ECOLOGY OF THE MORRO BAY KANGAROO RAT

(Dipodomys heermanni morroensis)

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NOVEMBER, 1988

Final Report; U. S. Fish and Wildlife Service;
Contract # 14-16-0001-85154 NR

SUMMARY:

BACKGROUND, MAJOR FINDINGS, AND RECOMMENDATIONS

BACKGROUND

1. The U. S. Fish and Wildlife Service and the California Department of Fish and Game directed and funded most of the research on Morro Bay kangaroo rats *(Dipodomys heermanni morroensis)* from 1970 through 1981. In 1978, the State of California purchased a 50 acre parcel adjacent to Montana de Oro State Park as the Morro Dunes Ecological Reserve.

2. The U.S.F.W.S. completed a Recovery Plan for the Morro Bay kangaroo rat in 1982. Later the same year the U.S.F.W.S, in cooperation with California Polytechnic State University, California Department of Fish and Game, California Department of Parks and Recreation, California Department of Forestry, California Conservation Corps, and California Department of Corrections, initiated the comprehensive program of research and habitat manipulation summarized in this report.

3. At the onset of this study, Morro Bay kangaroo rats were known to occur on Essential Habitat at the Buckskin, Junior High, and Bayview sites and they were thought to occur on Critical Habitat at the Pecho site. Populations at the Buckskin and Junior High sites are probably no longer extant and no Morro Bay kangaroo rats were found on Critical Habitat at the Pecho site.

4. The Bayview site covers approximately 200 acres (81 ha), but only 175 acres (71 ha) appeared to be suitable for Morro Bay kangaroo rats in 1982. In 1979, the estimated population size of Morro Bay kangaroo rats on the Bayview site was 170-175 individuals. By 1983, the population estimate had dropped to 50-100 individuals.

5. It is probably not possible to elucidate all of the factors involved in the historical decline of Morro Bay kangaroo rats, but there are at least 6 which undoubtedly account for a substantial portion of this trend:

A. Direct loss of habitat has been a major factor contributing to the decline in both the numbers of Morro Bay kangaroo rats and the size of their occupied range. Residential, municipal, commercial, and agricultural developments on occupied habitat have eliminated resident animals and decreased the amount of habitat available to remaining animals.

B. Change in the vegetation of occupied habitat, when sparse, low-growing brush gives way to dense, tall brush and trees, represents another factor contributing to the decline. Gradual plant succession probably resulted in the disappearance of Morro Bay kangaroo rats from several undisturbed sites between 1957 and 1973.

C. Predation by domestic cats and dogs as well as losses caused by vehicles, livestock (mainly horses), and pedestrian traffic over occupied burrow systems, could all elevate the mortality rate above that expected in populations not exposed to these factors. Expanding urbanization in the area is expected to accelerate Morro Bay kangaroo rat losses in the future. In

addition, other potential Morro Bay kangaroo rat predators include: coyote, gray fox, long-tailed weasel, badger, bobcat, southern alligator lizard, gopher snake, common kingsnake, western rattlesnake, barn owl, and great-horned owl.

D. Competition with other species of rodents might explain the absence of Morro Bay kangaroo rats from some sites which otherwise appear suitable; however no direct evidence is available to support this idea at the present time. Observations have indicated that sites occupied by populations of Botta's pocket gophers and/or California ground squirrels consistently fail to support Morro Bay kangaroo rats.

E. Fragmentation of the Morro Bay kangaroo rat population into several, small, isolated sub-populations would contribute to the decline in the overall population. Imbalances in sex and/or age ratios, lack of sufficient food resources, or an excessive amount of transitional (ecotone) habitat are all factors which could contribute to declining populations. If a temporary, localized extinction occurred in one sub-population; then, in the absence of a neighboring stock of animals to recolonize the habitat, that area would remain unoccupied.

F. The decline in the total population of Morro Bay kangaroo rats over the past 30 years coupled with the fragmentation of their population into isolated sub-populations suggests that inbreeding has increased over this time. Increased inbreeding would lead to a decrease in genetic diversity in the remaining population. Low levels of genetic diversity do not automatically imply loss of vigor, but the chance of genetic abnormalities in anatomy, physiology, or behavior certainly must be greater now than it was 30 years ago. Low variance in genetic composition also could render the population less able to meet the demands of sudden changes in environmental conditions.

MAJOR FINDINGS OF THE PRESENT STUDY

1. At this time, it appears that the only viable wild population of endangered Morro Bay kangaroo rats is the one inhabiting the Bayview site. The present distribution of Morro Bay kangaroo rats now encompasses only 12 — 15 ha at the Bayview site. Although highly unlikely, a few isolated individuals still may occur in the vicinity of the the Buckskin or Junior High sites.

2. There are about 34 ha of suitable but unoccupied habitat distributed over 13 isolated localities within the historic range of the Morro Bay kangaroo rat. Six of the 13 localities cover less than one ha each, 4 of the 13 localities cover less than 2 ha each, 2 of the 13 localities cover less than 7 ha each, and the largest of the 13 localities covers about 13 ha.

3. Virtually all lands within the historic range of the Morro Bay kangaroo rat lacking permanent structures and having suitable soil and slope could probably be made suitable for Morro Bay kangaroo rats after appropriate habitat modifications.

4. The density of Morro Bay kangaroo rats over their occupied range was no more than 1.5 animals / ha in 1984, no more than 3.8 animals / ha in 1985, and no more than 4.0 animals / ha in 1986.

5. The total population of Morro Bay kangaroo rats over their occupied range was estimated at 21 individuals in 1984, 51 individuals in 1985, and 50 individuals in 1986.

6. The average home range size of Morro Bay kangaroo rats during our study was .23 ha (95 % confidence interval = .20 – .26 ha). Male home range size did not differ from that of females. Home ranges of different animals overlapped considerably in both time and space.

7. Morro Bay kangaroo rats confined the majority of their movement to an area having a radius of 20 to 40 m. The longest dispersal recorded during the study was 400 m which occurred between 2 capture dates separated by a period of 728 days.

8. Using data from captive, known-aged Morro Bay and Lompoc kangaroo rats we developed an equation to predict the age of immature Morro Bay kangaroo rats captured in the field:

$$\text{PREDICTED AGE (days)} = 10^{[\text{body weight(g)} + 36.7299]} / 50.5566.$$

We then used this age estimate to predict the date of conception which we used as an indicator of breeding activity in the field population:

PREDICTED CONCEPTION DATE = DATE OF CAPTURE - PREDICTED AGE - 31 DAYS

9. Based on this formula, the majority of breeding activity in the field (76% of all conceptions) occurred between March and May. The peak month of breeding was April when 48 % were conceived.

10. There are several ways of estimating the amount of habitat required to support the preliminary recovery goal of 2,500 Morro Bay kangaroo rats. One way is to extrapolate required habitat using density estimates derived from the wild population at Bayview. Assuming a density of 4 animals / ha, the estimated amount of habitat required to support 2,500 individuals would be 625 ha (= 2.4 square miles). Caution should be taken in interpreting this habitat estimate because it is completely dependent upon the expected density of animals living in the area. If the density estimate was decreased, then the estimated area of habitat would be increased, and vice versa.

11. Another method of estimating required habitat (Lande 1987) makes use of demographic and dispersal characteristics of existing populations. For example, if the net lifetime production of female offspring per female Morro Bay kangaroo rat was equal to 1.0001 and the root-mean-squared dispersal distance per generation was 200 m, then the minimum habitat required to successfully support a population of Morro Bay kangaroo rats would be 363,439 ha (= 1,403 square miles!). Obviously this estimate is too high, but it illustrates the important fact that this method of estimating minimum habitat requirements is extremely sensitive to demographic characteristics as well as dispersal characteristics. Since the values in the example above are only crude approximations, results of this method must be regarded as only a crude approximation to estimating the habitat requirements of Morro Bay kangaroo rats.

12. The principal plant community at both the Pecho and Bayview study sites was Coastal Dune Scrub interspersed with some Chaparral components. The Coastal Dune Scrub community is composed of a mixture of herbaceous, subshrubby and shrubby species. In this community, dominance and relative species cover vary from site to site and year to year. Species often have patchy distributions, with aggregations of individual plants occurring at some sites and not at others. Some species (e.g. holly-leaf cherry, *Prunus ilicifolia*), by virtue of their size or density, may locally dominate to the exclusion of other species. However, over the entire area, they may be relatively unimportant.

13. Although the overall structure and appearance of the Coastal Dune Scrub habitat was similar at the Bayview and Pecho sites; Bayview had a lower plant species diversity, slightly more bare ground, and less shrub cover than Pecho. The plant species composition on the two study sites was similar; however, the relative coverage of the common species was markedly different. The Bayview site had two co-dominant species: silverweed *(Horkelia cuneata)* and deerweed *(Lotus scoparius)*. These two species were less common on the Pecho site and covered considerably less area. On the Pecho site, California sagebrush *(Artemisia californica)*, mock heather *(Ericameria ericoides)*, and deerweed were the dominant species. At Bayview these shrubs were less common and covered less area than at Pecho.

14. Six small mammal species were regularly caught at Pecho and/or Bayview: deer mice *(Peromyscus maniculatus)*, California pocket mice *(Perognathus californicus)*, western harvest mice *(Reithrodontomys megalotis)*, California mice *(Peromyscus californicus)*, dusky-footed woodrats *(Neotoma fuscipes)*, and Morro Bay kangaroo rats.

15. The species richness of the the small mammal communities occupying undisturbed habitat at Pecho ranged from 2 species (deer mice and either pocket mice or harvest mice) on some plots to 5 species (deer mice, pocket mice, harvest mice, California mice, and woodrats) on other plots. The general pattern of small mammal community structure on undisturbed habitat at Pecho was one in which deer mice had the highest density and either harvest mice or pocket mice had the second highest density. Woodrats and California mice were typically found in scattered patches of dense brush and small trees. California ground squirrels *(Spermophilus beecheyi)* and immature rabbits *(Sylvilagus)* were caught from time to time at the Pecho site.

16. The species richness of small mammal communities occupying undisturbed habitat at Bayview ranged from 2 — 6 species (Morro Bay kangaroo rats, pocket mice, deer mice, California mice, woodrats, and harvest mice). However, the predominant small mammal community at Bayview was composed of Morro Bay kangaroo rats and pocket mice living at fairly low densities. A few woodrats, California mice, and harvest mice occupied scattered patches of dense plant cover, and deer mice occurred sporadically throughout the Bayview site. The small mammal community occupying the Bayview site was markedly different from that at the Pecho site. In addition to the obvious differences in the species composition between Bayview and Pecho, the combined densities of all small mammals inhabiting the Bayview site in any given year were markedly less than those found anywhere at Pecho.

17. Multivariate Principal Component Analysis of small mammal communities at Bayview and Pecho revealed fairly good segregation between the two sites. Differences in plant cover on the two sites undoubtedly accounts for some of the differences in small mammal communities. For example, almost 87% of the plant cover at Bayview

consisted of Morro Bay kangaroo rat food plants compared to less than 60% at Pecho. The high coverage by silverweed and deerweed (both highly favored food plants) at Bayview played an important role in this difference. Bayview also had more buckbrush *(Ceanothus cuneatus)* and less yarrow *(Achillea borealis)* than Pecho. Ice plant *(Carpobrotus spp.)*, California aster *(Corethrogyne filaginifolia)*, and dudleya *(Dudleya caespitosa)* were dominant on some Pecho plots, but these three species were never dominant at Bayview. In addition to small mammal community differences associated with differences in plant cover, there is at least circumstantial evidence indicating that some sort of negative interaction exists between Morro Bay kangaroo rats and other species (e.g. pocket mice, deer mice, and harvest mice) normally found in habitat similar to that occupied by the rats.

18. If we are correct in assuming that the remnant population at Bayview persists there because of more favorable habitat conditions, then our results show that Morro Bay kangaroo rats today have a definite preference for Coastal Dune Scrub communities covered with plenty of buckbrush, deerweed, and silverweed and little yarrow. Stands of Coastal Dune Scrub having optimal cover of these 4 species usually are not populated uniformly by rats because of subtle differences in microhabitats within the stand. Those microhabitats that have a higher silverweed coverage and a lower croton *(Croton californicus)* coverage generally were preferred over other microhabitats not having this particular relationship of habitat attributes.

19. Unfortunately, lack of vegetation data has prevented quantitative comparisons of Morro Bay kangaroo rat habitat today with that available when their populations were larger and more widespread. Although a remnant population still persists at the Bayview site, the habitat there certainly must be different from what it was 30 years ago when they were far more abundant in that area. If the declining numbers and range of Morro Bay kangaroo rats are in any way a function of habitat deterioration over time, then our descriptions of the Bayview habitat should be considered as indicative of habitat conditions which are sufficient, but not necessarily optimal, for the animals there today.

20. Brush removal at Pecho resulted in an obvious reduction in shrub cover and a concomitant increase in bare ground and cover by herbs and subshrubs. In the first spring after clearing, plant species diversity increased markedly when herbaceous species appeared after the shrub canopy had been opened up. However, after two years, shrub cover increased, herbaceous cover decreased, and plant species diversity decreased as the shrub canopy recovered. Plant species capable of resprouting after clearing appeared to be favored over non-sprouting species. Brush removal increased the cover of kangaroo rat food plants by 10% to 15% which indicates that clearing has the potential to improve forage quality for the Morro Bay kangaroo rat. Within a few more years, secondary succession will probably bring the plant cover (except non-sprouting species) back to pre-cleared conditions.

21. The species richness of the small mammal communities occupying cleared habitat at Pecho gradually dropped to either 3 or 4 species (deer mice, pocket mice, California mice, and harvest mice). Clearing was responsible for the disappearance of woodrats and the extremely low densities of harvest mice during the last two years of the study. Brush removal had no noticeable effects on deer mouse populations, however the cleared habitat appeared to be more favorable to pocket mice later in the study. The appearance of ground squirrels on one of the cleared plots appears to be related to a prescribed burn in the immediate vicinity of this plot.

22. The overall effects of fire at Pecho were: increased soil fertility, increased soil pH, and inactivation of allelopathic soil chemicals. Because of the sandy soil, these changes will probably only persist for a few more years. Within a few weeks after the fire, many of the shrubs resprouted and gradually began regenerating a new canopy. Some seedlings of California sagebrush, coastal silver lupine *(Lupinus chamissonis)*, and mock heather became established on the plot, but no seedlings of *Prunus* were noted. By 1986, shrub cover had increased, but the burned plots still had a high species diversity and herbaceous plants still dominated. Several Eurasian weed species invaded the burned plots. On one plot, these weeds were restricted to the same areas where they were common before the fire. On another plot, weeds such as ripgut brome *(Bromus diandrus)* moved into the plot and assumed a dominant role. It is difficult to predict the permanency of these weedy species, but it is expected that as the shrubs continue to regenerate canopies, cover by weedy and opportunistic species gradually will diminish. In contrast to the cleared plots, the burned plots suffered an overall loss of cover by Morro Bay kangaroo rat food plants. Unfortunately, Morro Bay kangaroo rat forage preference has not been assessed on many of the plants that appeared after the fires so we are unable to predict whether or not Morro Bay kangaroo rats would use these species.

23. The species richness of small mammal communities occupying burned habitat at Pecho sharply dropped to 3 species (deer mice, pocket mice, and harvest mice) after the fires. Although the effects of burning were more immediate than those of brush removal, the general small mammal population responses were comparable on burned and cleared sites (ie. deer mice and pocket mice persisted, woodrats and harvest mice disappeared, and ground squirrels appeared). The fires may have created corridors of open habitat which enabled ground squirrels living at the base of the dunes to invade the burns and then spread eastward into cleared and undisturbed habitat near the burns. The spread of ground squirrels into manipulated habitats represents a serious obstacle to the future establishment of Morro Bay kangaroo rats at these sites.

24. Even though burning and clearing did not produce a numerically depauperate small mammal community like that seen at Bayview, burning and, after several years, brush removal did suppress populations of woodrats, California mice, and harvest mice. Both Cluster analysis and Principal Component Analysis failed to show a clear pattern of segregation among the 3 different plant assemblages at Pecho (undisturbed, cleared, and burned). Although the two manipulated habitats had more bare ground and herbaceous growth and less mock heather, golden yarrow, coastal silver lupine, sand almond, dead plant material, coastal buckwheat, and California sagebrush; the lack of segregation among the 3 habitat types suggests that clearing and burning did not bring the plant cover into a high degree of congruency with habitat that presently supports Morro Bay kangaroo rats at Bayview. We conclude that of the 3 habitat types available for reintroducing Morro Bay kangaroo rats at Pecho, the burned and cleared areas would be preferable to the undisturbed areas.

MANAGEMENT RECOMMENDATIONS

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

2. Serious consideration should be given to plowing a 10 to 15 acre experimental plot at the Pecho site. Complete removal of all shrubs by means of ground-breaking "rippers" would be preferable to more burning or brush clearing at this point because the latter two manipulation methods have not yet produced "ideal" results.

3. A ground squirrel control program should be instituted throughout the Critical Habitat as soon as possible. This action should be completed before Morro Bay kangaroo rats are allowed to range freely at Pecho.

4. Identification, purchase, and prescribed manipulation/restoration of "undeveloped" parcels of potentially suitable habitat should be undertaken by governmental agencies as soon as possible. Assuming that an average density of 4 individuals / ha could be achieved over all habitat, the total amount of land required to support the recovery goal of 2,500 individuals would be about 625 ha (= 1,500 acres = 2.4 square miles). Even if habitat could be created that would, for example, support an average density of 8 individuals / ha, the amount of land required still would be about 1.2 square miles.

5. A long range program of experimental habitat manipulation and/or restoration followed by successive introductions of Morro Bay kangaroo rats should be instituted for the Critical Habitat area as well as other sites (e. g. the Buckskin, Bayview, Junior High, and Santa Ysabel Essential Habitat areas).

6. Potential reintroduction sites having the following attributes: more buckbrush, deerweed, and silverweed; lower plant species diversity; more food plants; and little or no iceplant would be preferable to other Coastal Dune Scrub sites not having these characteristics.

7. Experiments should be undertaken to evaluate the efficacy of supplemental feeding as means of increasing the future density of wild populations of Morro Bay kangaroo rats.

8. Periodic ground reconnaissance trips should be made along the eastern boundary of public land in the Critical Habitat area to ensure early detection of erosion, invasion of weedy plants, runoff, and other adverse impacts to Critical Habitat originating from neighboring residential developments. When Morro Bay kangaroo rats become free ranging at Pecho, it may be necessary to monitor domestic pets, vehicles, livestock, and foot traffic in the area to ensure that the rats, as well as their burrows and food sources remain undisturbed.

RESEARCH RECOMMENDATIONS

1. Maintenance and expansion of the captive breeding facility along with the use of experimental procedures known to enhance reproductive output of captive animals are essential to ensure that animals will be available for future management projects.

2. Controlled food discrimination experiments should be conducted on captive Morro Bay kangaroo rats so that more precise habitat manipulation/restoration decisions can be made in the future.

3. Population estimates of the Morro Bay kangaroo rats at Bayview should be conducted every 1 — 2 years. Thorough ground searchs for signs of Morro Bay kangaroo rats should be conducted at the Pecho, Bayview, Buckskin, and Junior High / Santa Ysabel sites every year.

4. At the present time, the Bayview site represents the best field site for assessing the population response of Morro Bay kangaroo rats to habitat manipulation. A set of "before and after" experiments would allow direct comparisons of rat responses to several types of habitat manipulation and/or restoration procedures.

5. Every effort should be made to monitor (using biotelemetry and night vision equipment) all biological aspects of Morro Bay kangaroo rats during and after their tenure in protective enclosures. These animals would be the logical subjects for measurements which could be used to estimate minimum habitat requirements for the animals in their "new" habitats.

6. Continued monitoring of small mammal communities on the plots at Pecho will provide population baselines which can be used to assess possible competitive interactions between Morro Bay kangaroo rats and other small mammal species there. It would be particularly useful to design a set of field experiments which would directly measure the degree of actual competitive interactions.

7. Continued vegetation sampling of the cleared and burned plots is important in order to follow the succession of these plots back to maturity (pre-manipualtion conditions). These data should be correlated with results of small mammal sampling so that changes in habitat conditions can be evaluated in terms of small mammals.

8. Continued sampling of plant communities at all future reintroduction sites will become increasingly important as free ranging populations of Morro Bay kangaroo rats become established at these sites. Careful assessment of plant communities that are either used or not used by rats should provide a more precise evaluation of the importance of vegetation composition and structure as well as the efficacy of habitat manipulation techniques in providing optimal habitat for Morro Bay kangaroo rats.

9. A comprehensive examination of the genetic variance present in wild and lab animals using no risk, non-invasive genetic "fingerprinting" techniques should be conducted as soon as possible.

10. The preservation of Morro Bay kangaroo rat cellular and/or genetic specimens in a long-term "gene bank" should be initiated so that future scientific study may be conducted on properly preserved material. It may be possible to combine genetic preservation with genetic "fingerprinting" (above).

11. Field research biologists from various agencies and institutions could mount a more effective and expedient research effort on kangaroo rats if they worked through a local "research/recovery center" on a full time basis.

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I. INTRODUCTION

The first extensive trapping study of Morro Bay kangaroo rats *(Dipodomys heermanni morroensis)* was conducted in 1918 within 150 yards of the Sand Hill School (Dixon 1918). The school was located about 50 m south of Los Osos Valley Road, halfway between the intersections of Willow and Buckskin Drives with Los Osos Valley Road. Dixon described the area as having dense thickets of low-growing live oak, *Ceanothus*, and *Adenostoma* as well as abandoned fields and pastures covered with a good growth of annual plants. He noted that Morro Bay kangaroo rats were particularly abundant in the open fields, but they also were found inhabiting brushy places throughout the sandy region from Los Osos Creek westward to Morro Bay and the beach. The results of Dixon's snap trapping study in a field near Sand Hill School were 48 Morro Bay kangaroo rats captured over 144 trap nights of trapping from 25-27 September and 38 Morro Bay kangaroo rats captured over 70 trap nights from 6-7 November, 1918. He also caught several deer mice and one meadow vole in the sandy pasture as well as several dusky-footed woodrats, several California mice, one pinyon mouse, and one California pocket mouse at the entrances to woodrat houses in live oak and brush thickets. Apparently Dixon was expecting to find pocket mice and kangaroo rats occupying similar habitat much as they do in desert regions, because he was surprised to find that all of the pocket mice he collected in the (Morro Bay) region were caught in dense brush near woodrat nests rather than in open areas where he caught Morro Bay kangaroo rats.

