat burrow systems (A-J, AA-JJ), which appeared in 1988. Entrances recorded for each burrow system are shown as half-circles. Burrow systems which first appeared in June, July, and August (the first three months after the introduction) are shown in black. Burrow systems which appeared after August are shown as an open symbol.

Figure 17. Active periods (dark lines) for each Morro Bay kangaroo rat burrow in the enclosure from June to November 1988. The number of sample periods and the number of burrows active during each month are given at the bottom.




| | June | July | August | September | October | November |
|---|---|---|---|---|---|---|
| Number of burrow surveys | 16 | 7 | 9 | 5 | 3 | 4 |
| Number of active burrows | 7 | 9 | 14 | 25 | 32 | 29 |

before September (P and Q). In contrast, only 4 of the 19 burrow systems in the northeast corner (R, DD, EE, JJ) appeared between September and November. The remaining 15 burrow systems occurred west of line 5. The majority of this dramatic shift in burrow distribution occured between August and September and probably coincides with the introduction of the second male (#2702R) on 21 July. On the night of #2072R's release, 2 Morro Bay kangaroo rats were seen sparring in the northeast corner,. These animals were presumably the new male, (#2702R) and Female #2603L (known to occupy the northeast corner). On 29 September, Male #2702R was captured at station H1 and ran toward burrow system E (Fig. 13). On 10 and 11 October, Female #2603L was captured at station H7 and ran to burrow system W when released (Fig. 12). It is quite possible that Male #2702R displaced Female #2603L and took over the burrows in the northeast corner. Female #2603L probably moved west and dug new burrows.

Female # 2602L was caught a number of times in the northwest quarter of the enclosure. We verified her use of burrow systems Q and AA and we suspect that she also used other burrow systems in the northwest quarter of the enclosure during the study period.

## Plants Associated With Burrows

The number of individuals of each plant species associated with each burrow entrance is presented in Table 3. Burrow entrances were constructed near deerweed shrubs more often than other shrubs (20 of the 36 burrow systems were associated with 26 different deerweed plants). The second most frequently used plant was mock heather (13 burrow systems were associated with 13 different mock heather shrubs). California aster ranked third with 11 burrow systems associated with 12 California aster plants. Eight burrow systems were located on open ground, at least 61 cm (2 feet) from the nearest shrub. A few burrow systems also were associated with shrubby groundsel, black sage, California sagebrush, coast silver lupine, and

**Table 3.** Number of individual plants occuring within a 61 cm (2 ft) radius of the entrance to each burrow system in 1988. Numbers above each column are the code numbers given to each plant species (see methods). The two-letter abbreviations below each column number represent the first letter of the Genus followed by the first letter of the species (refer to methods). Each "X" in a cell indicates that 1 member of that species category was associated with that burrow system. The total frequency distribution of all species categories for the 36 burrow systems is given in the last row.

| BURROW | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | HERB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SYSTEM | Cf | Sb | Pf | Ec | Sm | Hc | Ac | Lc | Ls | Ee | Oc | Ep | Td | OPEN |
| A | | | | | | | | | X | | | | | |
| B | | | | | | | | | X | | | | | |
| C | | | | | | | | | X | | | | | |
| D | | | | | X | | | | X | X | | | | |
| E | | | | | | | | | XXX | X | | | | |
| F | X | | | | | | | | X | | | | | X |
| G | | | | | | | | | | | | | | X |
| H | | | | | | | | | | | | | | X |
| I | X | | | | | | | | XX | | | | | |
| J | | | | | | | | | XXX | | | | | |
| K | | | | | | | | | X | X | | | | |
| L | XX | | | | X | | | | X | X | | | | X |
| M | | | | | | | | | X | | | | | |
| N | X | | | | | | X | | | | | | | |
| O | X | | | | | | X | | X | X | | | | |
| P | X | X | | | | | | | | | | | | |
| Q | | | | | | | | | | X | | | | |
| R | | | | | | | | | | X | | | | |
| S | | X | | | | | | | | | | | | |
| T | X | | | | | | | | X | | | X | | |
| U | | | | | | | | | X | | | | | |
| V | X | | | | | | | X | XX | | | | | |
| W | | | | | | | | | | X | | | | |
| X | X | | | | | | | | X | X | | | | |
| Y | | | | | | | | | | | | | | X |
| Z | | | | | | | | | | X | | | | |
| AA | X | | | | | | | | | | | | | |
| BB | | | | | | | | | | X | | | | |
| CC | | | | | | | | | X | X | | | | |
| DD | | | | | | | | | X | | | | | |
| EE | | | | | | | | | X | | | | | |
| FF | | | | | | | X | | | | | | | |
| GG | | | | | | | | | | | | | | X |
| HH | | | | | | | | | | | | | | X |
| II | X | | | | | | | X | X | | | | | |
| JJ | | | | | | | | | | X | | | | X |
| TOTAL | 12 | 2 | 0 | 0 | 2 | 0 | 3 | 2 | 26 | 13 | 0 | 1 | 0 | 8 |
| | | | | | | | | | | | | | | |

coastal buckwheat. No burrow systems were constructed near sand almond, coast golden yarrow, horkelia, croton, or poison oak. When the actual frequency distribution of the number of plants located within a radius of 2 ft from each burrow entrance (Table 3) was compared to an expected frequency distribution of 69 of these plants based upon the % of total coverage of each species category (Table 2), a significant difference was found (Chi Square = 146.48, df = 13, $p < .001$). Thus, Morro Bay kangaroo rats constructed burrow entrances more frequently than expected near California aster, deerweed and mock heather and less frequently than expected in bare ground or near herbaceous growth.

In addition to the 36 definite Morro Bay kangaroo rat burrow systems, there were 5-10 burrows which were suspected, but not confirmed, to be made by Morro Bay kangaroo rat. None of these unconfirmed burrows had tail drags on the sand aprons adjacent to their entrances. These burrows had small entrances (2.5 cm X 2.5 cm, 1 in. X 1 in.) which were roughly characteristic of Morro Bay kangaroo rat burrow entrances. In addition to the definite Morro Bay kangaroo rat burrow systems and unconfirmed burrows, some Morro Bay kangarro rat burrow attempts were never completed and these were abandoned within a 5-7 days. Finally, there were 4 new burrow attempts which had not been completed by the time this report was prepared.

On 13 July, a large sand mound with no entrances and no signs of Morro Bay kangaroo rat use was found under a shrub. By the end of August, there were at least 13 such mounds ranging from 46 - 122 cm (1 1/2-4 ft) in diameter located at the bases of various shrubs in the enclosure (refer to Fourth Progress Report). Although these mounds had a similar appearance; some had angled burrow entrances on the mounds, others had angled burrow entrances (with little or no sand surrounding them) 15 - 30 cm (6-12 in) away the nearest mounds, and others lacked neighboring burrow entrances. After August, new, unaccountable sand mounds appeared quite infrequently.

It is possible that these sand mounds were constructed by pocket gophers;

however, instead of appearing as a "chain" of mounds typical of pocket gophers, they appeared as one continuous mound directly under a shrub. Furthermore, none of the burrow entrances had typical pocket gopher "plugs". On 31 August, the area outside the enclosure was searched for similar sand mounds. Several, conspicuous pocket gopher mounds were found, the closest being about 10 m (30 ft) from the northeast corner of the enclosure. All of the pocket gopher mounds found outside the enclosure followed the typical "chain" pattern. None of the pocket gopher burrows or other small mammal burrows found outside resembled the sand mounds found inside the enclosure.