Although Morro Bay kangaroo rats were once abundant in the sandy area South of Morro Bay (Grinnell 1922, Stewart 1958, and Stewart and Roest 1960), their populations have been declining since 1957 (Congdon 1971, Congdon and Roest 1975, Roest 1977, Toyoshima 1983, Roest 1984, Gambs 1986a, 1986c, 1986g, and Villablanca 1987). Direct loss of habitat; change in remaining habitat; predation by cats and dogs; destruction of burrows by vehicles, livestock, and pedestrian traffic; competition with other burrowing rodents; fragmentation of large populations into small sub-populations; and increased inbreeding are all factors which appear to have contributed to the long-term decline of this subspecies (Roest 1982b and Gambs 1986c). The significance of inbreeding may not be as great as other factors because inbreeding seems to be fairly common in some species of *Dipodomys*. As a consequence of this decline, the Morro Bay kangaroo rat *(Dipodomys heermanni morroensis)* 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.

PURPOSE AND OBJECTIVES

Continued threats to the existence of the Morro Bay kangaroo rat have led the U. S. Fish and Wildlife Service to initiate and sponsor research projects, including some of those cited above, to evaluate the current population status and habitat relationships of the subspecies. The present study was conducted as one part of the cooperative efforts of California Polytechnic State University, U. S. Fish and Wildlife Service, California Department of Parks and Recreation, and California Department of Fish and Game to implement certain aspects of the Recovery Plan for the endangered Morro Bay kangaroo rat (U.S.F.W.S. 1982).

The purpose of this study is to:

(A.) determine the contemporary status (including distribution and population size) of the Morro Bay kangaroo rat throughout its range;

(B.) quantitatively characterize, monitor, and map the existing natural vegetation of selected sites within the range of the Morro Bay kangaroo rat;

(C.) determine and quantitatively characterize the relationship of vegetational processes to the occurrence and size of Morro Bay kangaroo rat populations; and

(D.) develop methods for managing Morro Bay kangaroo rat habitat which are compatible with maintaining the integrity of the ecosystem.

GENERAL BIOLOGY AND ECOLOGY OF THE MORRO BAY KANGAROO RAT

Morphology

In his review if the kangaroo rats of California, Grinnell (1922) described the Morro Bay kangaroo rat as "the darkest colored of all known kangaroo rats and the only species in which there is not a sharp and continuous pure white band across the outer side of the flank". He also observed that the facial double crescent (areitiform) marking was heavier and darker than in most species and that the tail had a smaller crest and shorter tuft than in most other species. Roest (1984) developed a more comprehensive comparison of the morphology of Morro Bay kangaroo rats to their closest relatives.

Biological Characteristics

Morro Bay kangaroo rats construct shallow burrows in which they store food, rear young, and hide during the daytime. They are most active on nights during the spring, early summer, and fall. They show diminished activity above ground during the summer dry season and again during the winter rainy season. The main breeding season lasts from March through August, but occasional breeding at other times of the year has been documented (Roest 1984 and U.S.F.W.S. 1982). The estrous cycle generally lasts 18 to 20 days (range 7—35 days) and gestation requires 30 to 33 days. The average litter size is 3, young are weaned in about 30 days, and they reach adult size at an age of 95 to 100 days. Adult pelage is gained at an age of 135 to 140 days and the expected longevity is 2 to 3 years.

Ecological Relationships

Morro Bay kangaroo rats typically occur in the early seral stages of the soft chaparral (Coastal Sage Scrub) plant community where the soil type is a sandy loam (Roest 1982). They utilize patches of bare ground as escape routes and as foraging routes from their burrows to neighboring seed sources (shrubs and herbs). While animals may forage along the periphery of dense brush, they apparently do not penetrate the heavy brush or use it as a permanent residence (Roest 1973 and 1982b). In addition to natural mortality factors such as age, disease, agonistic interactions and predation; vehicle, livestock, and pedestrian traffic over burrow systems undoubtedly increase the mortality rate of populations occurring in areas where these forms of traffic are common. Table 1—1

TABLE 1-1. GENERAL ECOLOGICAL RELATIONSHIPS OF THE MORRO BAY KANGAROO RAT (modified from Stewart 1958, Roest 1973, Roest 1982b, and U.S. F.W.S. 1982).

ECOLOGICAL FEATURE	COMMENT / DESCRIPTION
SOIL TYPE	Sandy
SLOPE	Less than 15 %
HABITAT TYPE	Early Seral Stages of Coastal Dune Scrub
HABITAT STRUCTURE	Scattered Shrubs Less than 3 Feet Tall, Interspersed with a Mix of Herbaceous Food Plants and **BARE GROUND**
FOOD HABITS	**SEEDS**, Some Leaves, and Some Young Growth of: Black Sage, Bush Lupine, Dune Lupine, and Mock Heather, Filaree, Croton, Spineflower, Buckwheat, Sand Verbena, Phlox, Popcorn Flower, Monkey Flower, Dudleya, Cinquefoil, Deerweed, Tarweed, Cudweed Aster, Yarrow, Thistle, Wreath Plant, and Red Brome
BURROWS	MAIN BURROWS: 6 - 10 feet long, 6-10 inches deep, 2-3 rooms (1 nest), 1-2 main entrances, 1-2 escape entrances, and several blind tunnels SUBSIDIARY BURROWS: 2-5 feet long, 1 main entrance, 1 escape entrance, 1-2 rooms (no nest)
HOME RANGE	0.07 acre - 0.18 acre (= 0.03 ha -0 .07 ha) (= 3,050 - 7,841 square feet)
PARASITES	Fleas, Lice, Ticks, Intestinal Worms
POTENTIAL PREDATORS	Gray Fox, Long-tailed Weasel, Badger, Bobcat, Coyote, Great-horned Owl, Barn Owl, Western Rattlesnake, Gopher Snake, Common King Snake, Domestic Cats and Dogs
OTHER SMALL MAMMAL SPECIES FOUND IN SIMILAR HABITAT	Deer Mice, Harvest Mice, Pocket Mice, California Mice, Brush Mice, Dusky-footed Woodrats, and Meadow Voles

summarizes a much larger body of information on the ecology of Morro Bay kangaroo rats provided by Stewart (1958), Roest (1973), Roest (1982b), and U.S.F.W.S. (1982).

Distribution

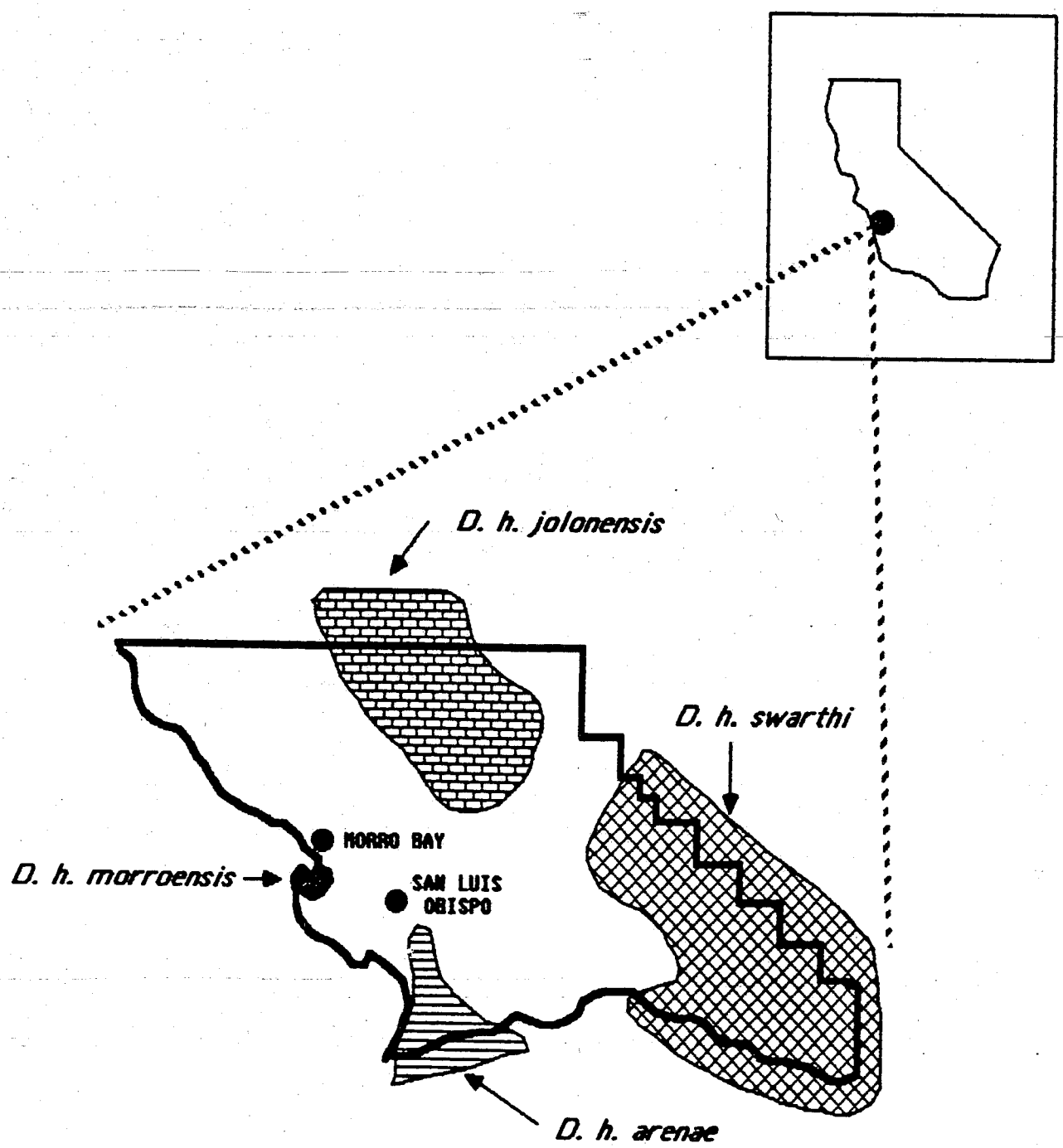
The distribution of the Morro Bay kangaroo rat, one of 9 subspecies of the Heermann's kangaroo rat *(Dipodomys heermanni)*, is restricted to a small area south and east of Morro Bay (Fig. 1). Morro Bay kangaroo rats are isolated by a distance of about 14 miles from their nearest neighboring subspecies of Heermann's kangaroo rat (Fig. 1—1 and U.S.F.W.S. 1982).

Grinnell (1922) estimated that the area of the Morro Bay kangaroo rat's known habitat was less than "4 miles square" [this is taken to mean "4 square miles" (U.S.F.W.S 1982)]. He observed that they occurred on sandy soil of the Upper Sonoran life zone in the immediate vicinity of Morro Bay from sea level up to 250 ft elevation. Apparently they occupied undeveloped parts of this range until the late 1950's. Stewart (1958) estimated that the range of Morro Bay kangaroo rats covered an area of 4.8 square miles in 1957, but not all of this area was occupied. After deducting about 2.3 square miles which were covered with oaks, eucalyptus, heavy chaparral, riparian communities, steep ravines, and human developments; Stewart and Roest (1960) estimated that there were about 2.5 square miles of suitable habitat available for Morro Bay kangaroo rats in 1957. Of the 2.5 square miles of suitable habitat, about 0.3 square mile was not occupied in 1957, leaving 2.2 square miles (1,400 acres or 567 hectares) of habitat which were actually occupied by Morro Bay kangaroo rats in 1957 (Roest 1977 and 1984). From 1957 to 1979, there was a sharp decline in the area of the Morro Bay kangaroo rat's occupied range. In 1971, Congdon (1971) and Congdon and Roest (1975) estimated the occupied range of Morro Bay kangaroo rats to be 1.75 square miles (1,120 acres or 453 hectares). By 1977, Roest (1977) estimated that their occupied range had decreased to 0.52 square miles (333 acres or 137 hectares). In a study conducted from May 1978 to October 1979, Toyoshima (1983) estimated that the occupied range of Morro Bay kangaroo rats was 0.49 square mile (314 acres or 127 hectares). Refer to Gambs (1986g) for comparative maps of the historical pattern of changes in their distribution.

Population Trends Through 1979

The first systematic population study on Morro Bay kangaroo rats (conducted in 1957) revealed raw population densities of: 76.4 rats / acre (188.8 rats/ hectare) on quadrat # 1, located on the present Bayview site; 21.3 rats / acre (52.6 rats / hectare) on quadrat # 2, located on the present Junior High / Santa Ysabel site; and 18.6 rats / acre (46.0 rats / hectare) on quadrat # 3, located on the present Pecho site (Stewart 1958). In order to compensate for a long interval between trapping sessions, Stewart reduced his raw density estimates to 57.3 rats / acre (141.6 rats / hectare) for the Bayview quadrat, 16.0 rats / acre (39.5 rats / hectare) for the Junior High / Santa Ysabel quadrat, and 14.0 rats / acre (34.6 rats / hectare) for the Pecho quadrat. He suggested that a normal population density for Morro Bay kangaroo rats would be about 15 rats / acre (37.1 rats / hectare) and a maximum density would be about 60 rats / acre (148.3 rats / hectare). Since the time of the first study, there have been a number of population studies conducted on Morro Bay kangaroo rats. Although these latter studies have employed a variety of methods to estimate densities, they all provide estimates of the total population size and the total range occupied by the population. Division of the

Figure 1-1. Distribution of four subspecies of Heermann's Kangaroo rat *(Dipodomys heermanni)* in San Luis Obispo County, California. The range of the Morro Bay kangaroo rat (*D. h. morroensis* is restricted to a small area along the southern edge of Morro Bay, whereas the ranges of the other three subspecies extend well beyond the confines of San Luis Obispo County. This map is modified from a map prepared by Roest (1984).



population size by the occupied range gives the average density of rats which then can be compared through time (Table 1–2).

Reasons for Decline

It is probably not possible to elucidate all of the factors involved in the decline of Morro Bay kangaroo rats, however there are at least 6 factors which undoubtedly account for a substantial portion of this trend.

1. Direct loss of habitat has been a major factor contributing to the decline in both the numbers of Morro Bay kangaroo rats and the size of their occupied range. Residential, municipal, commercial, and agricultural developments on occupied habitat have eliminated resident animals and decreased the amount of habitat available to remaining animals (Roest 1982b). As an example, the number of people living in the communities of Los Osos and Baywood Park has risen from about 1,500 residents in 1958 to over 12,000 residents in 1984 (estimates by San Luis Obispo County Planning Department, taken from Roest 1984).

2. Change in the vegetation of occupied habitat whereby sparse, low–growing brush gives way to dense, tall brush and trees represents another important factor contributing to the decline. This gradual process of vegetation succession probably resulted in the disappearance of Morro Bay kangaroo rats from several undisturbed sites between 1957 and 1973 (Roest 1973 and 1982b).

3. Predation by domestic cats and dogs as well as losses caused by vehicle, livestock (mainly horses), and pedestrian traffic over occupied burrow systems all represent additional sources of mortality which would elevate the mortality rate above that expected in populations not exposed to these factors. Expanding urbanization in the Los Osos / Baywood Park area is expected to accelerate Morro Bay kangaroo rat losses described in this category.

4. Competition with other species of rodents might explain the absence of Morro Bay kangaroo rats from some sites which otherwise appear suitable; however no direct evidence is available to support this idea at the present time. Observations by the authors and A. I. Roest (personal communication) indicate that sites occupied by populations of Botta's pocket gophers and/or California ground squirrels consistently do not support Morro Bay kangaroo rats. Since all three species construct extensive burrows, it is possible that they might compete for suitable burrow sites; however the apparent spatial isolation of these species may be a consequence of factors other than competitive interactions.

5. Fragmentation of the Morro Bay kangaroo rat population into several, small, isolated sub-populations would tend to facilitate the declining trend in the overall population. Imbalances in sex and / or age ratios, lack of sufficient long-term food resources, or an excessive amount of transitional (ecotone) habitat are all factors which could contribute to declining populations (Wilcove and Wilcox 1986). If a short-term fluctuation in one sub-population was severe enough to cause a temporary, localized extinction in that sub-population; then, in the absence of a neighboring, reserve stock of animals to colonize the habitat that area would remain unoccupied.

TABLE 1—2. POPULATION TRENDS OF MORRO BAY KANGAROO RATS FROM 1957 TO 1985 (modified from Stewart 1958, Stewart and Roest 1960, Congdon 1971, Congdon and Roest 1975, Roest 1977, and Toyoshima 1983).

YEAR	OCCUPIED RANGE (ha.)	TOTAL POPUL. SIZE	AVERAGE DENSITY (RATS / ha.)	AUTHORITY
1957	567 ha.	8,000	14.1 / ha.	Stewart 1958 Stewart and Roest 1960
1971	453 ha.	3,000	6.6 / ha.	Congdon 1971 Congdon and Roest 1975
1977	135 ha.	1270-1470	9.4-10.9 / ha.	Roest 1977
1978/ 1979	127 ha.	300-1,180	2.36-9.29 / ha	Toyoshima 1983

6. The decline in the total population of Morro Bay kangaroo rats over the past 30 years coupled with the fragmentation of their population into isolated sub—populations implies that the rate of inbreeding has progressively increased over this time span. Increased inbreeding would in turn lead to a decrease in the degree of genetic diversity among individuals in the remaining population. Although a low level of genetic diversity does not automatically imply loss of vigor, the chance of genetic abnormalities in the anatomy, physiology, or behavior of remaining animals certainly must be greater now than it was 30 years ago. Low variance in genetic composition could also render the population less able to meet the demands of a sudden change in environmental conditions (Wilcove 1987).

SYNOPSIS OF EFFORTS TO RECOVER THE MORRO BAY KANGAROO RAT

The California Department of Fish and Game, in cooperation with the U. S. Fish and Wildlife Service (U.S.F.W.S.), directed and funded most of the research on the Morro Bay kangaroo rat from 1970 through 1981. The State of California purchased a 50 acre parcel of undeveloped land adjacent to Montana de Oro State Park on July 12, 1978 and established the Morro Dunes Ecological Reserve (Lidberg 1982). The Ecological Reserve and that portion of Montana de Oro State Park referred to as the Pecho site (within the Critical Habitat) supported Morro Bay kangaroo rats through 1979, but their numbers there had declined considerably since 1957 (Toyoshima 1983).

The U.S.F.W.S. completed a Recovery Plan for the Morro Bay kangaroo rat in 1982. Later the same year the U.S.F.W.S, in cooperation with California Polytechnic State University, California Department of Fish and Game, California Department of Parks and Recreation, California Department of Forestry, California Conservation Corps, and California Department of Corrections, initiated a program of research and habitat manipulation aimed at preserving, protecting, and maintaining sufficient habitat to support a population of 2,500 Morro Bay kangaroo rats. The Recovery Plan identified one parcel of land owned by the State of California as Critical Habitat and 3 parcels of privately-owned land as Essential Habitat for the Morro Bay kangaroo rat (Fig. 1—2). Since its designation as Critical Habitat for the endangered Morro Bay kangaroo rat, most of the efforts to manage the subspecies and its habitat have been directed toward the Pecho site. Recent efforts to improve habitat at the Pecho site include: removal of iceplant from some of the area in late 1982, manual removal of various species of woody plants from two, 1 ha study plots in early 1983, and three prescribed burns in October of 1984, 1985, 1986. Although 4 study plots have been subjected to habitat modification, it has not been possible to evaluate the direct effects of these procedures on Morro Bay kangaroo rats because none have been found at the Pecho site since the start of field work on this project in 1983 (Gambs 1986g). Morro Bay kangaroo rats from the U.S.F.W.S., Morro Bay Kangaroo Rat Captive Breeding Facility at Cal Poly were introduced into an enclosure located on manipulated (burned) habitat at the Pecho site in May, 1988.

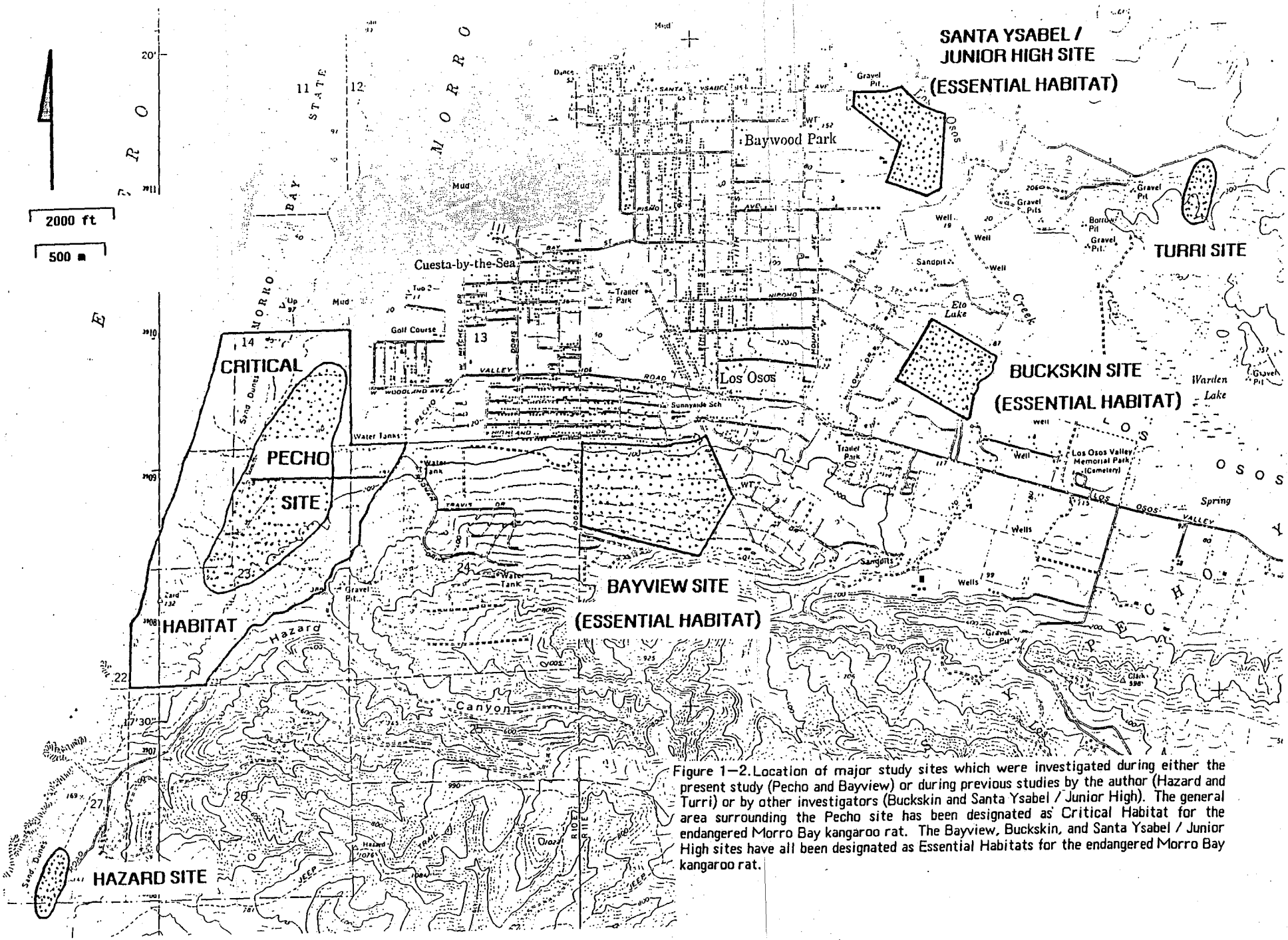


Figure 1—2. Location of major study sites which were investigated during either the present study (Pecho and Bayview) or during previous studies by the author (Hazard and Turri) or by other investigators (Buckskin and Santa Ysabel / Junior High). The general area surrounding the Pecho site has been designated as Critical Habitat for the endangered Morro Bay kangaroo rat. The Bayview, Buckskin, and Santa Ysabel / Junior High sites have all been designated as Essential Habitats for the endangered Morro Bay kangaroo rat.

The following outline of activities provides a brief chronology of those recovery efforts described above as well as other activities related to the recovery plan.

1982

- Field studies on small mammal population ecology and plant ecology were initiated on 4, 1 ha study plots located on state-owned land in the vicinity of the Morro Dunes Ecological Reserve (Pecho area).
- Iceplant was removed from selected sites in the Pecho area.

1983

- Field studies on small mammal population ecology and plant ecology continued at the 4 plots in the Pecho area. Two, 1/2 ha study plots were established at the Hazard area and one, 1 ha study plot was established at the Turri area.
- Two, of the four study plots in the Pecho area were subjected to manual brush removal in the spring.

1984

- Field studies on small mammal population ecology and plant ecology continued at the 4 plots in the Pecho area. One, 1 ha study plot was established at the Pecho area on a site which was selected for a controlled burn. Two, 1/2 ha study plots were established at the Bayview area on habitat that was occupied by Morro Bay kangaroo rats.
- Field work on the distribution of Morro Bay kangaroo rats throughout their original range began in the summer
- A captive breeding facility was established at California Polytechnic State University in the summer.
- The first controlled burn within Critical Habitat was conducted in the fall.
- Fences were installed along "Old Army Rd." and at the base of the dunes and signs were installed informing the public that the purpose of the burn was to restore habitat for Morro Bay kangaroo rats.

1985

- Field studies on small mammal population ecology and plant ecology continued at the 5 plots in the Pecho area and the 2 plots in the Bayview area. One, 1 ha study plot was established at the Bayview area on habitat that was occupied by Morro Bay kangaroo rats. Two, 1 ha study plots were established at the Pecho area. One of these plots was on a site selected for a controlled burn in the fall.
- Field work on the distribution of Morro Bay kangaroo rats throughout their original range was completed in the fall.
- Operation of the captive breeding facility continued through the year.
- The second controlled burn within Critical Habitat was conducted in the fall. More signs were installed informing the public that the purpose of the burn was to restore habitat for the Morro Bay kangaroo rat.

1986

- Field studies on small mammal population ecology and plant ecology continued at the 7 plots in the Pecho area and the 3 plots in the Bayview area.

- Operation of the captive breeding facility continues.
- A field experiment involving the release of *Dipodomys heermanni arenae* into a protected enclosure was conducted on private land south of Arroyo Grande, California.
- A fence along the boundary of the Morro Dunes Ecological Reserve and part of the Montana de Oro State Park boundary to "Old Army Rd." was constructed in the summer.
- A third prescribed burn was conducted on 27 October 1986 on a small triangle of land surrounded by dirt roads, immediately south of the 1984 prescribed burn.
- The U.S.F.W.S. purchased materials to construct two, 100 ft X 100 ft X 8 ft high enclosures to be used for the release of Morro Bay kangaroo rats at the Pecho site.

1987
- Field studies on small mammal population ecology and plant ecology continued on 2 burned plots and 2 control plots at Pecho.
- Operation of the captive breeding facility continues.
- No Morro Bay kangaroo rats were released at the Pecho site.

1988
- A protective, 150 ft X 150 ft X 5 ft high, enclosure was constructed by the California Conservation Corps and the USFWS on habitat that had been burned in the fall of 1984.
- Three Morro Bay kangaroo rats (1 male and 2 females) were released in the enclosure in May and one additional male was released in July. The California Departments of Fish and Game and Parks and Recreation provided funds to monitor the enclosure, document signs of predators, and describe the activities of the 4 rats inside.

At the onset of this study, Morro Bay kangaroo rats were known to occur on Essential Habitat at the Bayview, Buckskin, and Junior High sites. Populations at the Buckskin and Junior High sites have declined to a point where they are probably no longer extant. At the present time, the only wild population of Morro Bay kangaroo rats which appears to be maintaining itself is the one which occurs on the Bayview site (refer to U.S.F.W.S. 1982, Gambs 1986a, 1986c, 1986g, and Villablanca 1987 for further details on the distribution and status of *D. h. morroensis*). The Bayview site covers approximately 200 acres (81 ha); however no more than 175 acres (71 ha) appeared to be suitable for Morro Bay kangaroo rats in 1982 (U.S.F.W.S. 1982). By 1985, the area of remaining suitable habitat at Bayview was estimated to be no more than 51 acres (20 ha) (Gambs 1986c and Villablanca 1987). Just as the area of suitable habitat at Bayview has declined so has the size of the Morro Bay kangaroo rat population there. In 1979, the estimated population size of Morro Bay kangaroo rats on the Bayview site was 170-175 individuals (Toyoshima 1983). By 1983, the population estimate had dropped to 50-100 individuals (U.S.F.W.S. 1982 and Roest 1984).

II. STUDY AREAS

GENERAL PHYSIOGRAPHY, SOILS, AND VEGETATION IN THE HISTORIC RANGE OF THE MORRO BAY KANGAROO RAT

Physiography and Geologic History

The historic range of Morro Bay kangaroo rats is bounded on the west by the Pacific Ocean and Morro bay, on the south by the Irish Hills and on the north by Park Ridge (Gambs 1986d). The major physiographic features of this area have developed primarily in response to climatic and edaphic changes that occurred during the Ice Ages. At various times during this period, sea level receded several hundreds of feet when ice caps formed and rose again when the ice caps melted. Valleys were cut when sea level was low and were filled with sediments when sea level was high (Holland and Keil 1986b).

During the late Pleistocene (about 10,000 years ago), a major sand dune formation developed on the western portion of the Los Osos Valley and a sand sheet moved inland to cover the southern flank of the valley to elevations of over 900 ft on the hillsides as far east as Los Osos Creek. The areas of the Los Osos Valley covered by the sand dune/sheet complex have developed very similar edaphic and vegetation patterns. Morro Bay kangaroo rats colonized the area and became established over much of the stabilized sandy soil. Later, as the communities of Baywood Park, Los Osos, and Cuesta -by-the-Sea were developed on this sand dune/sheet complex, Morro Bay kangaroo rats were displaced from their native habitat.

Soils

Most of the area is covered by Baywood Fine Sand (a result of the sand dune/sheet complex discussed above) and the vegetation is generally a mosaic of Coastal Dune Scrub, Chaparral, and Coastal Oak Woodland. The historic and potential range of Morro Bay kangaroo rats occurs almost entirely within this soil type and vegetation mosaic.

The upland area of the Irish Hills is composed of Santa Lucia Shaly Clay Loam and is covered mostly by Chaparral, although Coastal Oak Woodland and Coastal Dune Scrub also are present. The eastern portions of the valley, inland from the coastal dune complex, are characterized by finer textured, alluvial soils such as Salinas Silty Clay Loam and Clear Lake Clay. The natural vegetation of these areas is Grassland, but much of the land is now used for agriculture. For the most part, these areas do not appear to be part of the historic or potential range of Morro Bay kangaroo rats.

Vegetation Development

The vegetation throughout the historic range of the Morrc Bay kangaroo rat (Gambs 1986a) developed in response to an interaction of both historical events (above) and specific environmental factors such as: climate (wind, temperature, rainfall, fog, etc.), topography, soils, parent material, biotic components, fire, drainage routes, coastal tides and past and present human activities. Consequently, the remaining vegetation of this area is a complex mosaic of relatively natural terrestrial, semi-aquatic and aquatic (both freshwater and saltwater) plant communities. The natural terrestrial plant communities are Pioneer Coastal Dune, Coastal Dune Scrub, Chaparral, Coastal Oak Woodland, and Grassland communities. The semi-aquatic and aquatic communities

consist of Riparian, Freshwater Marsh, Coastal Salt Marsh, and Estuarine communities (Fig. 2—1). Added to these natural communities are the numerous plants (eg. ornamentals, windrows, crops, and weeds) introduced to the area during the course of urban and agricultural development.

The western portion of the Los Osos Valley eastward to Los Osos Creek (the extent of the sand dune/sheet complex) is vegetated by a mosaic of four native plant communities: (1) Pioneer Coastal Dune (unstabilized); (2) Coastal Dune Scrub; (3) Chaparral; and (4) Coastal Oak Woodland. The Pioneer Coastal Dune community occurs on the youngest and most active dunes which are found near the ocean. The Coastal Dune Scrub and Chaparral communities occur on progressively older and more stabilized dunes. The Coastal Oak Woodland community occupies the oldest and most stable dunes and is considered to be the climax vegetation in this area. Morro Bay kangaroo rats are believed to have occupied large portions of the area currently or historically covered by the Coastal Dune Scrub community.

VEGETATION OF THE PECHO AREA

The Pecho area is located on the west-facing coastal dune complex (Baywood Fine Sand) with a slope ranging from 3 to 10% although it is steeper in some areas. The vegetation of the Pecho site is comprised of a complex mosaic of shrubby and herbaceous plants that are not arranged into well defined communities. This mosaic is composed of three major plant communities listed roughly in order of distance inland from the Pacific Ocean: (1) Pioneer Coastal Dune, (2) Coastal Dune Scrub, and (3) Chaparral. In addition, eucalyptus trees have been planted in scattered locations throughout the area (Fig. 2—2)

The first terrestrial community encountered inland from the ocean on the Pecho site is the Pioneer Coastal Dune community which occurs along the strand and on unstabilized dunes. Inland from this community are the Coastal Dune Scrub and Chaparral communities, respectively. Coastal Dune Scrub is located immediately east of the unstabilized dunes while Chaparral is generally restricted to older, stabilized dunes east of Pecho Road. However, small fingers of Chaparral extend down drainages and associate with the Coastal Dune Scrub community west of Pecho Road. In addition, isolated patches of Chaparral and individual plants occur as scattered components of the Coastal Dune Scrub throughout the area. East of the Pecho area, Coastal Oak Woodland dominates the oldest dunes and is considered to be the climax vegetation type for this area (Fig. 2—1). The major plant community on the site and the principal habitat for Morro Bay kangaroo rats is the Coastal Dune Scrub community. Since the Pecho study plots are situated in this community, it is considered in more detail (below). The other communities are described briefly by Holland (1986).

The Coastal Dune Scrub community as described by Holland and Keil (1986a) is roughly synonymous to coastal sage scrub (Munz 1968) and coastal sand plains and stabilized sand dunes (Hoover 1970). This community is found on the leeward side of the unstabilized sand dunes and is successionally older and more diverse than the Pioneer Coastal Dune community. Coastal Dune Scrub is located in areas somewhat sheltered from the harsh winds that blow along the beach and the soils generally contain more organic matter and less salt than those of the Pioneer Coastal Dune community. The Coastal Dune Scrub community is composed of a mixture of herbaceous, subshrubby and shrubby species that grow taller and denser than those found in the Pioneer Coastal Dune community. These plants generally have shallow root systems that tap surface water

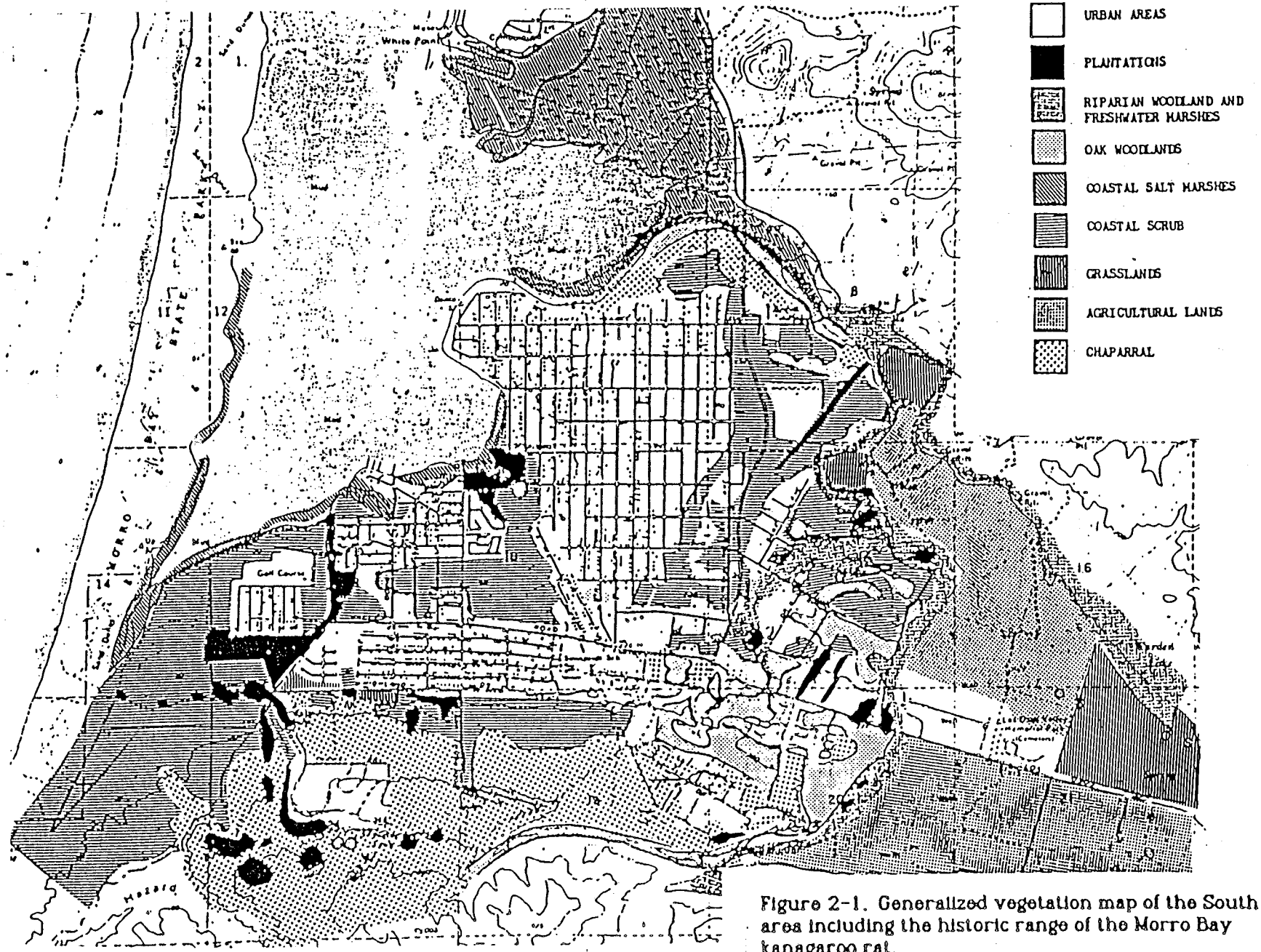


Figure 2-1. Generalized vegetation map of the South Bay area including the historic range of the Morro Bay kanagaroo rat.

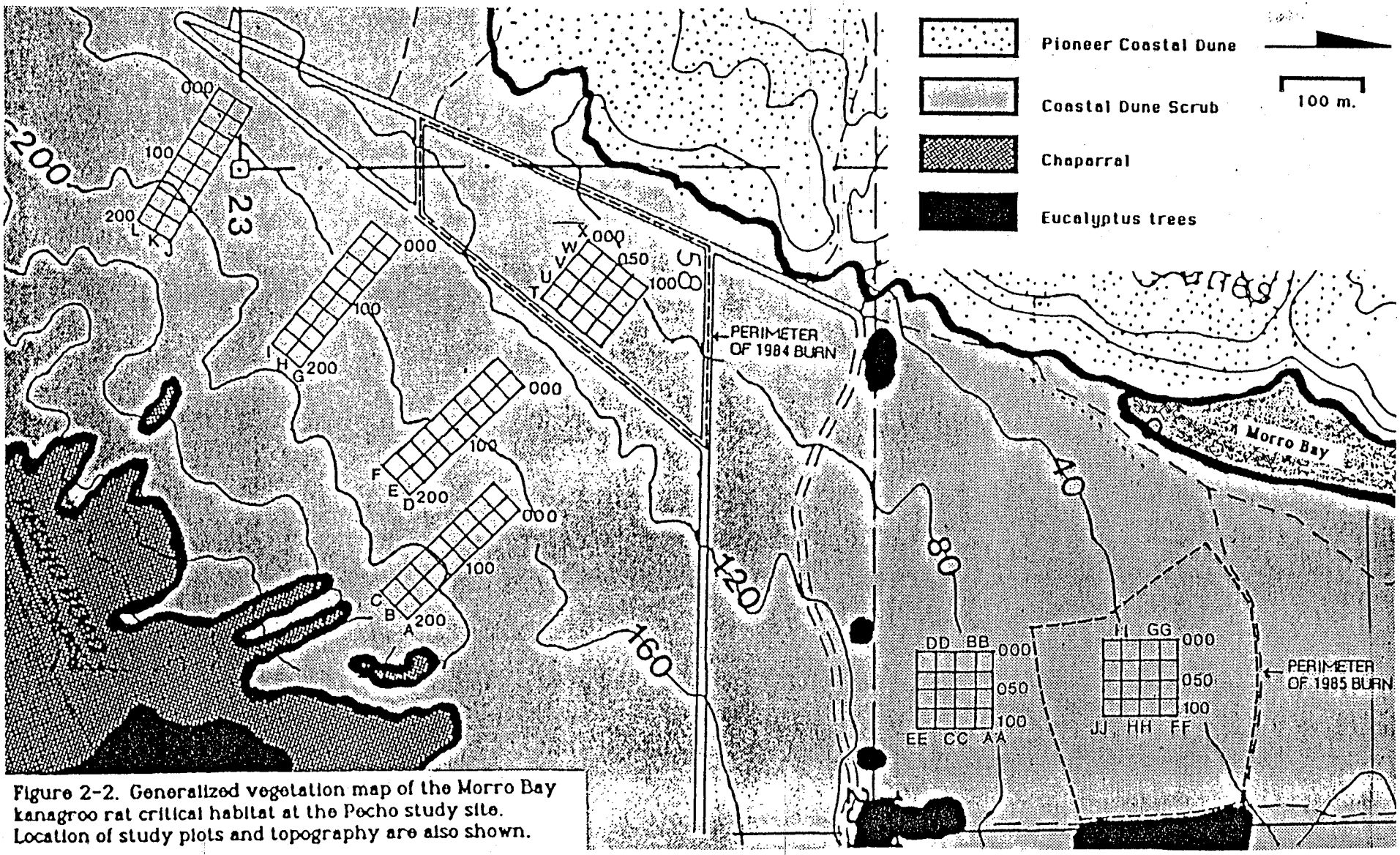


Figure 2-2. Generalized vegetation map of the Morro Bay kanagroo rat critical habitat at the Pocho study site. Location of study plots and topography are also shown.

available in the upper soil horizons. Dominant species are mostly soft-stemmed shrubs or subshrubs (obscurely shrubby and usually low growing plants) that have thin, often deciduous or semi-deciduous leaves.

The study plots, which are representative of the Pecho site, consist of a mosaic of shrubs and subshrubs that vary in density, cover, height, woodiness, and degree of summer dieback combined with herbaceous species that range from diminutive spring-flowering annuals to coarse succulents, bunchgrasses and mat-forming perennial herbs. In addition, much of the soil bears a crust-like cover of lichens that reduces soil erosion. The overall aspect of the vegetation is an open to dense shrubland with a predominantly gray-green color. The shrubs vary in height from about 0.2 to 2.0 m, but most are less than 1 m tall.

The shrub cover varies from site to site over the area. Species are often distributed patchily, with aggregations of individuals occurring at some sites and not at others. This patchiness may be due to environmental factors such as enhanced or decreased moisture availability or to reproductive success of an original colonizer. Some species spread by underground rhizomes and the resulting patch may actually be a single individual connected or formerly connected underground.

In a mixed mosaic of species such as that found on the Pecho site, dominance is variable from site to site and difficult to ascertain for the overall area. Some species, by virtue of their size or density, locally dominate to the exclusion of other species; but, over the entire area, these species may be relatively unimportant. For example, *Prunus ilicifolia* (holly-leaved cherry) is found only at a few locations; however, where it does occur it usually forms almost pure stands.