The dimensions of burrow entrances associated with some sand mounds were smaller than those of known Morro Bay kangaroo rat burrrow entrances in the enclosure. Although the entrances seemed too large for mice, given the abundance of pocket mice in the enclosure and the lack of information on pocket mouse burrows in this area, we cannot rule out pocket mice as the builders of these mounds. Finally, the sand mounds simply may have been created by Morro Bay kangaroo rats during the course of new burrows excavation. Since pocket gophers, pocket mice, and other small mammals live in the habitat outside the enclosure, but these sand mounds only were found inside the enclosure; circumstantial evidence suggests that Morro Bay kangaroo rats were creating the mounds without leaving typical signs (e.g. tail drags) on the freshly excavated sand. Further evidence that support this latter hypothesis is that Morro Bay kangaroo rat burrow systems K, L, M, O, T, U subsequently developed at burrow entrances originally associated with some of these mounds.

## SOIL TEMPERATURE

The general temperature regime of soils is the result of solar radiation input, longwave radiation output, and heat flow in the soil itself. During the day, the input of solar radiation exceeds the output of longwave radiation and the surface layer of soil is heated. As the heat content of the surface increases, a vertical temperature gradient is created. That is, there is a difference in temperature between the upper (warmer) and lower (cooler) soil layers. According to the second law of thermodynamics, heat will flow downward from the warmer, upper layer to the cooler, lower layers (Jumikis 1977). The flow of heat is a consequence of: molecular conduction (ie. when kinetic energy is passed between molecules), movement of cold or warm water in wet soils, movement of convective air currents in the pore spaces, evaporation, and transpiration (Kirkham 1972 and Jumikis 1977).

During the night, the input of solar radiation ceases but the output of longwave radiation continues and the surface layer of the soil cools. The temperature gradient is eventually reversed and heat begins to flow from the warmer, deeper layers to the cooler, upper layers by the same mechanisms of heat transfer described above. Associated with these processes of soil heating and cooling, other factors influence the supply of heat to the soil (e.g. soil color, vegetation cover, slope exposure, and weather). In addition to factors influencing the supply of heat, other factors influence the rate of heat flow in the soil (e.g. water content, porosity, bulk density, thermal conductivity, and heat capacity). All of these factors affect soil temperature and thus cause variability in temperature profiles between sites (Hanks and Ashcroft 1980 and Shul'gin 1965).

Because soil temperatures are largely determined by the diurnal cycle of solar radiation and longwave re-radiation, soil temperatures exhibit their own diurnal cycle with daily maxima and minima. Figures 18 and 19 show soil temperatures at three depths on a typical summer day (10 August) and a typical winter day (28 November), respectively. Disregarding actual temperatures, a distinct diurnal cycle (roughly a sine wave) is apparent at 10 cm in both the summer (Fig. 18) and winter (Fig. 19). At 30 cm a diurnal cycle is recognizeable, but the amplitude is less than at 10 cm and the periodicity lags behind the 10 cm cycle. At 60 cm (disregarding actual soil temperature) there is little or no change in temperature over 24 hour periods in summer or winter. This "damping" of the diurnal soil temperature cycle with

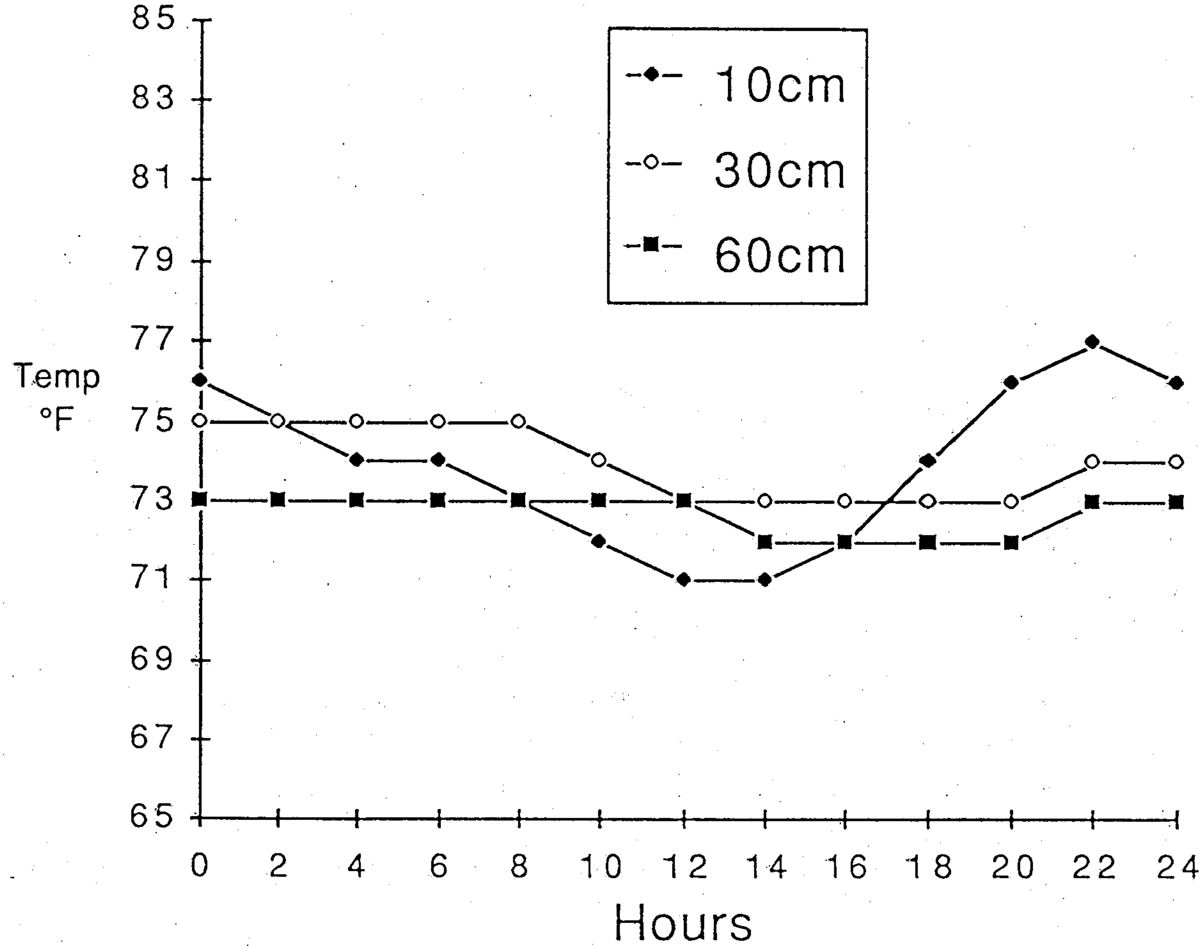



Figure 18. Daily pattern of soil temperatures (° F) in the enclosure at depths of 10, 30, 60 cm on 10 August, 1988.