The diversity of plant species in the Coastal Dune Scrub community of the Pecho site is illustrated by the large number of plant species (over 110) that have been collected and identified from the site. Species that dominate throughout most of the Coastal Dune Scrub community in the Pecho area are listed below. Other species found in this area are listed in Appendix B.

Artemisia californica	California sagebrush
Carpobrotus chilensis	ice plant
Carpobrotus edulis	ice plant
Ceanothus cuneatus	buckbrush
Corethrogyne filaginifolia	California aster
Croton californicus	croton
Dudleya caespitosa	dudleya
Ericameria ericoides	mock heather
Eriogonum parvifolium	coastal buckwheat
Lotus scoparius	deerweed
Lupinus chamissonis	coastal silver lupine
Prunus fasciculata var. *punctata*	sand almond
Salvia mellifera	black sage

Herbaceous species that are commonly found between and under the dominant shrubs in this community, especially following fire or clearing include:

Achillea borealis	yarrow
Amsinckia spectabilis	fiddleneck
Camissonia chieranthifolia	evening primrose
Camissonia micrantha	evening primrose
Cardionema ramosissimum	sand mat
Chenopodium californicum	California goosefoot
Chorizanthe augustifolia var. *eastwoodae*	chorizanthe
Cirsium occidentale var. *occidentale*	thistle
Eriophyllum multicaule	annual eriophyllum
Erysimum suffrutescens var. *lompocense*	wallflower
Phacelia distans	phacelia

VEGETATION OF THE BAYVIEW SITE

The Bayview area is located on the Baywood Fine Sand sheet east of the Pecho site (Fig. 1–2) on a north-facing slope with a grade ranging from 3 to 8% although it becomes steeper to the south. The general vegetation survey of the Bayview site was expanded to include the undeveloped land and horse ranch between Broderson Ave. and the Cabrillo Estates subdivision (Fig. 2–3). This 104.4 ha (258 acre) area measures 762 m (2,500 ft) X 1,372 m (4,500 ft) and is oriented along an east-west axis. Vegetation on the site consists of an intergrading assemblage of Coastal Dune Scrub, Chaparral, and Coastal Oak Woodland (Fig. 2–3). In addition, two small groves of bishop pines and a few isolated, individual pine trees occur on the upland portion of the site. The boundaries of the plant communities are not sharply defined and there is considerable overlap in species composition.

In addition to the native species, there are plantations of eucalyptus and Monterey cypress trees in the northwestern portion of the site. Weedy plants have invaded disturbed sites, especially along trails and near the homes bordering the northern edge of the site. Some of the homeowners along Highland Drive also have planted ornamentals immediately behind their lots and some of these have escaped into the natural vegetation. Most of the ornamentals are succulents that apparently have become established from clippings dumped in the brush.

For the most part, study plots and transect lines are located in the Coastal Dune Scrub community. However, some of the plots and lines extend up the slope into the lower fringe of the Chaparral. Only these two plant communities are discussed below. Other, neighboring plant communities are discussed by Holland (1986) and Holland and Keil (1986b).

The Coastal Dune Scrub community occupies the lower (northern) 1/2 to 1/3 of the Bayview site (Fig 2–3). The vegetation is dominated by a mixture of herbaceous species and low-growing to moderate sized shrubs and subshrubs which range from about 0.2 to 2.0 m tall. Much of the community is easy to traverse because the shrubs are soft-stemmed and there are open areas among the shrubs. These open areas have a mixture of herbaceous plants and exposed soil. Like the Pecho site, the soil surface in much of the Coastal Dune Scrub at Bayview is not just bare sand, but, instead, is covered by a thin crust of lichens or a carpet of moss. These low-growing plants are an

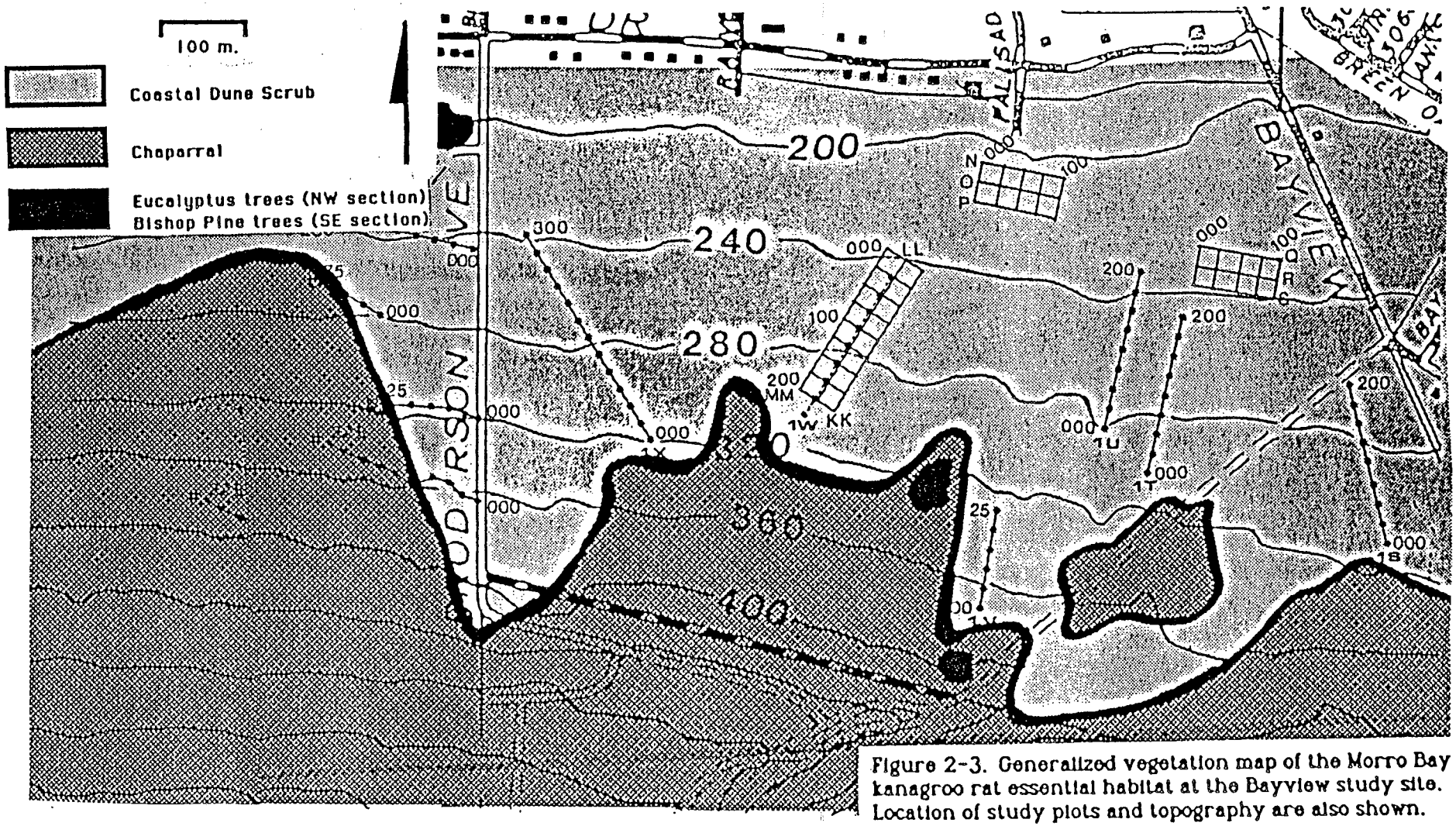


Figure 2-3. Generalized vegetation map of the Morro Bay kanagroo rat essential habitat at the Bayview study site. Location of study plots and topography are also shown.

important component of mature, undisturbed dune scrub communities and serve to stabilize the soil surface, preventing erosion.

The species composition within the Coastal Dune Scrub community varies considerably over the Bayview site. The species composition is dependent upon such factors as the amount of exposure to wind, the direction and slope of the terrain, the length of time that succession has been taking place, the amount and types of disturbance that have taken place in the past, and the degree of soil development. Common species in the Coastal Dune Scrub community at Bayview are listed below. Additional species found at Bayview are listed in Appendix C.

Artemisia californica	California sagebrush
Ceanothus cuneatus	buckbrush
Croton californicus	croton
Dudleya caespitosa	dudleya
Ericameria ericoides	mock heather
Eriogonum parvifolium	coastal buckwheat
Eriophyllum confertiflorum	common golden-yarrow
Helianthemum scoparium	rush-rose
Horkelia cuneata	silverweed
Lotus scoparius	deerweed
Salvia mellifera	black sage

Chaparral occupies the upper (southern) 1/2 to 1/3 of the Bayview site (Fig. 2—3). This community is composed of stiffly branched, leathery-leafed (sclerophyllous) shrubs mostly 1 to 3 m tall. The chaparral on the Bayview site varies from an extremely dense, almost impenetrable community with virtually no understory in the northern 1/3 of the site to a relatively open community with a sparse understory in the central portion. It is dominated by *Arctostaphylos morroensis* (Morro manzanita) which forms pure stands in many places. Common associated species are listed below. Other species are listed in Appendix C.

Adenostoma fasciculatum	chamise
Arctostaphylos crustacea	brittle-leafed manzanita
Ceanothus cuneatus	buckbrush
Heteromeles arbutifolia	toyon
Prunus ilicifolia	holly-leafed cherry
Quercus agrifolia var. *frutescens*	pygmy oak

The open Chaparral is found in the transitional (ecotonal) area which extends more or less across the center of the Bayview site between the dense Chaparral and the Coastal Dune Scrub. In the area where the two communities intergrade, the Chaparral is gradually replaced by Coastal Dune Scrub in the northern portion of the area. In this ecotonal area, the common Chaparral species (especially *Arctostaphylos morroensis* and *Ceanothus cuneatus)* are scattered and mixed with species typical of Coastal Dune Scrub such as *Ericameria ericoides* (mock heather), *Artemisia californica* (California sagebrush), *Eriogonum parvifolium* (coastal buckwheat), *Lotus scoparius* (deerweed), and *Horkelia cuneata* (silverweed). The transitional area between Chaparral and Coastal Dune Scrub is broad. As a result, drawing boundaries on a vegetation map (eg. Fig. 2—3) is difficult.

STUDY AREAS

In 1982 and 1983, all landowners of the 7 sites known to have supported Morro Bay kangaroo rats in the past (Pecho, Turri, Hazard, Bayview, Buckskin, Santa Ysabel, and Junior High) were contacted by letter and asked to permit zoological and botanical research on their land (Fig. 1–2). Landowners of all sites except Pecho, Turri, and Hazard either refused access or refused to respond to repeated requests. As a result, study plots could be established at only these three sites in 1983. The plots at the Turri and Hazard sites were sampled in 1983, but were eliminated from further investigation when no signs of Morro Bay kangaroo rats were found after the first year of study. Although not reported here, results of botanical studies at the Turri and Hazard sites are available from V. L. Holland and results of zoological studies at the two sites are provided in reports by Gularte (1983) and Gambs (1986d). In 1984, permission was granted to carry out botanical and zoological studies at the Bayview site. The bulk of the present report focuses on botanical and zoological data gathered over a period of 2 to 4 years from 7 study plots at the Pecho site and 3 study plots at the Bayview site.

Villablanca (1987) divided the historic range of Morro Bay kangaroo rats into 8 areas as originally described by Congdon and Roest (1975). Within each area, Villablanca designated specific study sites (Fig. 2–4) as follows: Area I – a site along Turri road north of the Los Osos / Baywood Park Landfill referred to as Extension; Area II – a site north of Santa Ysabel Ave. referred to as Bayside, a site near the south eastern end of Santa Ysabel Ave. referred to as Santa Ysabel, and three sites around the Los Osos Jr. High School referred to as Junior High West, Junior High North, and Junior High East; Area III – a site near the Los Osos Jr. High School referred to as Junior High South, a site along the southern side of Hollister Ave. referred to as Hollister, and a site at the northern end of Buckskin Dr. referred to as Buckskin; Area IV – a site north of Valley View Ln. referred to as Glen; Area V – two sites south of Highland Dr. referred to as Bayview East and Bayview West, a site near the southeast corner of section 24 referred to as Old Burn, and two sites on either side of Rodman Drive referred to as Cabrillo; Area VI – a site north of Old Army Road referred to as Pecho North; Area VII – four disjunct sites south of Old Army Road collectively referred to as Pecho South; and Area VIII – no study sites were designated in this area. Data gathered in 1984 and 1985 by Villablanca (1986 and 1987) have been incorporated into appropriate sections of this report.

Pecho Site

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'. The site is generally bounded by Morro Bay on the North, Pecho Road on the East, Hazard Creek on the South, and the Pacific Ocean on the West (Fig. 1–2). The average slope of the landscape on the site is ≤ 15%.

The original experimental design called for establishing 4 plots, 2 in habitat occupied by Morro Bay kangaroo rats and 2 in habitat that was not occupied by Morro Bay kangaroo rats. Once baseline studies had been conducted on all 4 plots, then 1 of the plots in occupied habitat and 1 of the plots in unoccupied habitat would be subjected to brush clearing. We would then be able to monitor the Morro Bay kangaroo rat populations as well as the changes in vegetation on the 4 plots and thereby assess their numerical

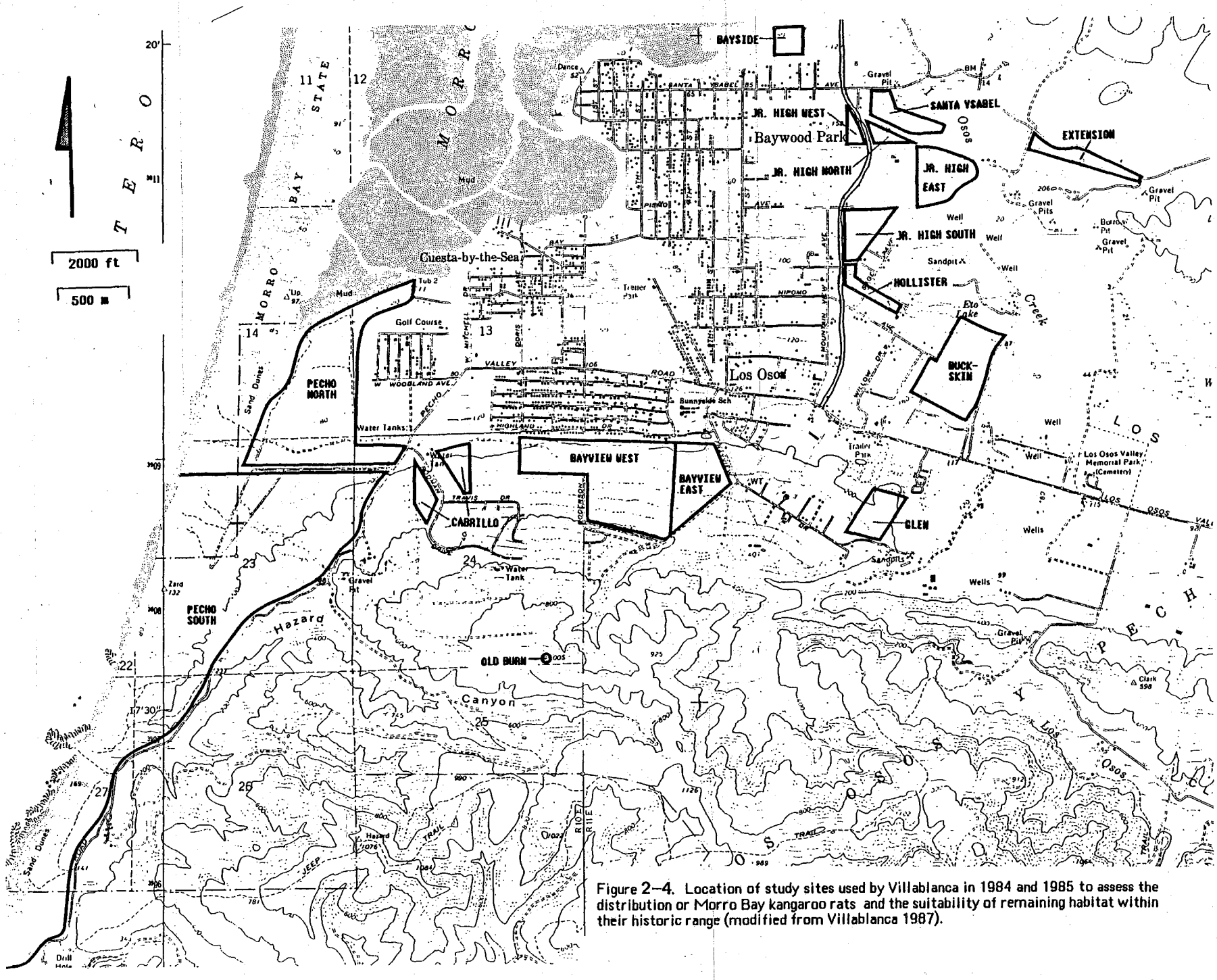


Figure 2–4. Location of study sites used by Villablanca in 1984 and 1985 to assess the distribution or Morro Bay kangaroo rats and the suitability of remaining habitat within their historic range (modified from Villablanca 1987).

response to brush removal. Prior to the winter of 1982/83, when field work was initiated, we expected that Morro Bay kangaroo rats still inhabited the Pecho area and in the fall of 1982 we even found burrows which suggested that this might be the case. Based upon trapping data from previous studies and our reconnaissance of the Pecho area, we located the 4 study plots (ABC, DEF, GHI, and JKL) according to the original experimental design (Fig. 2—5). We only had 2 months (January and February) in which to develop baseline data before brush clearing began on the two experimental plots. We were concerned that the restricted time allowed to gather baseline data during the winter might hinder our ability to detect changes in the small mammal and plant populations on the cleared plots. As it turned out, seasonal and temporal restrictions were the least of our worries because no Morro Bay kangaroo rats were found on any of the plots at Pecho during the first year.

Subsequent research efforts from the second through the fourth years of the study at the Pecho site focused upon searching for signs of Morro Bay kangaroo rats and systematically censusing small mammal and plant populations on the original plots as well as three newer plots in areas that had been selected for prescribed burns. Plant populations were not censused on some of the study plots at the Pecho site in 1985 because of an interruption in our contracts that year.

Plots ABC and DEF were located where Morro Bay kangaroo rats had been found in 1978/ 79; whereas plots GHI and JKL were located where no Morro Bay kangaroo rats had been found in 1978/79 (Toyoshima 1983). Plots DEF, GHI, TUVWX, AA-EE, and FF-JJ were all located where Morro Bay kangaroo rats had been found in 1977 (Roest 1977). All plots were referenced to existing surveyed points by means of traverse surveys (refer to Gambs 1986a, 1986b, 1986d, and 1986e for details of these surveys).

Plots ABC, JKL, and AA—EE, represent control (uncleared and unburned) plots which remained more or less undisturbed during the 4-year study. Plots DEF, GHI, TUVWX, and FF—JJ represent experimental plots in the sense that vegetation covering these plots was subjected to either manual clearing or prescribed burning during the course of the 4-year study.

Habitat management

Successional processes have resulted in a situation whereby the vegetation at the Pecho site apparently has become progressively less suitable for Morro Bay kangaroo rats (Roest 1973). In response to declining habitat quality at the Pecho site, the California Department of Fish and Game prepared a management plan for their Morro Dunes Ecological Reserve which called for a rotating program of brush removal to enhance habitat quality for Morro Bay kangaroo rats on the Ecological Reserve (Lidberg 1982). The habitat management program which has been implemented at the Pecho site (outlined below) generally has followed the management plan established for the Ecological Reserve.

Iceplant removal, January 1983 — About 30 cubic yards of iceplant were removed from some of the study plots and neighboring areas at the Pecho site in January 1983.

Brush removal, March to April 1983 — Plots DEF and GHI were subjected to manual brush clearing between 1 March and 19 April 1983. A number of small (1—5 m diameter) islands of brush were left intact on both plots, but the remaining brush within the boundaries of both plots was cut at ground level and hauled away. None of the

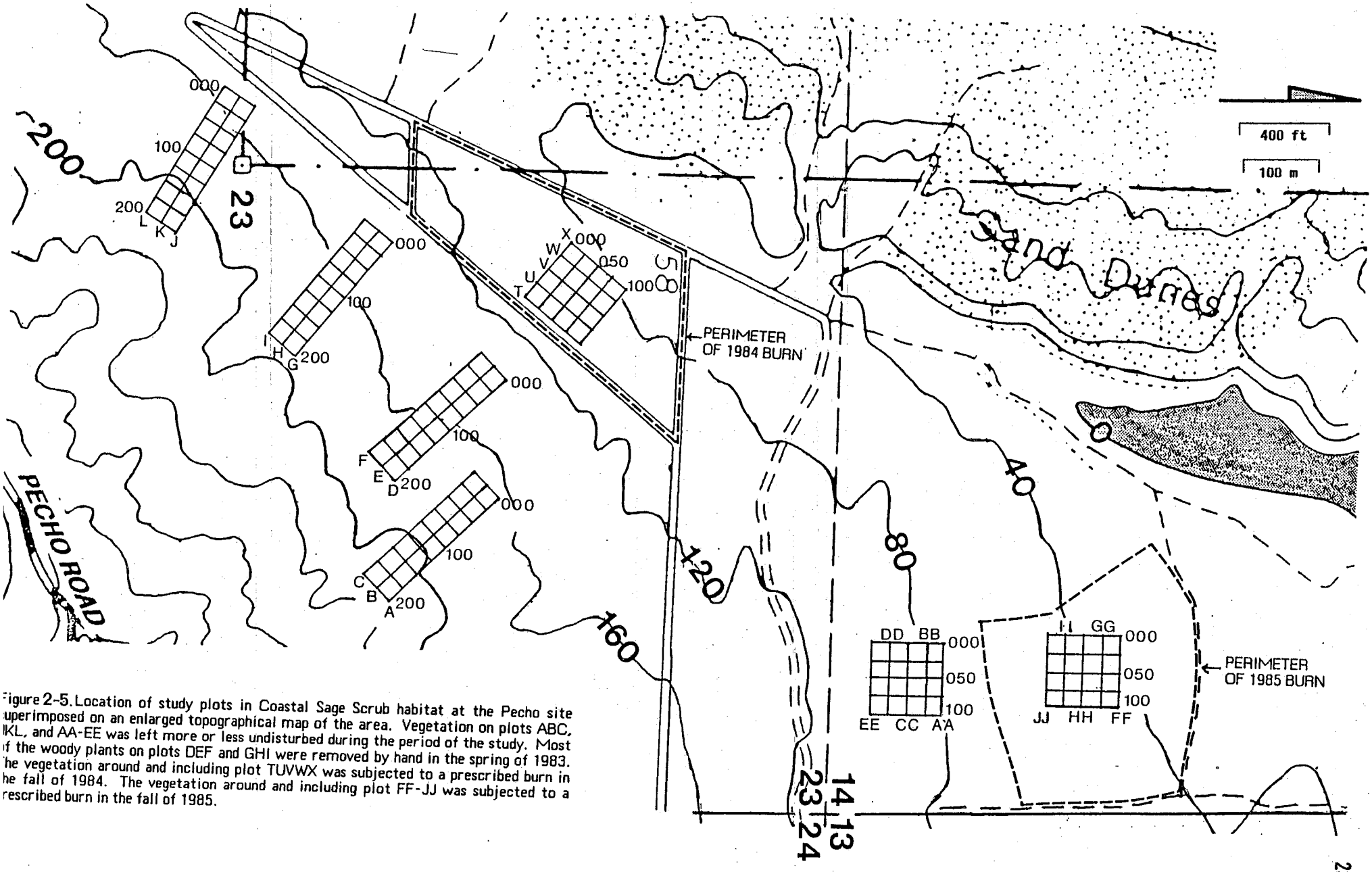


Figure 2-5. Location of study plots in Coastal Sage Scrub habitat at the Pecho site superimposed on an enlarged topographical map of the area. Vegetation on plots ABC, IKL, and AA-EE was left more or less undisturbed during the period of the study. Most of the woody plants on plots DEF and GHI were removed by hand in the spring of 1983. The vegetation around and including plot TUVWX was subjected to a prescribed burn in the fall of 1984. The vegetation around and including plot FF-JJ was subjected to a prescribed burn in the fall of 1985.

herbaceous plants were intentionally removed from the plots, but a number of these plants were injured or killed during the process of brush removal. A sharp "edge effect" was created between the plots and the surrounding habitat because brush was not removed from the zone immediately outside the perimeter of the plots.