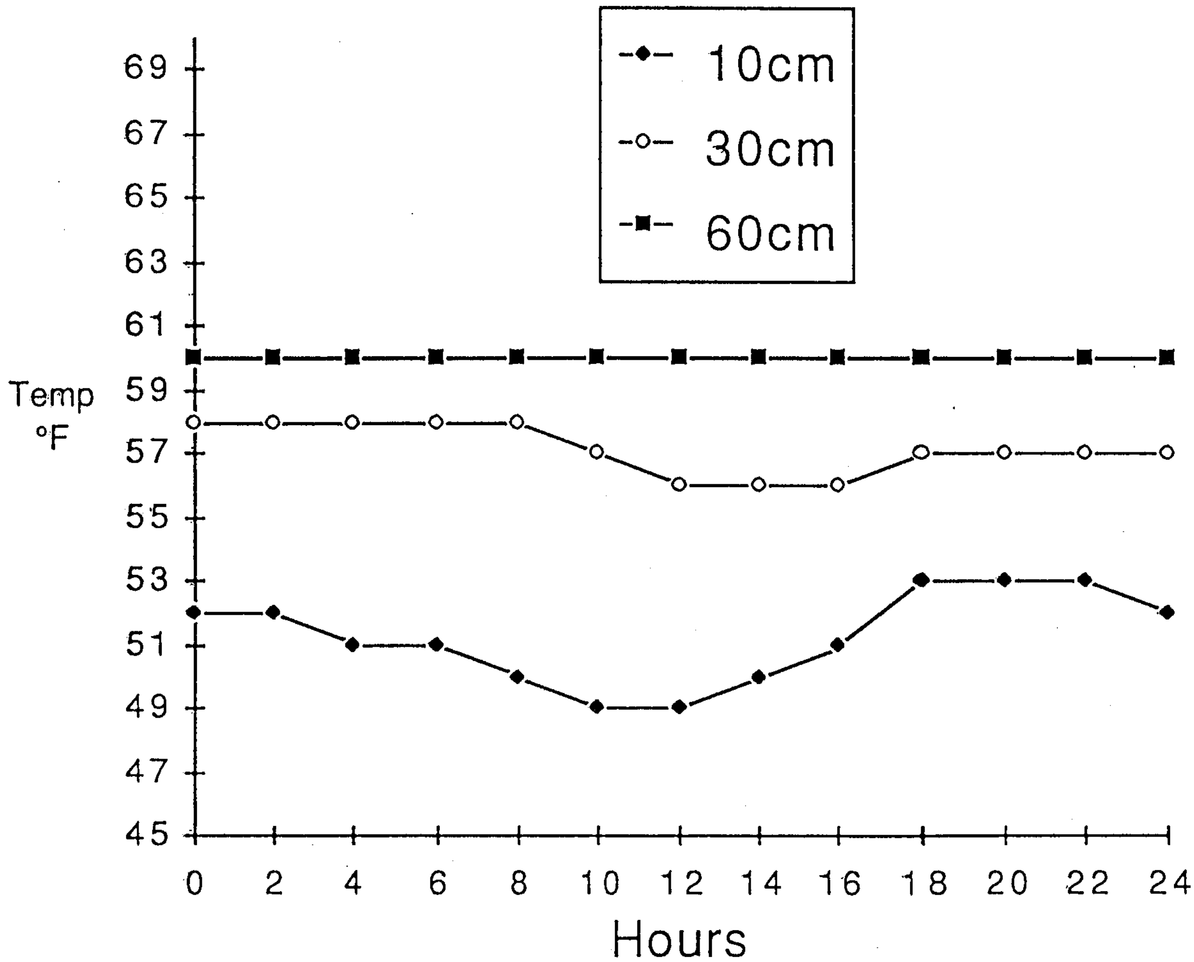



Figure 19. Daily pattern of soil temperatures (° F) in the enclosure at depths of 10, 30, 60 cm on 28 November, 1988.

increasing depth is caused by a resistance to heat conduction through the soil profile. That is, the upper soil layers absorb most of the available heat so that downward flow of heat is reduced (Shul'gin 1965). As a result, the temperature gradient decreases with increasing depth. Shul'gin (1965) found that "The 'damping' of diurnal soil temperature oscillations generally occurs at a depth between 35 and 100 cm. At or below this depth, soil temperature remains constant."

We found a time lag in diurnal soil temperature cycles which progressed from the upper to the lower soil depths (Fig's. 18 and 19). Both Shul'gin (1965) and Hanks and Ashcroft (1980) found that maximum soil temperature occurred at the surface at solar noon. Hanks and Ashcroft (1980) found that at a depth of 1 cm the maximum temperature occurred 2 hours after solar noon (14:00) and at 8 cm the maximum occurred at 16:00. In the present study, maximum soil temperature at 10 cm was reached between 18:00 and 22:00 and at 30 cm the maximum was reached between 00:00 and 06:00. A similar time lag occurs with nighttime cooling. Jumikis (1977) states that this time lag phenomenon is a result of "... the difference in coefficients of thermal conductivity and heat convection ..." between the different layers of soil. The upper soil layers have a lower thermal conductivity than the subsoil layers and this results in a resistance to downward heat flow because the upper layers absorb heat for a longer period of time before conducting heat to the lower layers. "Because a temperature gradient must develop before heat flows to lower depths, there is a time lag between maximum surface temperature and maximum temperature at the lower depths" (Hanks and Ashcroft 1980).

The crude monthly thermal regimes at 10, 30, and 60 cm in the enclosure are presented in Table 4. During June, July and August, the thermal gradients among minimum temperatures were much less than the gradients among maximum temperatures. This pattern resulted in a gradual rise in temperature at the 60 cm level. During September, October, November, and December, the thermal gradients among monthly minimum temperatures were much higher than the gradients among maximum temperatures. This pattern resulted in a gradual decline in

**Table 4.** Minimum and maximum soil temperatures (° F) at 3 depths (10, 30, 60 cm) in the enclosure from June through December 1988.

| | SOIL DEPTH | | | | | |
|---|---|---|---|---|---|---|
| | 10 cm | | 30 cm | | 60 cm | |
| MONTH | Min. | Max. | Min. | Max. | Min. | Max. |
| June | 66 | 80 | 68 | 73 | 69 | 70 |
| July | 66 | 80 | 68 | 76 | 69 | 73 |
| August | 67 | 82 | 71 | 76 | 71 | 73 |
| September | 62 | 74 | 67 | 72 | 69 | 72 |
| October | 56 | 68 | 62 | 69 | 65 | 70 |
| November | 47 | 64 | 55 | 66 | 61 | 66 |
| December | 41 | 56 | 48 | 59 | 52 | 61 |

temperature at the 60 cm depth. The shift in heat flow produced by these large-scale thermal gradients produced an interesting pattern of monthly median temperatures at the three soil depths. During the summer months (June, July, and August), median soil temperature was warmest at 10 cm and coolest at 60 cm. Between August and September a turnover occurred in median soil temperature such that during the winter months (September - December) it was coldest at 10 cm and warmest at 60 cm (Fig. 20). These trends and the turnover phenomenon are consistent with the descriptions of the annual cycle in soil temperature given by Hanks and Ascroft (1980), Jumikis (1977), and Shul'gin (1965).

The diurnal and annual cycles of soil temperature create some advantages for Morro Bay kangaroo rats and other burrowing animals. The "damping" effects on temperature oscillations with increasing depth creates a more stable thermal environment in their burrows than if they were continually exposed to surface conditions. Stewart (1958) found that Morro Bay kangaroo rat burrows typically reach depths of 15 - 25 cm. At these depth our results reveal that there is a noticeable diurnal oscillation in soil temperatures (10 and 30 cm in Fig's 18 and 19); however the extremes are markedly less than those at or near the surface. Morro Bay kangaroo rats in burrows are able to avoid summer heat stress and dehydration as a function of burrow depth. From June through August, the temperature at 10 cm never exceeded 82 °F and at 30 cm the summer maximum was 76 °F (Table 4). During the fall and winter months, substantially warmer subsoils may enable Morro Bay kangaroo rats to avoid cold stress or hypothermia. By December, the low temperatures were 41°F at 10 cm and 48°F and 52°F at 30 cm and 60 cm, respectively (Table 4). Although soil temperatures probably decline more as the winter progresses, we to not expect late winter soil temperatures to fall below about 40 °F at minimum burrow depths of around 8 cm. Provided Morro Bay kangaroo rats do not enter torpor when environmental temperature approaches 40 °F, we would expect that their body heat would raise the burrow temperature slightly above that of surrounding soils. The authors suspect that Morro Bay kangaroo rats can and do