Prescribed burn, October 1984 — A 13-acre area surrounding plot TUVWX was subjected to a prescribed burn on 24 October 1984 (Fig. 2—5). Brush cover on the area ranged from low and sparse near roads and trails and on higher sites to tall and dense on lower sites in the central part of the area. Most of the low, sparse brush carried the fire and was burned thoroughly, but the tall, dense brush resisted the fire and was not burned thoroughly. Stakes marking the sampling stations were protected from fire by clearing litter away from the base of the stakes and then enclosing them in 3' lengths of galvanized metal downspout material. Several of the tall stakes were charred inside the metal protectors, but all of the short stakes were relocated after the fire.

Prescribed burn, October 1985 — A 20-25-acre area surrounding plot FF-JJ was subjected to a prescribed burn on 3 October 1985 (Fig. 2—5). Brush cover on most of the area was low and sparse and much of the ground between the shrubs was covered with grass. There was a small patch of Coast Live Oak and dense brush located near the center of the burned area. All of the plant cover readily carried the fire and the entire area was burned thoroughly.

Bayview site

The Bayview site is located in the village of Los Osos, CA; in the NW 1/4 of Sec. 19, T30S, R11E, Morro Bay South Quadrangle; Longitude 120° 50', Latitude 35° 18'. The site is bounded by Highland Drive on the North, Broderson Avenue on the West, and Bayview Heights Drive on the East (Fig. 1—2). The average slope of the landscape on the site is ≤ 15%.

The research focus at the Bayview site was to census both the small mammal and plant populations in habitat known to support Morro Bay kangaroo rats. As soon as we obtained landowner permission to work at the Bayview site, we conducted a ground reconnaissance of the site and located 2 areas with definite signs of Morro Bay kangaroo rats. We established one study plot in each of the 2 areas (plots NOP and QRS) in early spring of 1984 (Fig. 2—6). Small mammals were censused for 3 years on both of these plots; but, because of an interruption in our contracts in 1985, plant populations were only sampled on the plots in 1984 and 1986. During the 1985 field season, Villablanca (1987) located several other areas at the Bayview site which supported moderate numbers of Morro Bay kangaroo rats. We established a third study plot (KKLLMM) at the new area with the highest number of rats and censused it during the last two years of study at the Bayview site. All 3 of these plots were located in an area that had supported Morro Bay kangaroo rats in 1979 (Toyoshima 1983). Each plot was referenced to a permanent landmark by means of a staff compass traverse survey (refer to Gambs 1986a for details of these surveys).

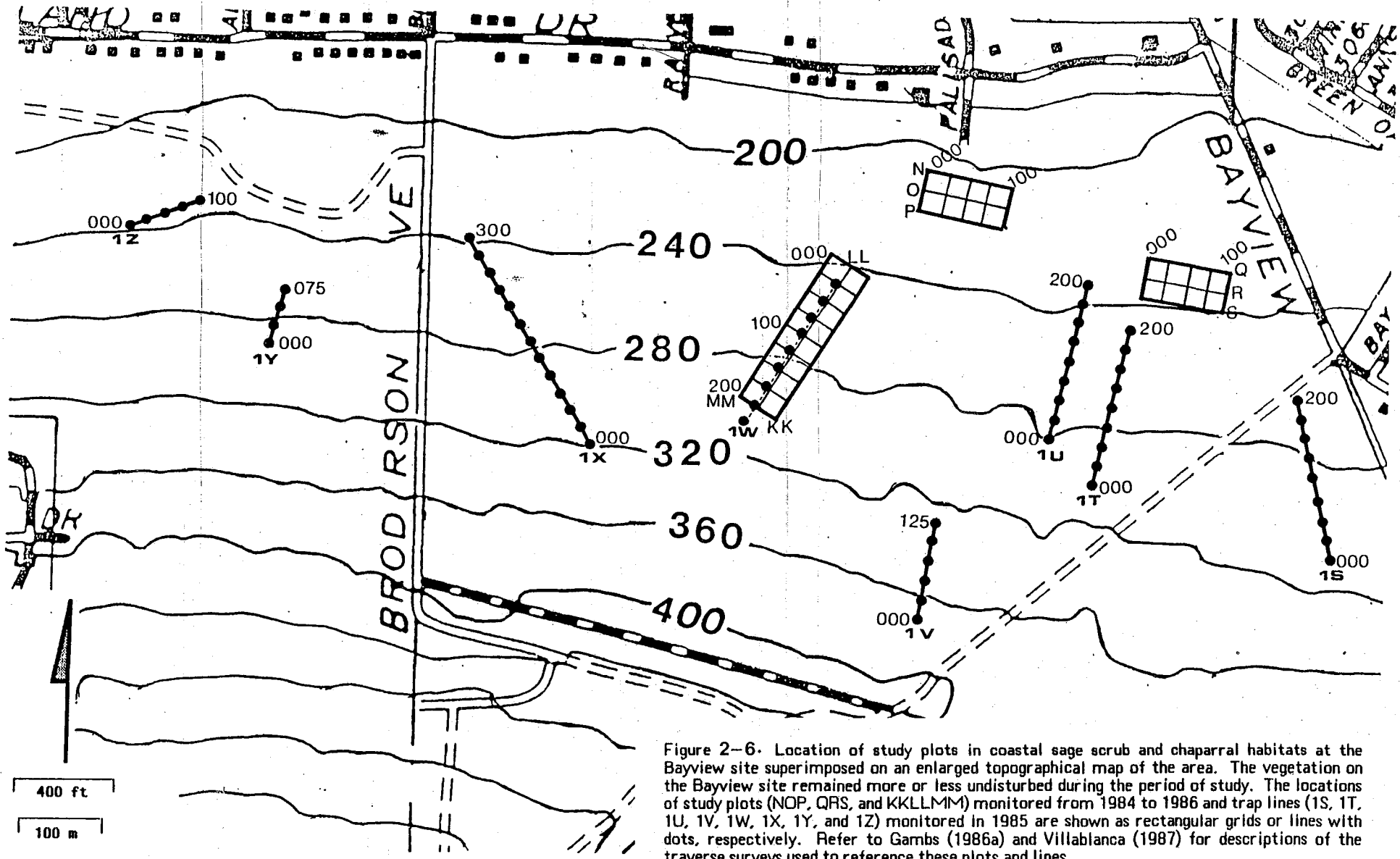


Figure 2–6. Location of study plots in coastal sage scrub and chaparral habitats at the Bayview site superimposed on an enlarged topographical map of the area. The vegetation on the Bayview site remained more or less undisturbed during the period of study. The locations of study plots (NOP, QRS, and KKLLMM) monitored from 1984 to 1986 and trap lines (1S, 1T, 1U, 1V, 1W, 1X, 1Y, and 1Z) monitored in 1985 are shown as rectangular grids or lines with dots, respectively. Refer to Gambs (1986a) and Villablanca (1987) for descriptions of the traverse surveys used to reference these plots and lines.

III. ZOOLOGICAL STUDIES

Although the overall zoological objective was to determine the contemporary status of the Morro Bay kangaroo rat throughout its range, a substantial body of information was collected on specific details of its life history as well as population characteristics of other mammal species associated with Morro Bay kangaroo rats. Methods, summary results, and conclusions of these studies are all incorporated in this chapter.

METHODS

All trapping was conducted under provisions of Federal Fish and Wildlife Permit No. PRT—690400, Joint State of California Department of Fish and Game / Federal Scientific Collector's Permit, and a Memorandum of Understanding by and between California Polytechnic State University and California Department of Fish and Game. Zoological field work was conducted by the author, Dr. Fred Bernstein, Mr. Robert Gularte, Mr. Tevis Underwood, Mr. Rocky Thompson, Mr. Lou Morton, Mr. Francis Villablanca, and Mr. Roy Toft.

TRAPPING, MARKING, AND DATA COLLECTION

The general trapping methodology involved placing two live traps within 5 m of each trapping station (refer to Gambs 1986g for further details). A small ball of cotton was placed in each trap and a small handful of rolled oats (bait) was divided between the interior of the trap and the ground in front of the trap. Every small mammal captured (except California ground squirrels) was marked with a numbered, stainless steel ear tag and released at its site of capture.

The following field data were collected from each Morro Bay kangaroo rat: date, weather, trap location, species, sex, age class, reproductive condition, body weight, tail length, ear length, hind foot length, dorsal coloration, and extent of hip stripe.

DISTRIBUTION OF MORRO BAY KANGAROO RATS AND ASSESSMENT OF HABITAT SUITABILITY WITHIN THEIR HISTORIC RANGE

In 1984 and 1985, Villablanca (1986 and 1987) conducted a comprehensive survey of the distribution of Morro Bay kangaroo rats as well as the suitability of remaining habitat throughout their historic range. All undeveloped portions of the Morro Bay kangaroo rat's historic range were ground surveyed (Fig 2—1). If a site appeared to have suitable habitat, it was systematically searched for signs of Morro Bay kangaroo rats and then traplines were established and run to verify their presence. A site was designated as occupied if Morro Bay kangaroo rats were captured there or if abundant signs of their presence were found in the area.

The optimal foraging habitat of Morro Bay kangaroo rats is generally considered to be open, sparsely vegetated habitat with abundant seed-producing species of shrubby, suffrutescent, and herbaceous plants. The root systems of these plants stabilize the sandy soil for their shallow burrow systems. The animals apparently avoid predation and forage most efficiently when there are plenty of open runways or fingers of bare ground to travel on while they are active above ground. Villablanca (1987) developed 5 habitat

criteria which he used to rate the suitability of sites for Morro Bay kangaroo rats. Using these criteria, an optimal (suitable) habitat would be one occurring on gently sloping terrain where the dominant shrubs were low to medium in height and widely spaced. Habitat which did not satisfy the 5 criteria was judged to be unsuitable for Morro Bay kangaroo rats. For purposes of clarity throughout this report, potential or actual Morro Bay kangaroo rat habitat is classified into the following categories:

1. Occupied habitat — habitat which actually supported Morro Bay kangaroo rats in the past as well as during the present study.

2. Suitable habitat — habitat which supported Morro Bay kangaroo rats in the past; did not support Morro Bay kangaroo rats during the present study; but still appeared to possess optimal soil, slope, and plant cover.

3. Potentially suitable habitat — habitat which supported Morro Bay kangaroo rats in the past, did not support them during the present study, and appeared to be unsuitable at the present time. This habitat would require some degree of manipulation to return it to a suitable status.

The size (area) of a habitat parcel as well as the ratio of peripheral edge (length) to overall size of a parcel will influence the number of animals that could be supported on suitable or potentially suitable habitats. Since each individual rat in a population requires a portion of habitat which is equal to or perhaps slightly less than its home range, larger habitat parcels will support larger populations and vice versa. The ratio of peripheral edge to size of a habitat parcel is one way of expressing the magnitude of external perturbations potentially impinging upon a population. Thus, an area measuring 1 km X 1 km would have a ratio of 4.0 whereas the ratios of a 2 km X 2 km area would be 2.0 and an 8 km X 8 km area would be 0.5. Conversely, if the rats were somehow dependent upon peripheral edges, then one might view such ratios from a beneficial rather than a detrimental perspective.

TRAPPING INTENSITY, EASE OF CAPTURE, AND RELATIVE ABUNDANCE

Trapping intensity is expressed as number of trap nights (TN) which is equal to the sum of the number of traps set each night minus the number of tripped traps, the number of stolen or missing traps, and the number of other animals (birds, reptiles, rabbits, and insects) captured.

Ease of capture is expressed as the ratio of the trapping intensity (TN) to the number of individuals captured. As an example, if 5 deer mice were caught (# CAP) during a trapping session with 50 TN, then the ease of capture for deer mice during that session would be 10 TN / CAP. The ease of capture for 1 deer mouse caught during another trapping session with 50 TN would be 50 TN / CAP.

Relative abundance is expressed as the number of individuals captured per 100 TN (#/100 TN). Relative abundance is equal to the reciprocal of the ease of capture multiplied by 100 [1 / (#TN / CAP) X 100]. As an example, the relative abundance of 5 deer mice captured during 50 TN = 1 / 10.0 X 100 = 10.0 individuals / 100 TN.

Although relative abundance cannot be used to compare absolute differences between populations occurring on different plots, it does provide a means of expressing animal abundance (in terms of trapping success) for months when standard population estimates could not be computed. The average annual relative abundance is derived by applying the above formula to the $\sum$ of TN and the $\sum$ of CAP over the indicated months of each year.

POPULATION AND DENSITY ESTIMATION

Capture / recapture data from 2-, 3-, and 4-day trapping sessions were used to calculate population estimates for each session using the Schnabel Method (Davis and Winstead 1980). The period of time between trapping sessions was about 30 days; however, over that period of time, some degree of population turnover (deaths, births, dispersals) probably occurred. In an attempt to compensate for the confounding effects of population turnover, data collected during each monthly trapping session were treated as independent samples from a closed population. Thus, the first time an individual was captured on any given month it was counted as a newly captured individual, regardless of whether or not it had been captured on previous months. Unfortunately, insufficient numbers of captures and/or recaptures prevented calculating Schnabel population estimates for several of the trapping sessions.

Density was expressed as the population estimate derived from the Schnabel method divided by the area trapped. The area trapped was obtained by assuming that each trapping station "trapped" a 25 m X 25 m (625 m^2) area. Thus, the 1/2 ha plots (NOP and QRS), containing 15 trapping stations, were considered to trap an area of 15 X 625 m^2 = 9,375 m^2 = 0.9375 ha. The 50 m X 200 m, 1 ha plots (ABC, DEF, GHI, JKL, and KKLLMM), containing 27 trapping stations, were considered to trap an area of 27 X 625 m^2 = 16,875 m^2 = 1.6875 ha. The 100 m X 100 m, 1 ha plots (TUVWX, AA-EE, and FF-JJ), containing 25 trapping stations, were considered to trap an area of 25 X 625 m^2 = 15,625 m^2 = 1.5625 ha. The average annual density estimate of each species was obtained by dividing the average of the daily population estimates during the indicated months by the appropriate area trapped.

HOME RANGE ESTIMATES

The home ranges of Morro Bay kangaroo rats were estimated using the Exclusive Boundary Strip method (Stickel 1954). All stations where an individual was captured were marked on a map of the appropriate study plot and each capture station was then considered to be the center of a square with sides equal to the distance between trapping stations (ie. 25 m X 25 m = 625 m^2). After squares had been drawn around all capture sites, the squares were connected by lines such that the area enclosed by the perimeter of the home range boundary was minimized. As an example, if one animal was caught at 3 adjacent stations on the same line (eg. N0+00, N 0+25, and N 0+50); its home range would be 3 X 625 m^2 = 1875 m^2. On the other hand, if another individual was caught at 3 neighboring stations which were on different lines (eg. N 0+00, O 0 + 25, and N 0 + 50); its home range would be (3 X 625m^2) + (2 X 312.5 m^2) = 2500 m^2. The second term in this equation represents 2 triangular-shaped areas which are required to provide a strip of land connecting the 3 neighboring capture points.

Villablanca (1987) estimated the home ranges of Morro Bay kangaroo rats caught on traplines at the Bayview site using a different procedure because all of his capture data were from linear trapping stations. He plotted all stations where an individual was captured on a map and then measured the maximum distance (m) between the two most extreme capture points. The home range of each individual was then considered to be a circle with a radius equal to 1/2 the maximum distance between extreme capture points. As an example, if he caught one animal at stations W 0 + 00, W 0 + 25, and W 0+ 50; then its home range size would be calculated using the following formula: Home Range = $\pi \times (25m)^2 = 1964\ m^2$.

ESTIMATION OF BREEDING SEASON IN MORRO BAY KANGAROO RATS

Since breeding activity was not observed in the field and recently impregnated females were indistinguishable from non-pregnant females, the seasonality of breeding in wild Morro Bay kangaroo rats had to be determined indirectly from capture dates and body weights of juvenile and subadult animals. The first problem was to determine the relationship between body weight and age so that we could estimate the birthdates of immature, field-caught animals based upon their weights. By subtracting the 31 day gestation period from the estimated birthdate of each animal, we were able to estimate the date of conception of all immature animals. Thus, the estimated breeding season of wild Morro Bay kangaroo rats is based upon predicted conception dates which in turn are based upon predicted ages derived from a regression analysis of the relationship between age and body weight. It should be emphasized that the longest period of trapping was from 23 March to 18 October, 1984. This means that the earliest and latest possible conception dates that could have been detected from these data were, respectively, mid-December of the previous year and September of the same year.

The known-age animals used to develop the relationship between body weight and age were young *D. h. morroensis* and *D. h. arenae* born in captivity at California Polytechnic State University over the last 30 years. The total sample size consisted of 17 different individuals as follows: 5 *D. h. morroensis* (1 raised by Stewart (1958) and 4 raised by Roest in the U.S.F.W.S. Morro Bay kangaroo rat captive breeding facility) and 12 *D. h. arenae* (2 raised by Kozik (1977), 3 raised by Studley (1978), and 7 raised by Roest in the captive breeding facility). We assumed that the birth weights and growth rates of both subspecies were sufficiently similar up to 95 days of age to allow all 17 individuals to be pooled for purposes of statistical analysis. The successive weights and ages of all animals less than 95 days old served as the raw data for linear regression analysis using statistical programs available in BIOSTAT I (Pimentel and Smith 1986a). Linear regression analyses of 180 values for body weight (Y) versus 55 values for age (X) were performed on (a) untransformed variables, (b) one or the other variable transformed to $\log_{10}$, and (c) both variables transformed to $\log_{10}$. The best fit between the two variables (correlation coefficient = .8607, coefficient of determination = .7408) was obtained when weight was left untransformed and age was transformed to $\log_{10}$ (Fig. 3–1). The regression equation for this relationship was $Y = -36.7299 + 50.5566(X)$; where Y = weight, X = $\log_{10}$ of age, slope = 50.5566, and the Y intercept = −36.7299. The 95 % slope confidence limits were 45.0252 and 56.0880. The analysis of variance results for this regression analysis are presented in Table 3–1.