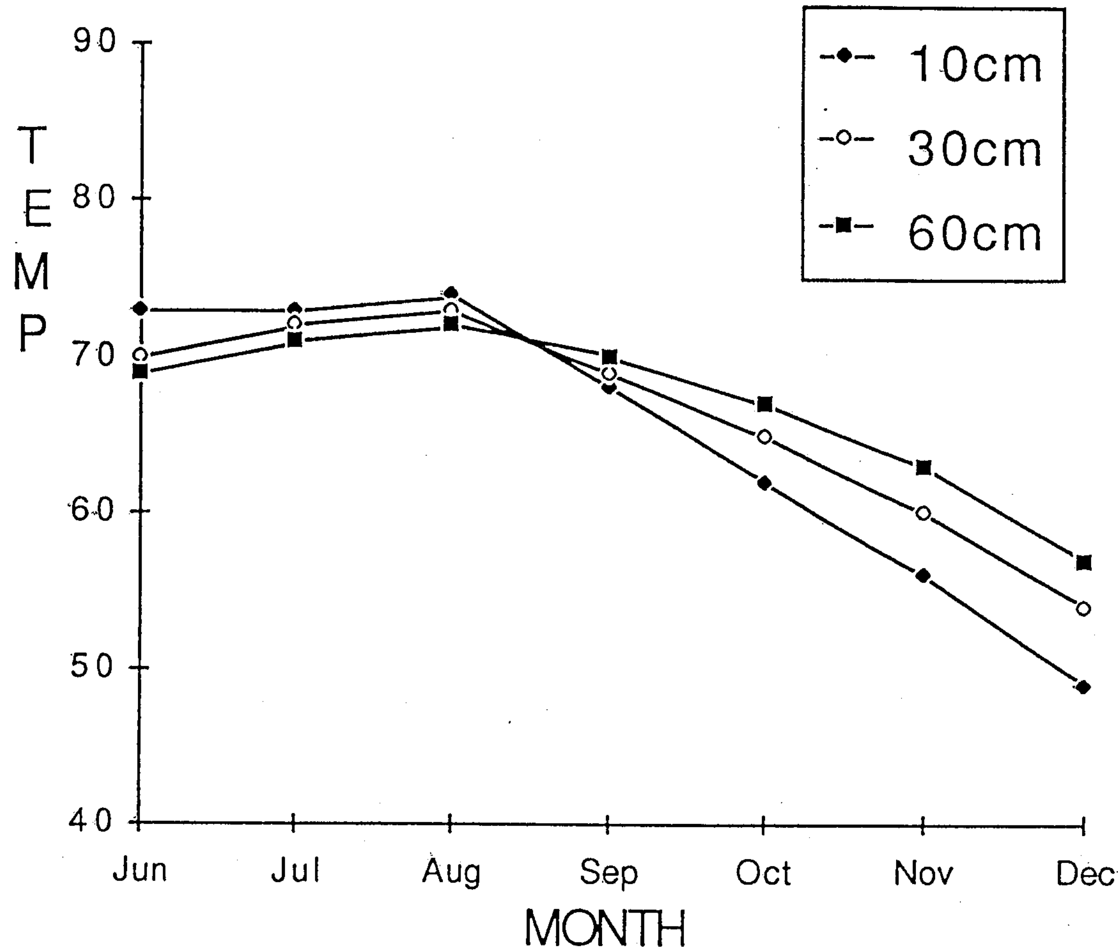



Figure 20. Median monthly soil temperature (° F) in the enclosure at depths of 10, 30, 60 cm.

burrow deeper than 25 cm. If this turns out to be the case, than any such burrow obviously would be located closer to the "damping" depth in the soil where diurnal and seasonal temperature oscillation reach a minimum. When compared to shallow burrows, burrows below 35 cm (e.g. 60 cm) would be subjected to little or no diurnal temperature oscillation, cooler summer temperatures, and warmer winter temperatures.

## SMALL MAMMAL POPULATION, DENSITY, AND RELATIVE ABUNDANCE ESTIMATES INSIDE THE ENCLOSURE

### Estimates Made Before the Introduction of Morro Bay Kangaroo Rats (April-May)

Deer mice

Deer mice *(Peromyscus maniculatis)* were the dominant species in the enclosure in April and May, before Morro Bay kangaroo rats were present. Their density was 49.39 deer mice/ha in April and 18.82 deer mice/ha in May (Table 5). The relative abundance of deer mice during this time ranged from 5.0 to 20.0 deer mice/100 TN.

California pocket mice

No California pocket mice *(Perognathus californicus)* were captured in the enclosure in April or May, prior to the introduction of Morro Bay kangaroo rats (Table 6).

Western harvest mice

Two western harvest mice *(Reithrodontomys megalotis)* were captured in the enclosure in April and 5 were captured in May (Table 7). Lack of recaptures

Table 5. Trapping intensity (#TN); capture results (# CAP, # NEW, and # RECAP); Relative abundance (#/100 TN); population estimates within the enclosure and density estimates (#/ha) for deer mice (*Peromyscus maniculatis* ) during each trapping session in 1988.

| DATE | #TN | #CAP | #NEW | #RECAP | #/100TN | POP.EST. | DEN. |
|---|---|---|---|---|---|---|---|
| 20 April | 20 | 2 | 2 | 0 | 10.0 | ~ | ~ |
| 21 April | 20 | 3 | 1 | 2 | 15.0 | 3.0 | 35.28 |
| 22 April | 20 | 4 | 1 | 3 | 20.0 | 3.6 | 42.34 |
| 26 April | 18 | 2 | 0 | 2 | 11.1 | 3.7 | 43.51 |
| 27 April | 19 | 2 | 0 | 2 | 10.5 | 3.8 | 44.69 |
| 28 April | 17 | 1 | 0 | 1 | 5.9 | 3.8 | 44.69 |
| 29 April | 17 | 2 | 1 | 1 | 11.8 | 4.2 | 49.39 |
| 10 May | 20 | 2 | 2 | 0 | 10.0 | ~ | ~ |
| 17 May | 20 | 2 | 1 | 1 | 10.0 | 4.0 | 23.52 |
| 18 May | 20 | 2 | 0 | 2 | 10.0 | 3.3 | 19.40 |
| 19 May | 20 | 2 | 0 | 2 | 10.0 | 3.2 | 18.82 |
| 20 May | 20 | 1 | 0 | 1 | 5.0 | 3.2 | 18.82 |
| 2 June | 20 | 0 | 0 | 0 | ~ | | |
| 3 June | 20 | 2 | 2 | 0 | ~ | | |
| 6 June | 20 | 0 | 0 | 0 | ~ | | |
| 7 June | 20 | 1 | 0 | 1 | ~ | | |
| 8 June | 20 | 1 | 0 | 1 | ~ | | |
| 9 June | 20 | 0 | 0 | 0 | ~ | | |
| 10 June | 20 | 0 | 0 | 0 | ~ | | |
| 9 August | 60 | 0 | 0 | 0 | | | |
| 10 August | 56 | 0 | 0 | 0 | | | |
| 11 August | 53 | 0 | 0 | 0 | | | |
| 12 August | 55 | 0 | 0 | 0 | | | |
| 15 August | 59 | 0 | 0 | 0 | | | |
| 16 August | 55 | 0 | 0 | 0 | | | |
| 17 August | 59 | 0 | 0 | 0 | | | |
| 18 August | 57 | 0 | 0 | 0 | | | |
| 19 August | 60 | 0 | 0 | 0 | | | |
| 21 September | 59 | 1 | 1 | 0 | 1.69 | ~ | ~ |
| 22 September | 60 | 1 | 0 | 1 | 1.66 | 1.0 | 4.72 |
| 23 September | 60 | 1 | 0 | 1 | 1.66 | 1.0 | 4.72 |
| 26 September | 59 | 1 | 0 | 1 | 1.69 | 1.0 | 4.72 |
| 27 September | 56 | 1 | 0 | 1 | 1.79 | 1.0 | 4.72 |
| 28 September | 58 | 1 | 0 | 1 | 1.72 | 1.0 | 4.72 |
| 29 September | 58 | 1 | 0 | 1 | 1.72 | 1.0 | 4.72 |
| 30 September | 57 | 0 | 0 | 0 | 0 | 1.0 | 4.72 |
| 4 October | 87 | 2 | 1 | 1 | 2.25 | 1.1 | 5.19 |
| 5 October | 88 | 3 | 1 | 2 | 3.41 | 1.6 | 7.55 |
| 6 October | 89 | 3 | 0 | 3 | 3.37 | 1.9 | 8.96 |
| 11 October | 88 | 2 | 0 | 2 | 2.27 | 2.1 | 9.90 |
| 12 October | 85 | 2 | 1 | 1 | 2.35 | 2.3 | 10.85 |
| 13 October | 86 | 3 | 1 | 2 | 3.49 | 2.8 | 13.21 |

**Table 6.** Trapping intensity (#TN); capture results (# CAP, # NEW, and # RECAP); Relative abundance (#/100 TN); population estimates within the enclosure and density estimates (#/ha) for California pocket mice (*Perognathus californicus*) during each trapping session in 1988.

| DATE | #TN | #CAP | #NEW | #RECAP | #/100TN | POP.EST. | DEN. |
|---|---|---|---|---|---|---|---|
| 20 April | 20 | 0 | 0 | 0 | | | |
| 21 April | 20 | 0 | 0 | 0 | | | |
| 22 April | 20 | 0 | 0 | 0 | | | |
| 26 April | 18 | 0 | 0 | 0 | | | |
| 27 April | 19 | 0 | 0 | 0 | | | |
| 28 April | 17 | 0 | 0 | 0 | | | |
| 29 April | 17 | 0 | 0 | 0 | | | |
| 10 May | 20 | 0 | 0 | 0 | | | |
| 17 May | 20 | 0 | 0 | 0 | | | |
| 18 May | 20 | 0 | 0 | 0 | | | |
| 19 May | 20 | 0 | 0 | 0 | | | |
| 20 May | 20 | 0 | 0 | 0 | | | |
| 2 June | 20 | 0 | 0 | 0 | | | |
| 3 June | 20 | 0 | 0 | 0 | | | |
| 6 June | 20 | 0 | 0 | 0 | | | |
| 7 June | 20 | 1 | 1 | 0 | ~ | | |
| 8 June | 20 | 0 | 0 | 0 | | | |
| 9 June | 20 | 0 | 0 | 0 | | | |
| 10 June | 20 | 0 | 0 | 0 | | | |
| 9 August | 60 | 2 | 2 | 0 | 3.33 | ~ | ~ |
| 10 August | 56 | 1 | 1 | 0 | 1.79 | ~ | ~ |
| 11 August | 53 | 0 | 0 | 0 | 0 | ~ | ~ |
| 12 August | 55 | 2 | 2 | 0 | 3.64 | ~ | ~ |
| 15 August | 59 | 4 | 1 | 3 | 6.78 | 9.3 | 43.87 |
| 16 August | 55 | 3 | 1 | 2 | 5.45 | 9.2 | 43.39 |
| 17 August | 59 | 2 | 2 | 0 | 3.39 | 12.1 | 57.08 |
| 18 August | 57 | 1 | 1 | 0 | 1.75 | 13.8 | 65.09 |
| 19 August | 60 | 5 | 4 | 1 | 8.33 | 19.8 | 93.39 |
| 21 September | 59 | 4 | 4 | 0 | 6.77 | ~ | ~ |
| 22 September | 60 | 6 | 5 | 1 | 10.0 | 24.0 | 113.21 |
| 23 September | 60 | 6 | 2 | 4 | 10.0 | 15.6 | 73.58 |
| 26 September | 59 | 2 | 0 | 2 | 3.39 | 14.3 | 67.45 |
| 27 September | 56 | 1 | 1 | 0 | 1.79 | 15.9 | 75.00 |
| 28 September | 58 | 3 | 1 | 2 | 5.17 | 16.3 | 76.89 |
| ~~29 September~~ | ~~58~~ | ~~4~~ | ~~0~~ | ~~4~~ | ~~6.90~~ | ~~15.3~~ | ~~72.17~~ |
| 30 September | 57 | 2 | 0 | 2 | 3.51 | 15.0 | 70.75 |
| 4 October | 87 | 5 | 1 | 4 | 5.75 | 15.3 | 72.17 |
| 5 October | 88 | 5 | 1 | 4 | 5.68 | 15.7 | 74.06 |
| 6 October | 89 | 2 | 0 | 2 | 2.25 | 15.6 | 73.58 |
| ~~11 October~~ | ~~88~~ | ~~12~~ | ~~5~~ | ~~7~~ | ~~13.64~~ | ~~17.8~~ | ~~83.96~~ |
| 12 October | 85 | 8 | 3 | 5 | 9.41 | 19.7 | 92.9 |
| 13 October | 86 | 4 | 1 | 3 | 4.65 | 20.6 | 97.17 |

Table 7. Trapping intensity (#TN); capture results (# CAP, # NEW, and # RECAP); Relative abundance (#/100 TN); population estimates within the enclosure and density estimates (#/ha) for Western harvest mice (*Reithrodontomys megalotis* ) during each trapping session in 1988.

| DATE | #TN | #CAP | #NEW | #RECAP | #/100TN | POP.EST. | DEN |
|---|---|---|---|---|---|---|---|
| 20 April | 20 | 0 | 0 | 0 | | | |
| 21 April | 20 | 0 | 0 | 0 | | | |
| 22 April | 20 | 0 | 0 | 0 | | | |
| 26 April | 18 | 0 | 0 | 0 | | | |
| 27 April | 19 | 0 | 0 | 0 | | | |
| 28 April | 17 | 1 | 1 | 0 | 5.9 | ~ | ~ |
| 29 April | 17 | 1 | 1 | 0 | 5.9 | ~ | ~ |
| 10 May | 20 | 2 | 2 | 0 | 10.0 | ~ | ~ |
| 17 May | 20 | 1 | 1 | 0 | 5.0 | ~ | ~ |
| 18 May | 20 | 1 | 1 | 0 | 5.0 | ~ | ~ |
| 19 May | 20 | 0 | 0 | 0 | 0 | ~ | ~ |
| 20 May | 20 | 1 | 1 | 0 | 5.0 | ~ | ~ |
| 2 June | 20 | 1 | 1 | 0 | ~ | | |
| 3 June | 20 | 0 | 0 | 0 | | | |
| 6 June | 20 | 0 | 0 | 0 | | | |
| 7 June | 20 | 0 | 0 | 0 | | | |
| 8 June | 20 | 0 | 0 | 0 | | | |
| 9 June | 20 | 0 | 0 | 0 | | | |
| 10 June | 20 | 0 | 0 | 0 | | | |
| 9 August | 60 | 1 | 1 | 0 | 1.66 | ~ | ~ |
| 10 August | 56 | 0 | 0 | 0 | 0 | ~ | ~ |
| 11 August | 53 | 0 | 0 | 0 | 0 | ~ | ~ |
| 12 August | 55 | 0 | 0 | 0 | 0 | ~ | ~ |
| 15 August | 59 | 1 | 1 | 0 | 1.69 | ~ | ~ |
| 16 August | 55 | 0 | 0 | 0 | 0 | ~ | ~ |
| 17 August | 59 | 0 | 0 | 0 | 0 | ~ | ~ |
| 18 August | 57 | 0 | 0 | 0 | 0 | ~ | ~ |
| 19 August | 60 | 0 | 0 | 0 | 0 | ~ | ~ |
| 21 September | 59 | 0 | 0 | 0 | | | |
| 22 September | 60 | 0 | 0 | 0 | | | |
| 23 September | 60 | 0 | 0 | 0 | | | |
| 26 September | 59 | 0 | 0 | 0 | | | |
| 27 September | 56 | 0 | 0 | 0 | | | |
| 28 September | 58 | 0 | 0 | 0 | | | |
| 29 September | 58 | 0 | 0 | 0 | | | |
| 30 September | 57 | 0 | 0 | 0 | | | |
| 4 October | 87 | 0 | 0 | 0 | | | |
| 5 October | 88 | 0 | 0 | 0 | | | |
| 6 October | 89 | 0 | 0 | 0 | | | |
| 11 October | 88 | 0 | 0 | 0 | | | |
| 12 October | 85 | 0 | 0 | 0 | | | |
| 13 October | 86 | 0 | 0 | 0 | | | |

prevented the calculation of population and density estimates for western harvest mice before the introduction of Morro Bay kangaroo rats. The relative abundance of harvest mice ranged from 0.0 to 10.0 harvest mice/100 TN.