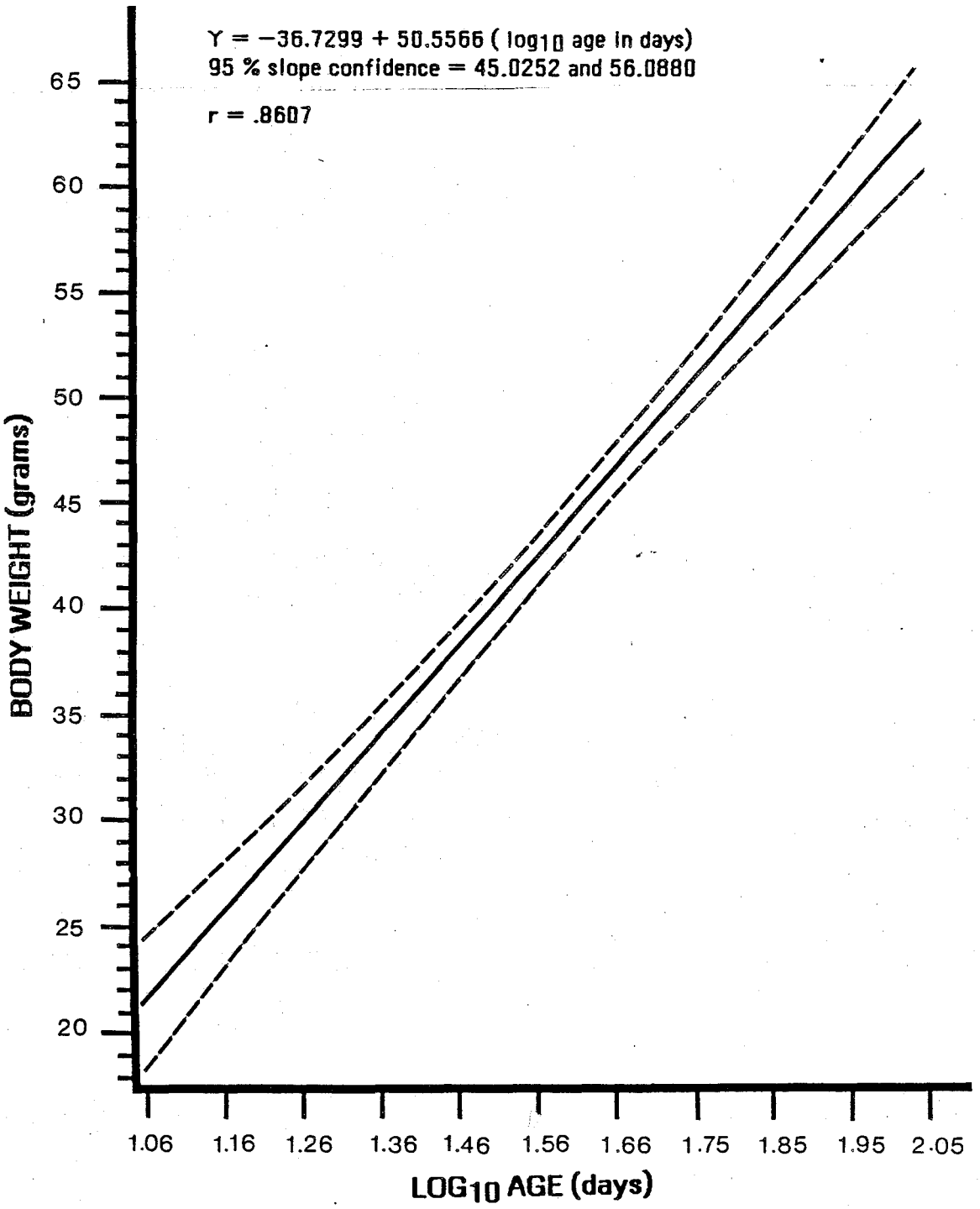


Figure 3−1. Linear regression (solid line) and 95 % confidence limits (dashed lines) of body weight (g) on $\log_{10}$ of age (days) of 5 *D. h. morroensis* and 12 *D. h. arenae*, all under 95 days of age, which were raised under laboratory conditions. The estimated age of an animal based upon its body weight is = $10^{\text{body weight} + 36.7299 / 50.5566}$.

Although the regression analysis enabled us to predict the age of young, wild-caught Morro Bay kangaroo rats, the validity of these predictions rests on at least two assumptions: (1) no difference in birth weights and general growth rates between *D. h. morroensis* and *D. h. arenae* and (2) no differences in growth rates between captive animals and animals living in the field.

Table 3–1. Analysis of variance table on the linear regression of body weight (Y) versus $\log_{10}$ of age (X).

SOURCE	SS	%	DF	MS	F–RATIO	PROB.
Groups	19219.413	87.55	54	355.915	16.282	.0000
Linear	16542.370	86.07	1	16542.370	327.502	.0000
Dev.	2677.066	13.93	53	50.511	2.311	.0001
Error	2732.424	12.45	125	21.859		
Total	21951.860		179			

By rearranging the regression equation and converting the log values for weight to an exponential expression, the following formula was developed to facilitate estimating age based on body weight:

$$\text{AGE (days)} = 10^{(\text{weight} + \text{Y intercept}) / \text{slope}}$$

As an example, the estimated age of an animal weighing 32 grams would be:

$$\text{AGE} = 10^{(32 + 36.7299) / 50.5566} = 10^{1.359446} = 23 \text{ days}$$

MULTIVARIATE ANALYSIS OF THE SIMILARITIES AND DIFFERENCES AMONG STUDY PLOTS BASED UPON SMALL MAMMAL ABUNDANCE

Small mammal populations on the study plots were expected to vary as a function of the species present, the year, the habitat type, and whether or not the plot had been modified by fire or clearing. Obviously a number of variables could influence the degree of similarity or difference between one small mammal community on one plot one year when compared to the same or different small mammal communities on different years. The rationale used here was to use the small mammals themselves to assess similarities and differences among the different plots over 4 years. This enables us to evaluate the variation in one plot over time as well as differences and similarities among: control plots which did not support Morro Bay kangaroo rats, control plots which did support Morro Bay kangaroo rats, experimental plots which had been cleared, and experimental plots which had been burned.

The relative abundances (# / 100 TN) of small mammals caught, tagged, and released on the various plots during the course of the study comprised the raw data used in these analyses. Implicit in this analysis is the assumption that all plots that could have been occupied were occupied during the study. The resulting plot years (one year of sampling data from one plot) were treated as individuals (rows) and the small mammal species were treated as variables (columns). The variables then were standardized to z scores because of broad differences in both the regularity of captures and the range of densities found for several of the species. Data transformation and all statistical analysis were accomplished using computer programs available in BIOSTAT II (Pimentel and Smith 1986). The 4 multivariate analyses used were as follows: (1) Principal Coordinate Analysis (PCORD) using an association matrix formed from Gower's general similarity coefficients and Q mode analysis, (2) Nonmetric Multidimensional Scaling (MDS) using the same association matrix as used in PCORD and an Euclidian distance matrix calculated from input trial vectors, (3) Principal Component Analysis (PCA) using all plot years as a single group so that the results of PCA could be compared to the first 2 methods, and (4) Cluster Analysis (CLUST) using a dissimilarity index formed from Gower's general similarity coefficients. The first 2 of these analytical methods are ordination procedures which, using multidimensional mathematical solutions, produce successive, two dimensional graphs that show the degree of association among all of the plot years (points) according to which pair of axes are selected. The axes of the graphs represent the various dimensions (up to 4) of the multidimensional dissimilarity space. The axes (dimensions) are ranked such that the first axis accounts for the greatest degree of dissimilarity and subsequent axes account for progressively less dissimilarity among the plot years. Only the first 2 axes will be shown here because they usually account for the majority of the dissimilarity among the "individuals" being compared. The third method (single group PCA) uses eigenvalues and eigenvectors that are extracted from a variable by variable, variance-covariance (dispersion) matrix to construct multidimensional principal component axes which are linear combinations of variables. Each axis is orthogonal to the others and thus each axis shows an independent pattern of variation. The principal component axes are ranked such that the first axis accounts for the greatest degree of variation and subsequent axes account for progressively less variation among the plot years. The degree and direction of participation of each variable on each principal component axis is given in the analysis so that the overall pattern of relationships among plot years can be interpreted in terms of the variables (species) used in the analysis. Unless substantial discrepancies appear among the results of PCA, PCORD, and MDS analyses, only the PCA results will be shown because, unlike the other 2 methods, PCA permits an examination of the importance of each species in determining the overall pattern of relationships among the various plot years. The fourth method is an agglomerative, hierarchical, cluster analysis procedure which is used to produce a dendrogram (a one-dimensional summary of relationships among the plot years). The linking procedure used to forming the dendrograms was the group average method (UPGMA). The relative goodness of fit of the dendrogram to the original dissimilarities is indicated by an overall cophenetic correlation correlation coefficient. Although cluster dendograms often misrepresent complex relationships, the results of cluster analysis will be included along with the PCA results because the dendogram provides a simplified overview of the relationships. Further elaboration of these multivariate statistical methods can be found in Manly (1986).

RESULTS AND DISCUSSION

RECENT TRENDS IN THE DISTRIBUTION OF MORRO BAY KANGAROO RATS

Prior to our investigations, Morro Bay kangaroo rats were thought to occur on about 127 ha of habitat (Toyoshima 1983); including portions of the Pecho, Bayview, Junior High / Santa Ysabel, and Buckskin sites (Figure 1—2). After several years of trapping at the Pecho and Bayview sites and ground reconnaissance over other portions of their range, Gambs (1986a) estimated that by 1985, the occupied habitat of Morro Bay kangaroo rats had dwindled to about 20 ha (Figure 3—2). The majority of the population was centered at the Bayview site with only a few animals present at the Junior High East and Buckskin sites in 1984. By 1985, those at the Junior High East site apparently disappeared as a result of habitat disturbance and one individual was caught at the Buckskin site and transported to the captive breeding facility. At the close of 1985, over 95% of the Morro Bay kangaroo rat population resided at the Bayview site.

Results of an intensive study of the distribution of Morro Bay kangaroo rats, completed in the fall of 1985 (Villablanca 1986), suggest that the total occupied habitat was about 13.3 ha. Villablanca found Morro Bay kangaroo rats occupying 10.0 ha at the Bayview East site, 2.6 ha at the Bayview West site, and 0.7 ha at the Buckskin site. The likelihood that any animals still occur at the Buckskin and Junior High East sites is quite remote because no signs were found there in 1986. It is possible that there are scattered individuals still living in the vicinity of the Buckskin and/or Junior High sites; however, the numbers of any such individuals are probably so low that they are unable to consistently reproduce at rates which would insure their replacement. At the present time, it appears that both the Buckskin and Junior High sub-populations of Morro Bay kangaroo rats are either extinct or rapidly approaching extinction. Thus, the best estimate of the area occupied by Morro Bay kangaroo rats in 1986 is about 12 — 15 ha at the Bayview site (Fig. 3—3). The Bayview population appears to be moderately viable in the sense that immature animals were caught during all three years of our study.

DISTRIBUTION OF EXISTING SUITABLE HABITAT FOR MORRO BAY KANGAROO RATS

Residential, agricultural, commercial, and recreational developments in the Los Osos and Baywood Park areas have all been significant factors which have restricted and fragmented Morro Bay kangaroo rat habitat over the years. Gradual change of plant cover on undeveloped habitat has further reduced the amount of usable habitat for those populations of Morro Bay kangaroo rats still in existence. In 1984 and 1985, Villablanca (1986 and 1987) conducted a habitat suitability survey of all remaining habitat within the historic range of the Morro Bay kangaroo rat. The results of this habitat study (Villablanca 1987) have been summarized and projected to 1986 for purposes of the present report.

The only remaining habitat which is either occupied or appears to be suitable for Morro Bay kangaroo rats is dispersed over 16 small patches, covering a total area of 47.7 ha (Fig. 3—4). Three of these sites (Bayview West, Bayview East, and Buckskin) were occupied by Morro Bay kangaroo rats in 1985 (Table 3—2); however, only the 2 Bayview sites were known to be occupied in 1986. In addition to the 12.6 ha of occupied habitat at the 2 Bayview sites, there were 18.7 ha of suitable habitat at Bayview which were not occupied by Morro Bay kangaroo rats in 1986. The other 14 (unoccupied) sites which had suitable habitat encompass a total area of 16.4 ha (this includes the site at Buckskin

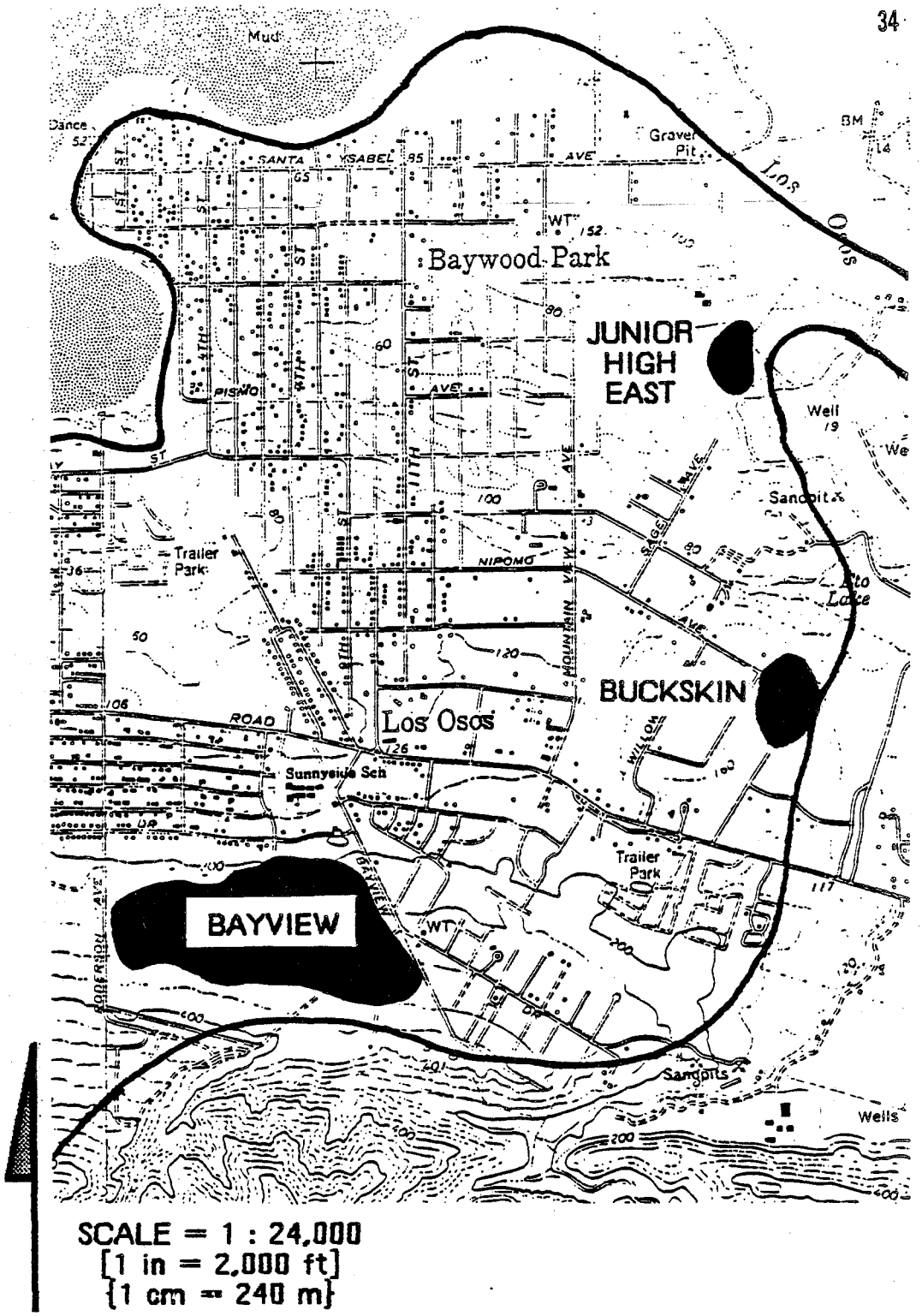


Figure 3–2. Approximate distribution of Morro Bay kangaroo rats *(Dipodomys heermanni morroensis)* in 1984 and 85. The solid outer line follows the extreme limits of the range as described by Stewart and Roest (1960). The shaded areas (modified from Gambs 1986a and Villablanca 1986) represent those portions of the range which were known to be occupied by Morro Bay kangaroo rats in 1984 and / or 1985. A small group of animals occupying the most northern locality (Junior High East) was present in 1984, but no evidence of their presence could be found in 1985 (Roest personal communication).

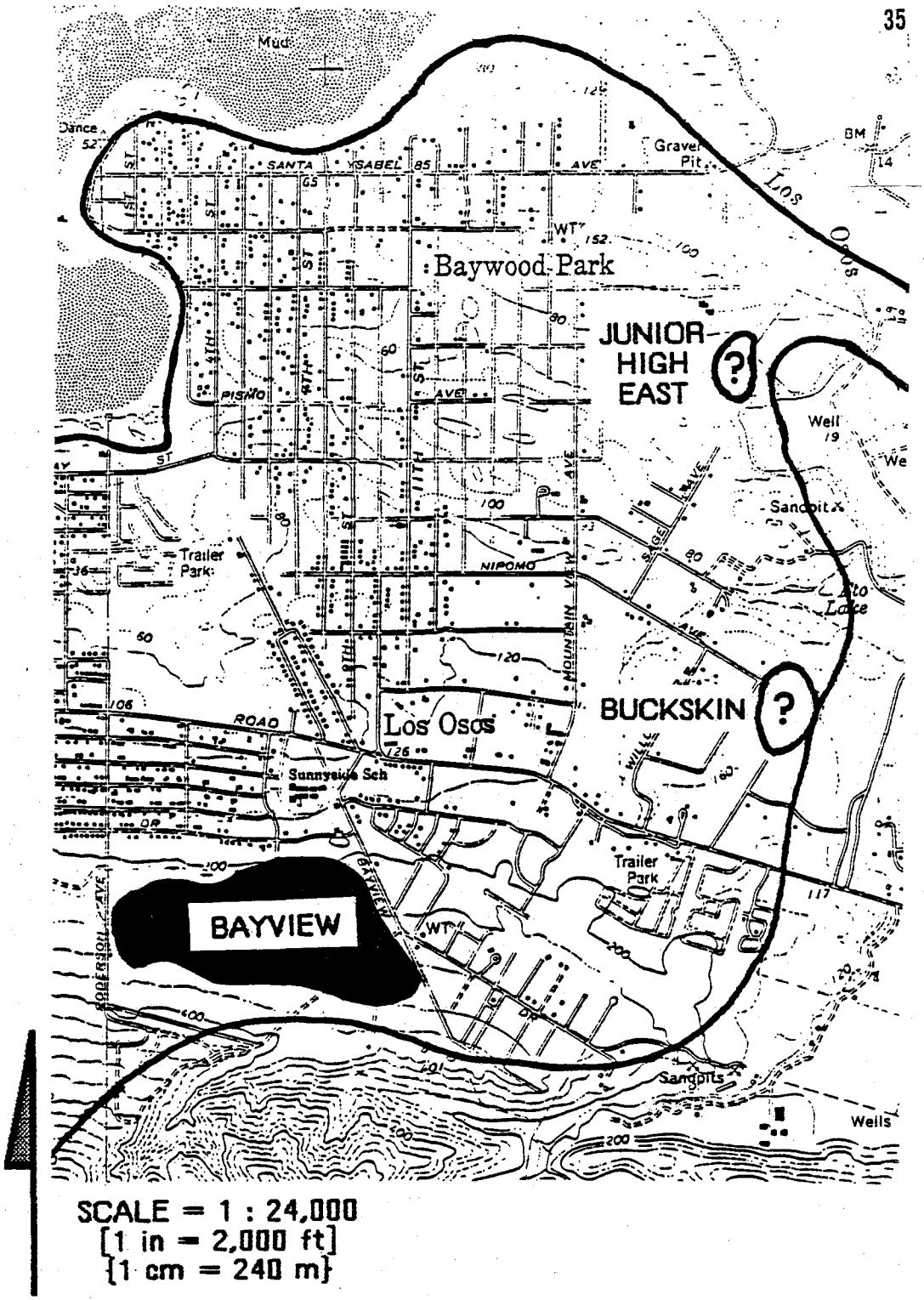


Figure 3—3. Approximate distribution of Morro Bay kangaroo rats *(Dipodomys heermanni morroensis)* in 1986. The solid outer line follows the extreme limits of the range as described by Stewart and Roest (1960). The shaded areas (modified from Gambs 1986a and Villablanca 1987) represent those portions of the range which were known to be occupied by Morro Bay kangaroo rats in 1986. The small groups of animals which occupied the 2 most northern localities (Junior High East and Buckskin) in 1984 and 1985 appeared to be absent or at extremely low levels in 1986. At the present time, the only population which appears to be viable is the one at the Bayview site.

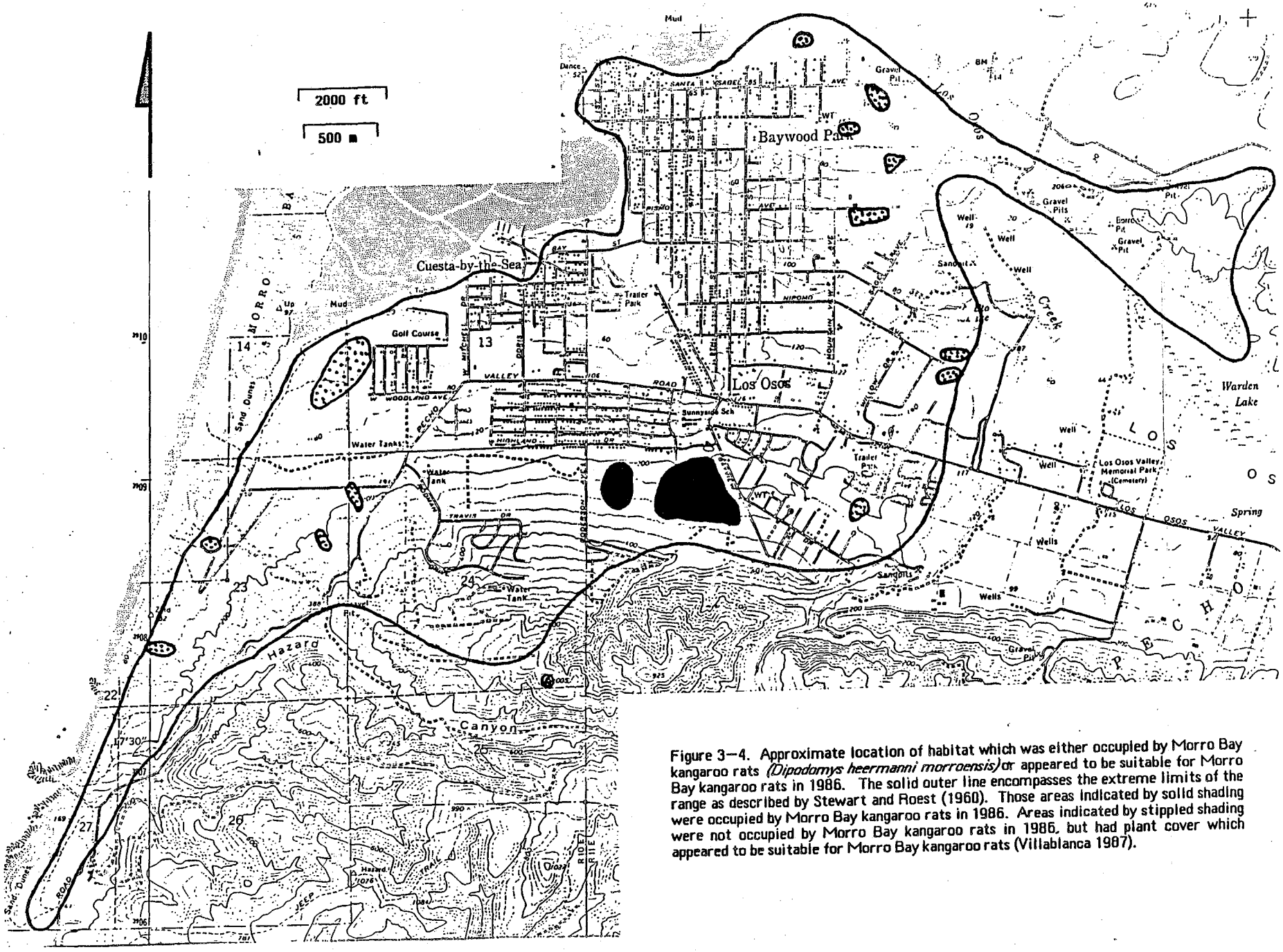


Figure 3—4. Approximate location of habitat which was either occupied by Morro Bay kangaroo rats *(Dipodomys heermanni morroensis)* or appeared to be suitable for Morro Bay kangaroo rats in 1986. The solid outer line encompasses the extreme limits of the range as described by Stewart and Roest (1960). Those areas indicated by solid shading were occupied by Morro Bay kangaroo rats in 1986. Areas indicated by stippled shading were not occupied by Morro Bay kangaroo rats in 1986, but had plant cover which appeared to be suitable for Morro Bay kangaroo rats (Villablanca 1987).

which was occupied in 1985 but showed no signs of occupancy in 1986). Not only does the Bayview site support the only viable population of wild Morro Bay kangaroo rats, but there is also more suitable habitat there than at any other site within their historic range. Every effort should be made to insure the continued existence of these animals and their habitat at the Bayview site.