Morro Bay kangaroo rats

No Morro Bay kangaroo rats were captured in the enclosure in April or May (Table 8).

**Estimates Made After the Introduction of Morro Bay Kangaroo Rats (August - October)**

Deer mice

By August, three months after the first release of Morro Bay kangaroo rats, deer mice (which had been dominant in the enclosure before the release) declined to a statistically insignificant level in the enclosure (Tables 5 and 9). Deer mice reappeared in September-October with a density of 13.21 deer mice/ha and a relative abundance of only 2.22 deer mice/100 TN.

California pocket mice

California pocket mice (which had been absent from the enclosure before the introduction of Morro Bay kangaroo rats) became the most abundant small mammal in the enclosure after the release (Tables 6 and 9, Figure 21). In August, the density of pocket mice jumped to an astounding 93.39/ha (the population estimate of pocket mice in the enclosure was 19.8 individuals) and their relative abundance was 3.89 pocket mice/100 TN (Table 6). By September-October, their density rose to 97.17/ha (the population estimate of pocket mice in the enclosure was 20.6) and their relative abundance climbed to 6.46/100 TN. Although these population and density estimates are quite high, they are probably realistic because 14 different

**Table 8.** Trapping intensity (#TN); capture results (# CAP, # NEW, and # RECAP); Relative abundance (#/100 TN); population estimates within the enclosure and density estimates (#/ha) for Morro Bay kangaroo rats (*Dipodomys heermanni morroensis*) during each trapping session in 1988.

| DATE | #TN | #CAP | #NEW | #RECAP | #/100TN | POP.EST. | DEN. |
|---|---|---|---|---|---|---|---|
| 20 April | 20 | 0 | 0 | 0 | | | |
| 21 April | 20 | 0 | 0 | 0 | | | |
| 22 April | 20 | 0 | 0 | 0 | | | |
| 26 April | 18 | 0 | 0 | 0 | | | |
| 27 April | 19 | 0 | 0 | 0 | | | |
| 28 April | 17 | 0 | 0 | 0 | | | |
| 29 April | 17 | 0 | 0 | 0 | | | |
| 10 May | 20 | 0 | 0 | 0 | | | |
| 17 May | 20 | 0 | 0 | 0 | | | |
| 18 May | 20 | 0 | 0 | 0 | | | |
| 19 May | 20 | 0 | 0 | 0 | | | |
| 20 May | 20 | 0 | 0 | 0 | | | |
| 2 June | 20 | 0 | 0 | 0 | | | |
| 3 June | 20 | 0 | 0 | 0 | | | |
| 6 June | 20 | 0 | 0 | 0 | | | |
| 7 June | 20 | 0 | 0 | 0 | | | |
| 8 June | 20 | 0 | 0 | 0 | | | |
| 9 June | 20 | 0 | 0 | 0 | | | |
| 10 June | 20 | 0 | 0 | 0 | | | |
| 9 August | 60 | 1 | 1 | 0 | 1.66 | | |
| 10 August | 56 | 0 | 0 | 0 | 0 | ~ | ~ |
| 11 August | 53 | 1 | 0 | 1 | 1.89 | 1.0 | 4.72 |
| 12 August | 55 | 0 | 0 | 0 | 0 | 1.0 | 4.72 |
| 15 August | 59 | 0 | 0 | 0 | 0 | 1.0 | 4.72 |
| 16 August | 55 | 1 | 0 | 1 | 1.82 | 1.0 | 4.72 |
| 17 August | 59 | 0 | 0 | 0 | 0 | 1.0 | 4.72 |
| 18 August | 57 | 0 | 0 | 0 | 0 | 1.0 | 4.72 |
| 19 August | 60 | 1 | 0 | 1 | 1.66 | 1.0 | 4.72 |
| 21 September | 59 | 1 | 1 | 0 | 1.69 | | |
| 22 September | 60 | 0 | 0 | 0 | 0 | ~ | ~ |
| 23 September | 60 | 1 | 0 | 1 | 1.66 | 1.0 | 4.72 |
| 26 September | 59 | 0 | 0 | 0 | 0 | 1.0 | 4.72 |
| 27 September | 56 | 0 | 0 | 0 | 0 | 1.0 | 4.72 |
| 28 September | 58 | 0 | 0 | 0 | 0 | 1.0 | 4.72 |
| 29 September | 58 | 1 | 1 | 0 | 1.72 | 2.0 | 9.43 |
| 30 September | 57 | 1 | 0 | 1 | 1.75 | 2.0 | 9.43 |
| 4 October | 87 | 0 | 0 | 0 | 0 | 2.0 | 9.43 |
| 5 October | 88 | 0 | 0 | 0 | 0 | 2.0 | 9.43 |
| 6 October | 89 | 0 | 0 | 0 | 0 | 2.0 | 9.43 |
| 11 October | 88 | 1 | 1 | 0 | 1.14 | 3.0 | 14.15 |
| 12 October | 85 | 1 | 0 | 1 | 1.18 | 3.0 | 14.15 |
| 13 October | 86 | 0 | 0 | 0 | 0 | 3.0 | 14.15 |

**Table 9.** Relative abundance (#/100TN) and density (#/ha) for each species captured in the enclosure in 1988. Trapping efforts (#TN) are given for each monthly trapping session. *D. H. morroensis* = Morro Bay kangaroo rats, *Pg. cal.* = California pocket mice, *Pm. man.* = deer mice, *Rd. meg.* = Western harvest mice.

Morro Bay kangaroo rats first introduced (between May and August)

| | | | | | |
|---|---|---|---|---|---|
| Month(1988) | | April | May | August | Sept.-Oct. |
| Trapping effort | | 131TN | 100TN | 514TN | 990TN |
| *D. h. morroensis* | #/100TN | ~ | ~ | 0.78 | 0.61 |
| | Density | ~ | ~ | 4.72 | 14.15 |
| *Pg. cal.* | #/100TN | ~ | ~ | 3.89 | 6.46 |
| | Density | ~ | ~ | 93.39 | 97.17 |
| *Pm. man.* | #/100TN | 12.21 | 9.00 | ~ | 2.22 |
| | Density | 49.39 | 18.82 | ~ | 13.21 |
| *Rd. meg.* | #/100TN | 1.53 | 5.00 | 0.39 | ~ |
| | Density | ~ | ~ | ~ | ~ |

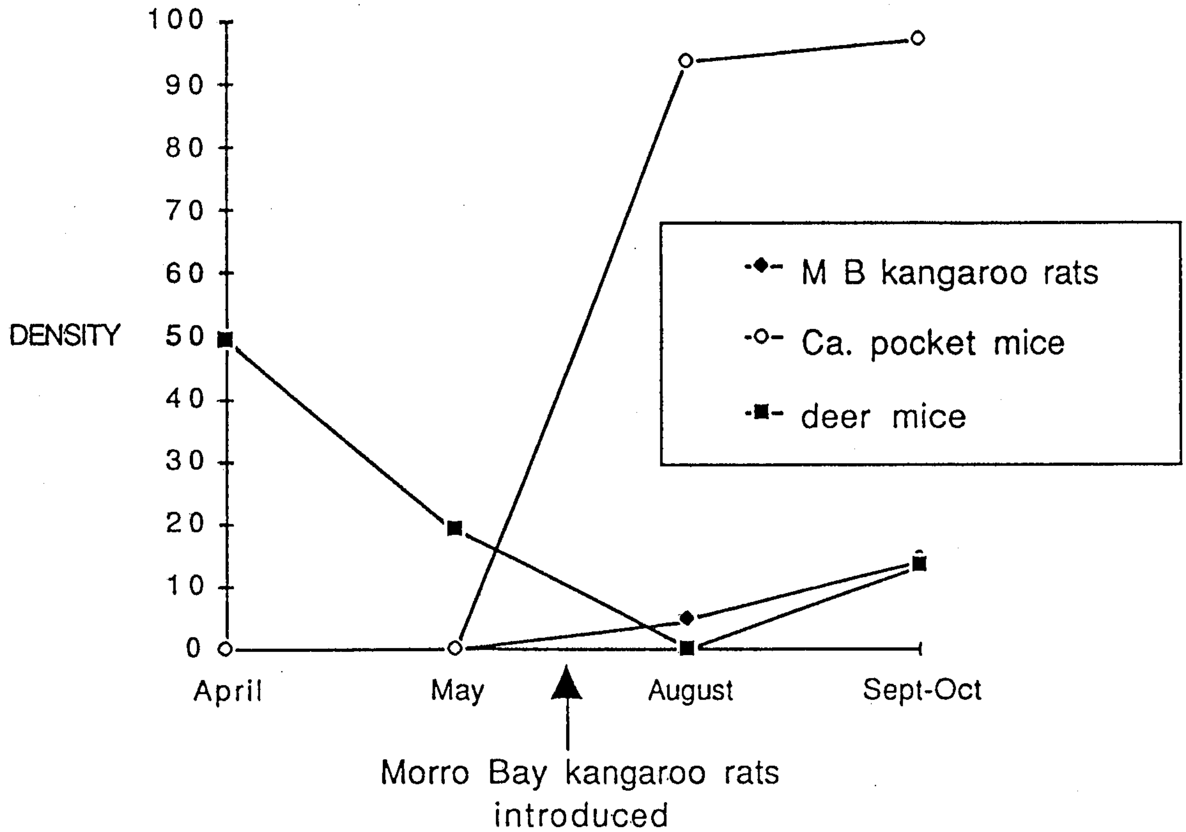



Figure 21. Small mammal densities (#/ha) from 4 trapping sessions in the enclosure in 1988.

pocket mice were captured in the enclosure in August and 24 different individuals were captured in September-October.

Western harvest mice

Two western harvest mice were captured in the enclosure in August yielding a relative abundance of 0.39 harvest mice/100 TN, which represents a marked decrease from their relative abundance before Morro Bay kangaroo rats were present (Tables 7 and 9). Once again, lack of recaptures prevented population and density estimates for harvest mice. No western harvest mice were captured in the enclosure during the September-October trapping session.

Morro Bay kangaroo rats

Only 1 of the 4 introduced Morro Bay kangaroo rats was trapped in the enclosure in August (Table 8). As a result, the population estimate in the enclosure was 1, the density estimate was 4.72 Morro Bay kangaroo rats/ha, and the relative abundance was 0.78 rat/100 TN. Three Morro Bay kangaroo rats were captured in September-October. The population estimate in the enclosure was 3.0 which was equal to a density of 14.15 Morro Bay kangaroo rats /ha. The population estimate of Morro Bay kangaroo rats in the enclosure in September - October is very close to or exactly equal to the number of rats present there. If, as we suspect, male #2601R no longer exists in the enclosure, then the population estimates would be exactly equal to the known number of rats there in October 1988.

## RELATIONSHIP OF MORRO BAY KANGAROO RAT NUMBERS TO THE NUMBER OF BURROW SYSTEMS

Assuming there were only 3 animals present in the enclosure during the September - October trapping session, our burrow system data allow us to develop a verified relationship between a "known" number of Morro Bay kangaroo rats present and a minimum, known number of burrow systems associated with these animals.

The total number of active burrow systems in the enclosure was 25 in September and 32 in October (Figure 17) which gives an average of about 29 burrow systems during the September - October trapping session. Assuming that only 3 Morro Bay kangaroo rats were reponsible for these 29 active burrow systems, we estimate that, on average, one Morro Bay kangaroo rat maintains 10 active burrow systems during the fall. If we extrapolate the figures to a population of 14 animals inhabiting 1 ha of similar habitat, then we would expect to find 140 active burrow systems/ha being maintained by 14 rats during the fall months.

Using a similar procedure, we are able to develop another relationship between rats and burrows for the summer (August). Although we caught only 1 Morro Bay kangaroo rat in the enclosure during the August trapping session, we know there were at least 3 animals present there because we caught the other 2 later in the year. The number of active burrow systems present in August was 17 (Figure 17). Thus, we estimate that, on average, 1 Morro Bay kangaroo rat maintains 6 active burrow systems during the summer. If we extrapolate these figures to a population of 14 animals inhabiting 1 ha of similar habitat, then we would expect to find 84 active burrow systems /ha being maintained by 14 rats during the summer months.

The difference between our summer burrow estimate of 84 active burrow systems/ha and our fall estimate of 140 active burrow systems/ha may represent a real difference or it may be confounded by supplemental feeding which was completely terminated on 3 August. Since residual feed mix was still abundant during our August trapping session, our burrow system estimate may be too low. That is, if the number of active burrow systems is positively related to food abundance/availability, then we would expect fewer active burrow systems in August than later in the year when there was substantially less residual feed mix in the enclosure. Assuming that the number of burrow systems is positively related to food abundance/availability, then we would expect more than 6 active burrow systems/individual in August under field conditions. It may well be that our fall estimate of 10 active burrow systems/individual is a better estimate of both the summer and fall relationships of burrow systems to individuals. Of course, if the number of burrow systems turns out to be independent of food sources, then our projection of 10 burrow systems/individual in the summer is too high. At this point, we have no evidence to suggest that the number of burrows/individual in summer/fall would be less than 6 active burrow systems/Morro Bay kangaroo rat.

## EFFECTS OF THE ENCLOSURE AND MORRO BAY KANGAROO RATS ON OTHER SMALL MAMMALS: POPULATION COMPARISONS BETWEEN THE ENCLOSURE AND PLOT TUVWX

Trapping was conducted from 27 May through 5 June on plot TUVWX by Jeff Souza, a Cal Poly student, one week after our May trapping session inside the enclosure. Another trapping session on plot TUVWX also was conducted from 1 - 23 October by Rita Leone, a Cal Poly student. This latter session on TUVWX overlapped our 21 September to 13 October trapping session in the enclosure, about 4 months after the first introduction of Morro bay kangaroo rats to the enclosure.

### Deer mice

The density of deer mice on plot TUVWX in May-June was 5.23 deer mice/ha, which was less than 1/3 the estimate of 18.82 deer mice/ha in the enclosure in May. The relatively high densities of deer mice inside the enclosure before the release of Morro Bay kangaroo rats may be the result of disturbance caused by construction. Deer mice have typically responded quickly with increased densities on plots that were manually cleared or burned at the Pecho site, however their densities gradually decreased over time (Gambs and Holland 1988). The density of deer mice on plot

TUVWX in October increased to 13.38 deer mice/ha, which was essentially equal to the 13.21 deer mice/ha we found in the enclosure in September - October. The fall density of deer mice in the enclosure was unexpected since none were captured inside during August and, at the Bayview site, where wild Morro Bay kangaroo rats were present, deer mice were never found at densities greater than 1 mouse/ha (Gambs and Holland 1988). Of the 5 deer mice captured in the enclosure during the September - October trapping session, 3 were subadult or juvenile animals and 2 were lactating, adult females. These were probably transients which dispersed from outside areas rather than permanent residents of the enclosure. The apparent absence of deer mice in the enclosure in August can probably be attributed to the presence of Morro Bay kangaroo rats there.