TABLE 3–2. SUMMARY OF AREAS THAT WHERE KNOWN TO BE OCCUPIED BY MORRO BAY KANGAROO RATS IN 1985 AND AREAS WHICH SHOWED NO SIGNS OF USE BY MORRO BAY KANGAROO RATS IN 1985, BUT HAD PLANT COVER WHICH APPEARED TO BE SUITABLE FOR MORRO BAY KANGAROO RATS (modified from Villablanca 1987).

NAME OF GENERAL AREA	NAME OF SPECIFIC LOCALITY	AREA OF OCCUPIED HABITAT (ha)	AREA OF SUITABLE, (UNOCCUPIED) HABITAT (ha)
SANTA YSABEL/ JUNIOR HIGH	Bayside	0	1.7
	Santa Ysabel	0	1.4
	Junior High North	0	0.6
	Junior High East	0	0.9
	Junior High West	0	0.4
	Junior High South	0	1.0
BUCKSKIN	Buckskin	0.7	1.2
GLEN	Glen	0	0.8
BAYVIEW	Bayview East	10.0	12.7
	Old Burn	0	0.2
	Bayview West	2.6	6.0
PECHO	Pecho North	0	0.9
	Pecho South	0	6.6
TOTAL		13.3	34.4

The size and distribution of potentially suitable habitat (habitat which could be made suitable with appropriate modification) includes nearly any land lacking permanent structures within the historic range of the Morro Bay kangaroo rat which has suitable soil and an average slope of 15 % or less. Refer to the habitat descriptions, map, and discussion in the Botanical Study for further details on the plant communities in the historical range of the Morro Bay kangaroo rat.

RELATIVE ABUNDANCE, POPULATION ESTIMATES, AND DENSITY OF MORRO BAY KANGAROO RATS AT THE BAYVIEW SITE

Raw data and computations used to make monthly estimates of relative abundance, population size, and density of Morro Bay kangaroo rats at the Bayview site from 1984 to 1986 have been provided to the U.S.F.W.S in several different reports (Gambs 1986a and 1986g, and Villablanca 1986 and 1987). The emphasis here will be to summarize and evaluate the annual estimates over the past 3 years and attempt to arrive at an overall estimate of total numbers of Morro Bay kangaroo rats in existence during each field season.

The annual summaries (below) include all data collected from 3 different study plots (NOP, QRS, and KKLLMM) and 8 different traplines 1S, 1T, 1U, 1V, 1W, 1X, 1Y, and 1Z) that were monitored for one or more field seasons at the Bayview site. Except for a minor difference in methods used to report population estimates, all methodologies used to describe data collected from study plots are completely comparable to those used to describe data collected from traplines. Population estimates derived from study plots are reported as the number of animals present in each plot, whereas population estimates derived from traplines are reported as the number of animals present in the area of occupied habitat. Although population estimates derived from trapline data are inflated when compared to those derived from plot data, this doesn't create a serious problem because density estimates from both sources of data could be standardized to the number of animals per ha.

<u>1984</u> Although signs of Morro bay kangaroo rats were seen at both plots NOP and QRS prior to trapping in 1984, plot QRS turned out to support the vast majority of animals caught that year (Table 3—3). Relative abundance of Morro Bay kangaroo rats ranged from 0 to 1.7 animals / 100 TN on plot NOP and 0 to 8.3 animals / 100 TN on plot QRS. The annual average relative abundance of animals on both plots was 1.8 animals / 100 TN. Density estimates were 0 animals / ha throughout the year on plot NOP and ranged from 0 to 6.0 animals / ha on plot QRS. Like relative abundance, the annual average density of Morro Bay kangaroo rats was quite low (0.7 ± 0.4 animals / ha). The low values for relative abundance and density in 1984 can be partly attributed to at least 3 factors: extremely low capture rates at plot NOP throughout the season, extremely low capture rates during the last 5 months of trapping on plot QRS, and relocation of 3 animals from plot QRS to the captive breeding facility. Low capture rates could be indicative of few animals, very little above-ground activity, or avoidance of traps. Although the removal of 3 animals from plot QRS obviously depleted their numbers on the plot, we found no evidence of new animals moving in to replace them later in the season. If there had been a substantial number of rats at the Bayview site in 1984, then those that were removed should have been replaced by new animals later in the year. The apparent lack of replacement of translocated animals coupled with low capture rates and low estimates for both relative abundance and density suggest to us that there were few rats inhabiting the Bayview site in 1984. Allowing for some degree of error associated with the removal of animals and the inclusion of repetitive zeros in the averages, we conclude that **the density of Morro Bay kangaroo rats over the occupied range at Bayview was no more than 1.5 animals / ha in 1984.**

The total area of occupied habitat in 1984 was no more that 14.2 ha (12.6 ha at Bayview, 0.7 ha at Buckskin, and 0.9 ha at Junior High East). By applying the estimated density of 1.5 Morro Bay kangaroo rats / ha derived from the Bayview site to the other areas, **we obtained an overall estimate of 21 Morro Bay kangaroo rats in existence in 1984.** Intuitively, a total estimate of 21 animals seems low, but even if we used the highest monthly density estimate for 1984 (6.0 rats / ha) we would only estimate the total population to be 85 which is undoubtedly too high.

Table 3—3. Summary of Morro Bay kangaroo rat trapping data collected from two study plots at the Bayview site in 1984. Trapping intensity is shown as # Trap Nights (1 TN = 1 trap set for 1 night). The number caught each day (# of Cap.) includes new captures and recaptures. Ease of capture (Average # TN / Cap.) indicates the number of trap nights required to catch one animal. Relative abundance (Avg. # Cap. / 100 TN) provides a means of comparing the relative numbers present when conventional population estimates could not be computed. When possible, population estimates were computed for each day using the Schnabel technique and then averaged for each month (Average Pop. Est.). Densities (# / ha) were computed by dividing the average population estimate by the area trapped.

PLOT OR TRAPLINES	DATES OF TRAPPING	# TRAP NIGHTS	# OF CAP.	AVERAGE #TN/CAP.	AVG.# CAP. /100 TN	AVERAGE POP.EST.	DENSITY (#/ha)	REFERENCE
NOP	23-24/MAR/84	60	1	60.0	1.7	0.0	0.0	Gambs 1986a
"	27-28/APR/84	60	1	60.0	1.7	0.0	0.0	"
"	25-26/MAY/84	59	0	0.0	0.0	0.0	0.0	"
"	19-21/JUN/84	87	0	0.0	0.0	0.0	0.0	"
"	10-13/JUL/84	112	0	0.0	0.0	0.0	0.0	"
"	02-03/AUG/84	56	0	0.0	0.0	0.0	0.0	"
"	04-05/SEP/84	57	0	0.0	0.0	0.0	0.0	"
"	17-18/OCT/84	56	0	0.0	0.0	0.0	0.0	"
QRS	23-24/MAR/84	59	3	19.7	5.1	2.0	2.1	Gambs 1986a
"	27-28/APR/84	60	5	12.0	8.3	3.0	3.2	"
"	25-26/MAY/84	60	5	12.0	8.3	6.0	6.4	"
"	19-21/JUN/84	89	1	89.0	1.1	0.0	0.0	"
"	10-13/JUL/84	118	1	118.0	.8	0.0	0.0	"
"	02-03/AUG/84	59	1	59.0	1.7	0.0	0.0	"
"	04-05/SEP/84	60	0	0.0	0.0	0.0	0.0	"
"	17-18/OCT/84	57	0	0.0	0.0	0.0	0.0	"
Σ		1109	18	429.7	28.7	11	11.7	
N		16	16	16	16	16	16	
AVERAGE		**69.3**	**1.1**	**26.9**	**1.8**	**.7**	**.7**	
STD.ERROR		5.1	.4	9.5	.7	.4	.4	

1985 One new study plot and 8 new traplines were established at the Bayview site in 1985. (Table 3–4). Not only did the lone animal caught on plot NOP in 1984 fail to reappear there in 1985, but no other animals were caught on plot NOP in 1985. The cause of this localized "extinction" remains unknown because there were fair numbers of animals in neighboring plots and traplines (Table 3–4) and the habitat on the plot appeared about the same both years.

Relative abundance of Morro Bay kangaroo rats was 13.3 animals / 100 TN on plot KKLLMM, ranged from 3.4 to 7.9 animals / 100 TN on plot QRS and ranged from 1.5 to 14.8 animals / 100 TN on the 8 traplines. The annual average relative abundance of animals on all plots and traplines in 1985 (5.1 animals / 100 TN) was well over twice that found in 1984. Density was 4.9 animals / ha on plot KKLLMM, ranged from 0 to 4.7 animals / ha on plot QRS, and ranged from 0 to 5.8 animals / ha on the 8 traplines. The annual average density of Morro Bay kangaroo rats at the Bayview site in 1985 (2.1 ± 0.4 animals / ha) was 3 times higher than it was in 1984. The values for average annual relative abundance and density are probably slightly low, because 3 animals from plot QRS and 1 animal from line 1W were translocated to the captive breeding facility in 1985. In contrast to what we found in 1984, at least some of the animals that were removed in 1985 were replaced by new animals later in the season. The replacement of some translocated animals coupled with higher estimates for both relative abundance and density suggest to us that there were substantially more rats inhabiting the Bayview site in 1985 than in 1984. Allowing for some degree of error associated with the removal of animals and the inclusion of repetitive zeros in the averages, we conclude that **the density of Morro Bay kangaroo rats over the occupied range at Bayview was no more than 3.8 animals / ha in 1985.**

The total area of occupied habitat in 1985 was no more that 13.3 ha (12.6 ha at Bayview and 0.7 ha at Buckskin). By applying the estimated density of 3.8 Morro Bay kangaroo rats / ha derived from the Bayview site to the Buckskin and Bayview areas, **we obtained an overall estimate of 51 Morro Bay kangaroo rats in existence in 1985.** If we used the highest monthly density estimate for 1985 (5.8 rats / ha) we would undoubtedly overestimate the total population at 77 animals because some areas (eg. plot NOP) supported no animals and other areas (eg. Buckskin) obviously had far fewer than 5 animals / ha.

Table 3—4. Summary of Morro Bay kangaroo rat trapping data collected from three study plots and 8 traplines at the Bayview site in 1985. Trapping intensity is shown as # Trap Nights (1 TN = 1 trap set for 1 night). The number caught each day (# of Cap.) includes new captures and recaptures. Ease of capture (Average # TN / Cap.) indicates the number of trap nights required to catch one animal. Relative abundance (Avg. # Cap. / 100 TN) provides a means of comparing the relative numbers present when conventional population estimates could not be computed. When possible, population estimates were computed for each day using the Schnabel technique and then averaged for each month (Average Pop. Est.). Population estimates for the 3 plots were based on the number / area trapped, whereas population estimates for the 8 traplines were based on the number / area of occupied habitat. Densities (# / ha) were computed by dividing the average population estimate by the area trapped.

PLOT OR TRAPLINES	DATES OF TRAPPING	# TRAP NIGHTS	# OF CAP.	AVERAGE #TN/CAP.	AVG.# CAP /100 TN	AVERAGE POP.EST.	DENSITY (#/ha)	REFERENCE
NOP	04-06/APR/85	85	0	0.0	0.0	0.0	0.0	Gambs 1986a
"	24-26/APR/85	88	0	0.0	0.0	0.0	0.0	"
"	05-06/JUN/85	49	0	0.0	0.0	0.0	0.0	"
QRS	04-06/APR/85	88	3	29.3	3.4	0.0	0.0	Gambs 1986a
"	24-26/APR/85	87	5	17.4	5.7	2.0	2.1	"
"	05-07/JUN/85	89	7	12.7	7.9	4.4	4.7	"
KKLLMM	20-22/AUG/85	158	21	7.5	13.3	8.3	4.9	Gambs 1986a
1S,1T,1U,1V	05-07/JUN/85	198	3	66.0	1.5	0.0	0.0	Villablanca 1987
"	01-18/JUL/85	396	7	56.6	1.8	7.0	.7	"
1W,1X,1Y,1Z	05-13/JUN/85	186	15	12.4	8.1	12.0	4.6	Villablanca 1987
"	01-18/JUL/85	216	32	6.7	14.8	15.0	5.8	"
Σ		1640	93	208.6	56.5	46.7	22.8	
N		11	11	11	11	11	11	
AVERAGE		**149.1**	**8.5**	**19.0**	**5.1**	**4.4**	**2.1**	
STD. ERROR		29.9	3.1	6.9	1.6	1.6	.7	

<u>1986</u> In 1986, Morro Bay kangaroo rat populations at the Bayview site were monitored on the same 3 study plots used in 1985, but not on the 8 traplines which were monitored in 1985. After watching the number of rats dwindle to 0 on plot NOP during the 1984 field season and then finding none at all in 1985, we were prepared to declare plot NOP unoccupied at the start of the 1986 field season. Much to our surprise, Morro Bay kangaroo rats reappeared on plot NOP sometime between mid-June of 1985 and late March of 1986. Apparently there had been a sufficient increase in rats at the Bayview site in 1985 to promote localized dispersal which resulted in occupancy of the previously unoccupied plot. Thus, in contrast to previous years, all 3 plots at Bayview supported moderate numbers of Morro Bay kangaroo rats throughout the 1986 field season.

Relative abundance of Morro Bay kangaroo rats at the Bayview site in 1986 ranged from 3.6 to 11.4 animals / 100 TN on plot NOP, from 11.5 to 14.3 animals / 100 TN on plot QRS, and from 13.2 to 15.4 animals / 100 TN on plot KKLLMM. The annual average relative abundance of animals on all plots in 1986 (11.5 animals / 100 TN) was over twice that found in 1985 and over six times greater than that found in 1984. Density ranged from 2.1 to 10.0 animals / ha on plot NOP, from 4.7 to 5.3 animals / ha on plot QRS, and from 0.6 to 3.0 animals / ha on plot KKLLMM. The annual average density of Morro Bay kangaroo rats at the Bayview site in 1986 (4.0 ± 0.9 animals / ha) was nearly twice that found in 1985 and over five times greater than that found in 1984. Since only one animal from plot KKLLMM was translocated to the captive breeding facility in 1986, the values for average annual relative abundance and density probably were not significantly influenced by this procedure. The higher estimates for both relative abundance and density suggest to us that there were even more rats inhabiting the Bayview site in 1986 than there were in 1985. We conclude that **the average density of Morro Bay kangaroo rats over the occupied range at Bayview was no more than 4.0 animals / ha in 1985** (minor depletion by translocation and lack of zeros in the averages convinced us not to add 2 standard errors to the overall density estimate for 1986).

The total area of occupied habitat in 1986 was probably no more than just the 12.6 ha at the Bayview site. By assuming an average density of 4.0 Morro Bay kangaroo rats / ha over the area of occupied habitat at Bayview, **we obtained an overall estimate of 50 Morro Bay kangaroo rats in existence in 1986.** If we used the highest monthly density estimate for 1986 (10.0 rats / ha) we would undoubtedly overestimate the total population at 126 animals because that estimate was almost twice as high as the next highest density estimate.

The average total population estimates for Morro Bay kangaroo rats presented in this report (21 in 1984, 51 in 1985, and 50 in 1986) are slightly lower than the estimate of 80 animals by Gambs (1986a) and the estimate of 50 to 150 animals by Villablanca (1987). We believe that our present estimates come closer to approximating both the patchy distribution of the animals over the occupied habitat and the irregular fluctuations in density which occur among the different patches as well as within the same patch over time.

Table 3—5. Summary of Morro Bay kangaroo rat trapping data collected from three study plots at the Bayview site in 1986. Trapping intensity is shown as # Trap Nights (1 TN = 1 trap set for 1 night). The number caught each day (# of Cap.) includes new captures and recaptures. Ease of capture (Average # TN / Cap.) indicates the number of trap nights required to catch one animal. Relative abundance (Avg. # Cap. / 100 TN) provides a means of comparing the relative numbers present when conventional population estimates could not be computed. When possible, population estimates were computed for each day using the Schnabel technique and then averaged for each month (Average Pop. Est.). Densities (# / ha) were computed by dividing the average population estimate by the area trapped.

PLOT OR TRAPLINES	DATES OF TRAPPING	# TRAP NIGHTS	# OF CAP.	AVERAGE #TN/CAP.	AVG.# CAP /100 TN	AVERAGE POP.EST.	DENSITY (#/ha)	REFERENCE
NOP	01-03/APR/86	86	3	28.7	3.6	2.0	2.1	Gambs 1986g
"	23-25/APR/86	86	6	14.3	7.0	2.0	2.1	"
"	13-15/MAY/86	88	10	8.8	11.4	9.3	10.0	"
QRS	01-03/APR/86	87	10	8.7	11.5	4.4	4.7	Gambs 1986g
"	23-25/APR/86	89	12	7.4	13.5	4.7	5.0	"
"	13-15/MAY/86	84	12	7.0	14.3	5.0	5.3	"
KKLLMM	01-03/APR/86	158	22	7.2	13.9	1.0	.6	Gambs 1986g
"	23-25/APR/86	151	20	7.5	13.2	4.7	2.8	"
"	20-22/MAY/86	156	24	6.5	15.4	5.0	3.0	"
Σ		985	119	96.1	103.8	38.1	35.66	
N		9	9	9	9	9	9	
AVERAGE		**109.4**	**13.2**	**10.7**	**11.5**	**4.2**	**4.0**	
STD. ERROR		11.4	2.4	2.4	1.3	.8	.9	

HOME RANGE ESTIMATES OF MORRO BAY KANGAROO RATS

Previous studies of Morro Bay kangaroo rats (Stewart 1958, Roest 1973 and 1982b) indicated that their home ranges were quite small (0.03 to 0.07 ha) and that their home ranges did not appear to overlap. However, these earlier estimates were made at a time when rat densities were much higher than they are now (eg. Stewart obtained an adjusted density estimate of 141.6 rats / ha on one quadrat at the Bayview site in 1957).

In addition to finding lower densities now, recent field work also suggests that the average home range size of Morro Bay kangaroo rats has steadily increased since the time of the first studies. Villablanca (1987) estimated that the home ranges of animals captured on traplines at the Bayview site varied from 0.19 to 0.28 ha. In contrast to earlier investigators, Villablanca found strong evidence that Morro Bay kangaroo rat home ranges overlapped considerably in both time and space. He found that 23 % of all capture occasions involved simultaneous captures of 2 different animals at the same trap station. Furthermore, 68 % of the 27 animals he studied were caught at stations where at least one other animal had been caught previously during his 3 month study.

The present report considers home range data collected from 40 animals (26 females and 14 males) caught at the 3 Bayview plots in 1984, 1985, and / or 1986. Of these 40 animals; 6 were trapped only in 1984, 9 were trapped only in 1985, 9 were trapped in both 1985 and 1986, 15 were trapped only in 1986, and 1 was trapped in both 1984 and 1986. In order to avoid inflated home range estimates as a result of dispersal that might occur between years, those that were caught on 2 different years were treated as different replicates of the same individuals for purposes of home range analysis (Table 3–6).

Since home range area might be expected to increase with increasing numbers of captures, the average home range areas of animals caught 1 through 9 times were analyzed before attempting further numerical analysis. Figure 3–5 reveals a sharp difference in home range areas of animals captured 1–3 times compared to those captured 4–9 times. The difference between the mean home range of animals caught less than 4 times (906.2 m^2) was significantly different ($t = -9.027$, $df=46$, $p \leq .0005$) from the mean home range of animals caught 4 or more times (2326.4 m^2). In view of the very low estimates from animals caught less than 4 times, we decided to use only those home ranges from the 18 Morro Bay kangaroo rats caught 4 or more times in subsequent analyses (Table 3–7). The average home range area of the 11 adult females in this subset (2329.4 ± 199.3 m^2) was not significantly different from the average home range area of the 7 adult males (2321.4 ±224.7 m^2). We conclude that the average home range size of Morro Bay kangaroo rats at the Bayview site was .23 ha (95% confidence interval = .20 – .26 ha) during the period of our study. Our estimated home range area agrees very well with Villablanca's (1987) independent estimate and further confirms that an average Morro bay kangaroo rat today requires from .2 to .3 ha (= 1/2 – 3/4 acre ≈ 22,000 to 32,000 ft^2) of habitat rather than .05 ha (≈ 1/8 acre = 5,000 ft^2) as was the case 30 years ago.

Table 3–6. Exclusive boundary strip home range areas of all individuals captured on the 3 study plots at the Bayview site from 1984 to 1986. Ages are: A = adult, SA = subadult, and J = juvenile.