Western harvest mice

In contrast to deer mice, western harvest mice have exhibited very low densities or complete absence on recently disturbed study plots at the Pecho site. The density of western harvest mice on plot TUVWX in May was 14.89/ha; whereas lack of recaptures prevented harvest mouse population and density estimates inside the enclosure. The relative abundance of 5.0 harvest mice/100 TN inside the enclosure in May was less than 1/2 the 10.33 harvest mice/100 TN found on TUVWX. Ground disturbance and heavy trampling during construction probably destroyed much of the grasses and herbs in the enclosure which are apparently needed by western harvest mice. In October, the density of harvest mice on plot TUVWX dropped to 5.76/ha; whereas no harvest mice were captured in the enclosure in September - October. Only 2 harvest mice were captured in the enclosure in August and we suspect these were transients from outside. Although western harvest mouse numbers in the enclosure were low in April and May, their complete disappearance from the enclosure by September can probably be attributed to the presence of Morro Bay kangaroo rats there. No western harvest mice have been captured on other study plots at Bayview which were occupied by wild Morro Bay kangaroo rats

(Gambs and Holland 1988).

California pocket mice

California pocket mice were found at a density of 8.57/ha on plot TUVWX in May; however none were captured inside the enclosure in April or May. In October, their density on TUVWX had nearly doubled to 15.04 pocket mice/ha. California pocket mouse densities at the Pecho site are typically higher in the summer and fall months than during the spring months (Gambs - pers. obs.). The dramatic increase in numbers of pocket mice inside the enclosure (from 0/ha in May to over 97/ha in September-October) was more extreme than previously reported for the Pecho area (Gambs 1986g). Pocket mice have never been found at densities higher than 6.5/ha on study plots at Bayview which were occupied by Morro Bay kangaroo rats (Gambs and Holland 1988). Furthermore, we have never found a small mammal species to occur at such high densities as those seen for pocket mice in the enclosure during September - October, 1988.

Approximately 1/3 to 1/2 of the pocket mice captured in the enclosure between August and September-October were subadult or juvenile animals. Dispersal into the enclosure was undoubtedly one factor involved in producing the enormous density of pocket mice there. We doubt if supplemental feed was a significant factor in attracting pocket mice because we discontinued feeding by mid-July and little if any remained on the ground by September. Other, unknown, factors also may have contributed to the fall pocket mouse "explosion" in the enclosure.

Dusky-footed woodrats and California mice

One dusky-footed woodrat *(Neotoma fuscipes)* and 2 California mice *(Peromyscus californicus)* were captured on plot TUVWX in May, but neither of these species was captured in the enclosure. This difference in small mammal species diversity is attributed to the greater structural diversity of vegetation on plot TUVWX. Dusky-footed woodrats and California mice were captured near a dense stand of holly-leaf cherry *(Prunus illicifolia)* on plot TUVWX; however no similar plant structure occurred inside the enclosure.

## COMPETITORS AND PREDATORS

### California ground squirrels

There were at least 3 active ground squirrel burrow systems inside the enclosure in April. During that month, a total of 7 California ground squirrels (2 adults and 5 juveniles) were captured in the enclosure and released outside. The location of these 7 captures (near the aviary fence) suggested that, in addition to those inside, ground squirrels from outside somehow were gaining entry to the enclosure. On 2 May, an adult ground squirrel was captured in the enclosure, marked with red dye, and released outside. The following day, this same animal was recaptured inside the enclosure. No burrowing activity was seen near the enclosure but several 7-10 cm (3-4 in) diameter holes were found in the roof net, immediately adjacent to the 6 in support posts.

Five different California ground squirrels (2 adults and 3 juveniles) were captured in the enclosure from 1-9 May. One of the adults and all 3 juveniles were found dead in traps. In an attempt to deter ground squirrels from entering the enclosure, aluminum flashing was nailed over all 6 in support posts by 26 May. No California ground squirrels were captured, and no ground squirrel activity was seen in the enclosure from 9 May through the end of 1988. Two California ground squirrels were captured outside the enclosure, at the base of the aviary wire, in June. Their tracks were seen periodically outside the enclosure through the end of 1988.

### Snakes

Three striped racers (2 during construction and 1 on 29 April) were found stuck in the aviary wire and removed. One gopher snake and one 45 cm (1 1/2 ft) long striped racer were seen inside the enclosure in April and May, respectively; but we were unable to remove these 2 snakes. One 45 cm (1 1/2 ft) gopher snake was captured and removed from the enclosure on 13 July. No snakes were captured in the funnel traps located along the inside aviary wire fence. Snake tracks were frequently seen going through the 1.3 cm (1/2 in) mesh aviary wire as well as inside the enclosure until 15 July (the last time snake activity was seen in the enclosure). Installation of aluminum flashing around the outer base of the aviary wire fence began on 24 June and was completed on 13 July. We have no evidence that suggests the loss of Morro Bay kangaroo rats to snakes in the enclosure.

## OTHER ANIMALS IN THE ENCLOSURE

### Birds

Sparrows, mostly white-crowned and some golden-crowned, began to appear in the enclosure soon after construction was completed. Direct field observations on 18 May revealed that the sparrows were able to snip a hole in the roof net with their bill which allowed them to squeeze through and enter the enclosure. Once inside, the birds were never observed to land upside down on the roof net and leave the way they entered. As a result, sparrows were able to enter the enclosure but were not able to leave easily and the number of birds in the enclosure progressively increased. On 3 August there were at least 19 sparrows, mostly white-crowned, inside the enclosure. Sixteen sparrows were captured in small mammal traps and released outside during the August trapping session and 5 more were found dead (outside the traps). On 25 August, 6 days after trapping ended that month, there were still at least 12 sparrows in the enclosure. The rough count stayed at 15-20 birds for the remainder of 1988; but there were undoubtedly more than 20 present on some days. Bird activity on the sand surface often was great enough to obscure any signs of Morro Bay kangaroo rat activity.

Other than sparrows, 1 house finch and 1 unidentified, sparrow-sized bird were seen in the enclosure. One juvenile, red-tailed hawk dove through the roof net on 11 December. It was captured and removed from the enclosure unharmed. No other bird species were seen inside the enclosure.

A total of 26 sparrows were captured in small mammal traps in the enclosure. Only 1 of these was found dead and the other 25 were released outside. In addition, 17 sparrows and the unidentified bird were found dead on the ground. Most had broken necks which we think was the probable cause of death. No external wounds were found on any of these dead birds.

On 3 occasions, dead sparrows were found at the entrances to Morro Bay kangaroo rat burrows (H, Z, EE). These birds apparently were pulled halfway into the entrance (crossways) by Morro Bay kangaroo rats attempting to partially or completely plug their burrow entrances. Other than broken necks and possibly broken backs, the birds were intact with no external wounds or missing feathers. The bird at burrow H was removed after it was found. The entrance to burrow Z, blocked by 2 dead sparrows, was never altered by us and it remained inactive (although other entrances to that burrow were active). The entrance to burrow EE was only partially blocked and remained active.

Two California thrashers, 3 scrub jays, 4 brown towhees, and 4 white-crowned sparrows were captured in traps outside the enclosure, at the base of the aviary fence. One turkey vulture was seen perched on a 6 in support post.

Lizards

Several western fence lizards were seen in the enclosure during the summer months and two were captured in small mammal traps. One alligator lizard was removed from the outer surface of the aviary wire in April. No alligator lizards were seen in the enclosure in 1988.

Scorpions

One scorpion was found under a trap in the enclosure.

## PRESENCE OF OTHER ANIMALS AND PEOPLE IN THE VICINITY OF THE ENCLOSURE

Tracks of birds, rodents, California ground squirrels, rabbits, domestic cats, domestic dogs, bobcats, raccoons, snakes, owls, and deer were all observed between the aviary fence and the outer, barbless wire fence. In addition, human and horse tracks were frequently observed outside the barbless wire fence.

No human vandalism was observed on the enclosure in 1988. Small holes in the roof net, caused by birds and ground squirrels, were the only animal-related damage to the enclosure that we found in 1988.

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