YEAR	PLOT	TAG #	SEX (AGE)	# OF CAP'S.	HOME RANGE AREA(m2)
1984	NOP	1023	F(A)	2	2500.0
1984	QRS	0501	F(A)	5	2187.5
1984	QRS	1123	F(A)	6	2812.5
1984	QRS	1128	F(A)	2	625.0
1984	QRS	1170	F(J)	1	625.0
1984	QRS	1319	F(SA)	1	625.0
1985	KKLLMM	1417	M(A)	2	1250.0
1985	KKLLMM	1463	F(SA)	2	1250.0
1985	KKLLMM	1468	M(A)	3	1250.0
1985	KKLLMM	1582	M(A)	3	1250.0
1985	KKLLMM	1690	F(A)	1	625.0
1985	KKLLMM	1691	F(A)	3	1250.0
1985	KKLLMM	1695	F(A)	3	625.0
1985	KKLLMM	1697	F(A)	3	1250.0
1985	KKLLMM	1840	M(A)	1	625.0
1985	QRS	0115	F(A)	6	1875.0
1985	QRS	1412	F(SA)	1	625.0
1985	QRS	1415	F(SA)	1	625.0
1985	QRS	1450	F(SA)	2	1250.0
1985	QRS	1540	M(SA)	1	625.0
1985	QRS	1542	F(A)	1	625.0
1985	QRS	1552	F(SA)	2	1875.0
1985	QRS	1594	M(A)	1	625.0
1985	QRS	1595	F(SA)	1	625.0
1986	KKLLMM	1170	F(A)	1	625.0
1986	KKLLMM	1417	M(A)	4	3125.0
1986	KKLLMM	1468	M(A)	9	2500.0
1986	KKLLMM	1599	M(A)	2	1562.0
1986	KKLLMM	1690	F(A)	9	1875.0
1986	KKLLMM	1691	F(A)	9	1875.0
1986	KKLLMM	1695	F(A)	9	1250.0
1986	KKLLMM	1697	F(A)	9	2500.0
1986	KKLLMM	1840	M(A)	4	2500.0
1986	KKLLMM	1909	M(A)	6	1250.0
1986	KKLLMM	1945	M(J)	1	625.0
1986	KKLLMM	1946	M(J)	1	625.0
1986	KKLLMM	1948	M(J)	1	625.0
1986	KKLLMM	2173	F(A)	1	625.0
1986	NOP	1845	F(A)	7	2187.5
1986	NOP	1847	F(A)	8	2500.0
1986	NOP	1916	F(A)	3	625.0
1986	NOP	1929	M(A)	1	625.0
1986	QRS	1594	M(A)	7	2500.0
1986	QRS	1595	F(A)	1	625.0
1986	QRS	1841	M(A)	5	1875.0
1986	QRS	1842	F(A)	9	3750.0
1986	QRS	1843	M(A)	8	2500.0
1986	QRS	1864	F(A)	5	2812.5

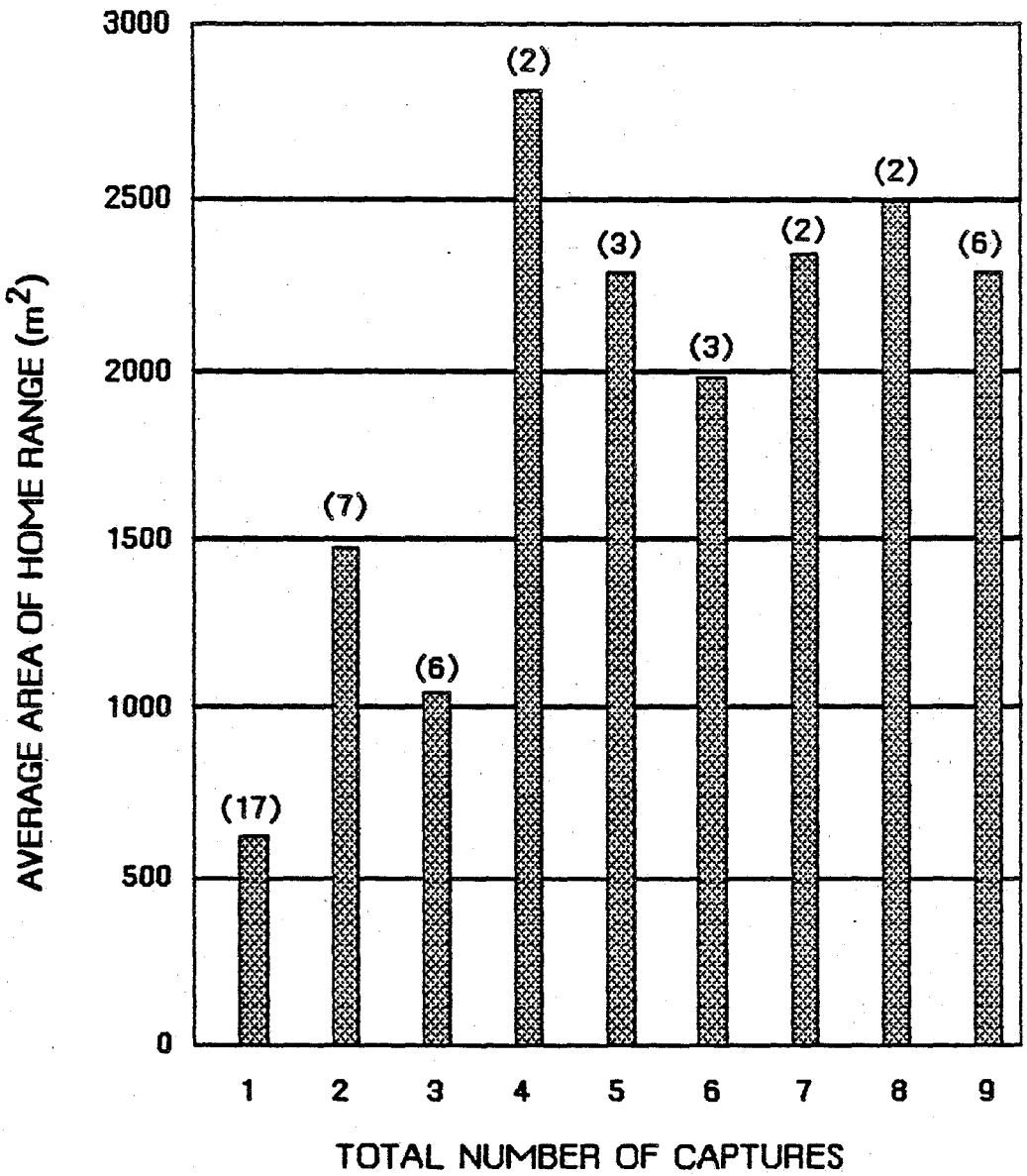


Figure 3—5. Average home range size of groups of Morro Bay kangaroo rats caught on 3 study plots at the Bayview site plotted against the number of times that animals in each group were captured during any one field season. The number of individuals comprising each group is shown in parentheses above each histogram bar. Thirty individuals (62.5 %) were caught less than 4 times and 18 individuals (37.5 %) were caught 4 or more times during the 3-year study.

It is possible that lower density conditions today permit a higher degree of home range overlap and thus larger home ranges than was typical 30 years ago, but we have no way of evaluating the extent of home range overlap among populations studied in the past. There is little doubt that, compared to past conditions, the larger home ranges and lower densities seen in Morro Bay kangaroo rats today are indicative of diminished, fragmented, and sub - optimal habitat conditions. Every effort should be made to rejuvenate existing habitat and create more suitable habitat as soon as possible.

Table 3–7. Exclusive boundary strip home ranges of 18 adult Morro Bay kangaroo rats which were caught 4 or more times per year on 3 study plots at the Bayview site. Home range area was determined according to the procedures outlined by Stickel (1954).

YEAR	PLOT	TAG #	SEX (AGE)	# OF CAP'S.	HOME RANGE AREA (m^2)
1985	QRS	0115	F(A)	6	1875.0
1984	QRS	0501	F(A)	5	2187.5
1984	QRS	1123	F(A)	6	2812.5
1986	KK–MM	1697	F(A)	9	2500.0
1986	KK–MM	1695	F(A)	9	1250.0
1986	KK–MM	1691	F(A)	9	1875.0
1986	KK–MM	1690	F(A)	9	1875.0
1986	NOP	1845	F(A)	7	2187.5
1986	NOP	1847	F(A)	8	2500.0
1986	QRS	1842	F(A)	9	3750.0
1986	QRS	1864	F(A)	5	2812.5
1986	KK–MM	1909	M(A)	6	1250.0
1986	KK–MM	1840	M(A)	4	2500.0
1986	KK–MM	1468	M(A)	9	2500.0
1986	KK–MM	1417	M(A)	4	3125.0
1986	QRS	1594	M(A)	7	2500.0
1986	QRS	1843	M(A)	8	2500.0
1986	QRS	1841	M(A)	5	1875.0
N					18.0
MEAN					2326.4
STD. ERROR					145.6

MOVEMENT PATTERNS OF MORRO BAY KANGAROO RATS

Previous investigators have indicated that adult Morro Bay kangaroo rats remain fairly close to their main burrows and only rarely move to different localities. Our results generally support these observations and provide additional data on certain details. Of the 10 animals that we were able to follow for 2 or more years, all but 1 remained on the same plot where they were initially caught. These observations suggest that once an animal takes up residency in an area, it is far more likely to remain there rather than move to a different locality. The most typical pattern of movement that we observed was one in which an animal would be caught at 2 to 6 trap stations all located within 25 to 50 m of each other. It appears that males may have slightly greater dispersal tendencies than females or subadults. In comparing the frequency distributions of distances moved between successive captures to an expected model based upon the overall proportion of captures at various distances from previous capture sites; Villablanca (pers. comm.) found that adult males (but not females or subadults) moved 25 m or >100 m from previous capture sites more frequently than expected, and they moved 0 m, 37 m, 50 m, 57 m, or 75 m from previous capture sites less frequently than expected. The one animal (female # 1170) that did change plots was caught twice as a juvenile on plot QRS on 25 and 26 May 1984. It was not seen again until 22 May 1986, when it was caught as an adult on plot KKLLMM. Animal # 1170 not only moved the greatest distance between capture localities (400 m) but it also had the longest documented longevity (728 days) of any animal caught during our study. The only other long-range movements were by male # 1840 (moved 160 m over 203 days) and female # 1465 (moved 250 m over 48 days.

Further information on movement patterns can be derived from home range data as well as the linear distance between successive capture sites. Assuming that Morro bay kangaroo rats have circular home ranges and that their main burrows are located at the centers of these areas, then the radius of a circle (with area = mean home range size) should approximate the average distance that animals would be expected to range out from their burrows. Applying these hypothetical relationships to the results obtained in the present study, we would predict that an average excursion away from the main burrow would require a Morro Bay kangaroo rat to cover a round-trip distance of at least 54.4 m [$= 2 \times \sqrt{(2326/\pi)}$]. The only field data which permit even a superficial evaluation of the predicted round-trip distance (above) are the average distances between successive captures obtained from the same 18 animals used to estimate home range size. Assuming that: (1) the home range of Morro Bay kangaroo rats is indeed circular, (2) each animal always returns to its home burrow after being released, and (3) the average distance between successive captures roughly approximates the average one-way distance traveled by an animal during its nightly excursions away from the main burrow, then the average distance between captures should approach 27.2 m (the radius of the circular home range hypothesized above). The 18 animals used for home range estimation had average distances between successive captures which ranged from 9.1 – 85.0 m. The mean (±standard error) of these average distances was 23.9 (± 4.0) m which was surprisingly close to the hypothesized radius of 27.2 m. Obviously, there are alternate interpretations of these proposed relationships, but the experimental design used in this study did not permit us to evaluate these alternatives. The best that we can say at this time is that Morro Bay kangaroo rats at the Bayview site tended to confine the majority of their activity to an area having a radius of 20 – 30 or 40 m. Long range dispersals were rare, but localized home range extensions or shifts may occasionally occur from one year to the next or during the course of one field season.

BREEDING SEASON IN MORRO BAY KANGAROO RATS AT THE BAYVIEW SITE

In a comprehensive summary of both museum specimen data and live trapping data collected through 1979, Roest (1984) reported that of 24 females with embryos; 83% were caught in May, 13% were caught in June, and 4% were caught in August. His summary also revealed that of the 115 juvenile [immature] rats he examined; 56% were caught in August, 17% were caught in May, 12% were caught in July, and the remaining 15% were caught in March, April, June, September, or November. The 7 immature animals reportedly caught in November were specimens taken by Dixon (1918) and housed at the University of California — Berkeley, Museum of Vertebrate Zoology. Gambs surveyed all of the specimens collected by Dixon as well as his field notes and determined that there were 10 (not 7) immature Morro Bay kangaroo rags caught in 1918 (MVZ #'s 29033, 29035 — 29042, and 29052) and all of them were caught between 25 and 27 September (not in November as reported by Roest 1984). Thus, the latest recorded date of capture for an immature Morro Bay kangaroo rat was September and the earliest recorded date was March.

Data from the present study reveal that of 4 conspicuously pregnant females, 1 was caught in April, 2 were caught in June, and 1 was caught in July. Only one female gave birth in a trap and that occurred on 25 April 1986. Of 9 females that showed conspicuous signs of lactation, 3 were caught in April, 2 were caught in May, 2 were caught in June, 1 was caught in July, and 1 was caught in August. These limited data suggest that pregnancy, parturition, and lactation occurred between the months of March and August in 1984, 1985, and 1986.

The focus of the present study was to elucidate whether or not there was a recognizable peak in breeding behavior among the Morro Bay kangaroo rats at the Bayview site. Using the regression equation for age (vs) body weight derived from known-aged Morro Bay and Lompoc kangaroo rats (see methods) we predicted the age of immature animals using the formula below:

$$\text{PREDICTED AGE (days)} = 10^{[\text{body weight(g)} + 36.7299] / 50.5566}.$$

Then, by a process of back dating, we were able to predict the date of conception using the formula below:

PREDICTED CONCEPTION DATE = DATE OF CAPTURE - PREDICTED AGE - 31 DAYS

If breeding behavior immediately precedes conception, then the predicted conception dates of immature animals should be coincident with adult breeding behavior.

A total of 21 immature Morro Bay kangaroo rats (2 in 1984, 16 in 1985 and 3 in 1986) were caught on 3 plots and 5 of the 8 traplines at the Bayview site. Immature animals were those which, regardless of their body weight, had either a juvenile or subadult pelage. The smallest of these animals weighed 18.5 grams when it was caught on 21 May 1986 and the largest weighed 56.0 grams when it was first caught on 25 April 1985 (Table 3—8).

Table 3—8. Capture dates, body weights, and predicted ages, birthdates, and conception dates for 21 immature Morro Bay kangaroo rats captured at the Bayview site from 1984 — 1986. Refer to the text for details on the techniques used to predict ages, birthdates, and conception dates.

TAG #	DATE OF CAPTURE	BODY WT. (g)	PREDICTED AGE(days)	PREDICTED DATE BORN	PRED. DATE CONCEIVED
1170	5/25/84	32.0	23	5/02/84	4/01/84
1391	8/02/84	54.0	62	6/01/84	5/01/84
1412	4/06/85	37.0	29	3/08/85	2/05/85
1415	6/06/85	30.5	21	5/16/85	4/15/85
1422	6/11/85	37.5	29	5/13/85	4/12/85
1450	7/01/85	43.0	38	5/24/85	4/23/85
1463	7/02/85	39.5	32	5/31/85	4/30/85
1465	7/02/85	25.5	17	6/15/85	5/15/85
1479	7/16/85	52.0	57	5/20/85	4/19/85
1540	4/04/85	43.0	38	2/25/85	1/25/85
1552	4/25/85	56.0	68	2/16/85	1/16/85
1582	6/05/85	46.0	43	4/23/85	3/23/85
1595	6/05/85	28.0	19	5/17/85	4/16/85
1600	6/06/85	44.0	40	4/27/85	3/27/85
1690	8/20/85	39.0	31	7/20/85	6/19/85
1691	8/20/85	42.0	36	7/15/85	6/14/85
1695	8/21/85	51.0	54	6/28/85	5/28/85
1701	7/17/85	44.0	40	6/07/85	5/07/85
1945	5/21/86	20.5	14	5/07/86	4/06/86
1946	5/21/86	18.5	12	5/09/86	4/08/86
1948	5/21/86	23.5	16	5/05/86	4/04/86
AVERAGE =		38.4	34.2		
STANDARD ERROR=		2.4	3.5		

The monthly frequency distribution of immatures caught at Bayview did not show any particularly strong modal pattern. (Fig. 3—6). Since trapping intensity varied from month to month and year to year, it could be that the monthly frequency of capturing immatures was simply a function of trapping intensity. To test this hypothesis, the actual numbers of immature animals caught each month were pooled over the 3 years and compared to the expected numbers of animals that should have been caught each month, assuming that capture frequency was proportional to trapping intensity (Fig. 3—6). Although a comparison of the actual and expected distributions reveals a certain degree of discrepancy on some months, the two distributions are not significantly different (Chi Square = 7.718, df = 5, $.10 < p \leq .20$; actual and expected values were pooled for March and April and for September and October). Thus, there were probably about the same relative number of immatures in the population from April through August and when greater trapping was exerted more immatures were caught and vice versa.

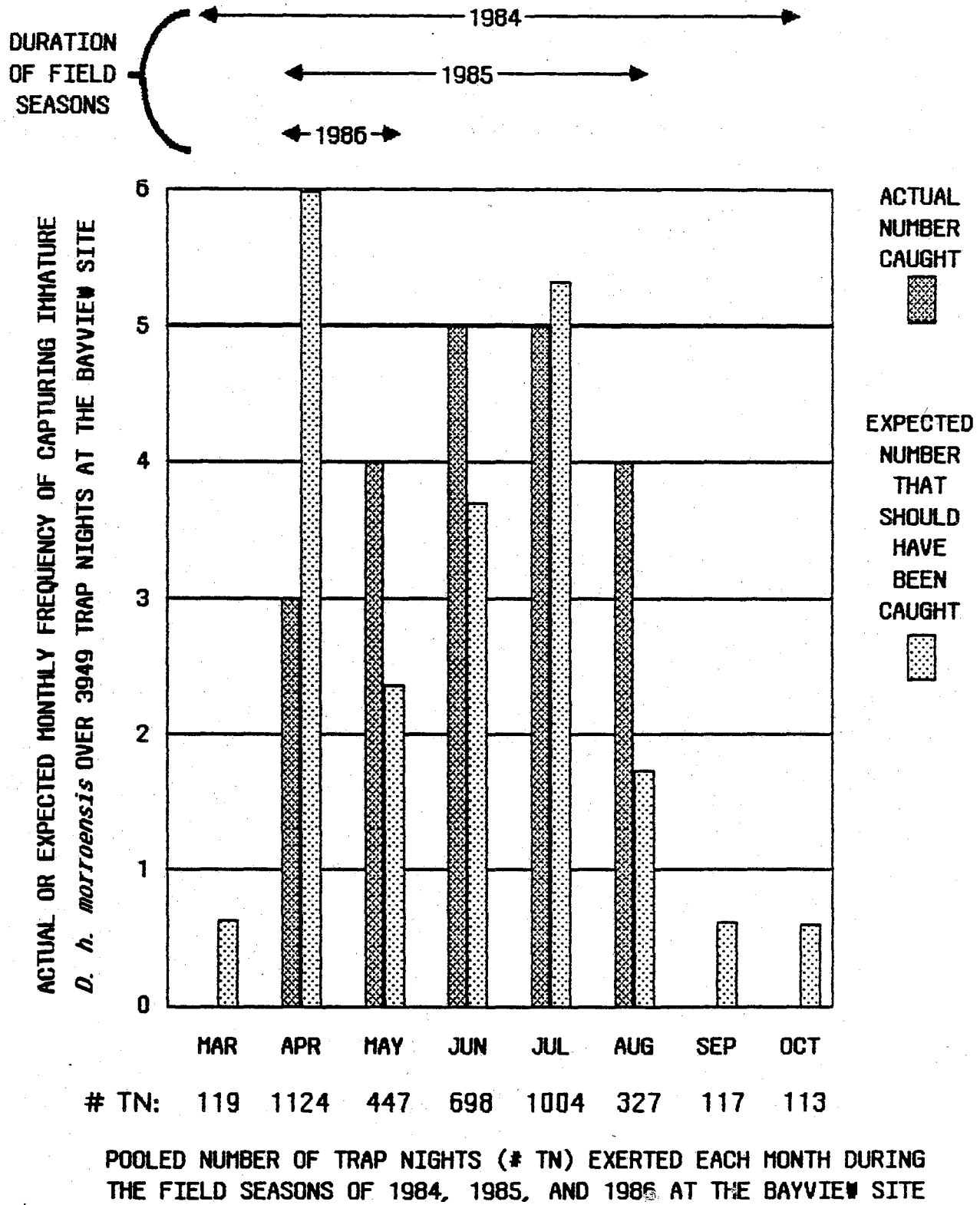


Figure 3–6. Comparison of the actual number of immature Morro Bay kangaroo rats captured to the expected number of animals that should have been captured if they had been caught in proportion to trapping intensity (# of Trap Nights). Trap nights and actual number of rats caught were pooled for all months of trapping in 1984, 1985, and 1986.

The predicted ages of immature animals varied considerably with the month when they were caught. Three animals caught in April ranged from 29 — 68 days old; whereas 4 animals caught in May ranged from 12 — 23 days old (Fig. 3—7). The animals caught in April obviously were from much earlier litters than those caught in May. Although the average age of immatures tended to increase progressively from June to August, the rate of increase was only about half what it should have been if all these animals had been born at the same time. These results indicate that breeding does occur over a period of several months, but predicted age alone lacks the level of detail necessary to reveal the presence or absence of a peak in breeding activity.

Analysis of predicted conception dates does provide a means of determining whether or not breeding activity peaks at some period during the year. If conception dates were uniformly distributed over the year, a continuous breeding season would be indicated; whereas a non-uniform distribution would suggest a discrete breeding season. The 21 predicted conception dates from all three years were pooled by month to facilitate analysis (Fig. 3—8). All of the predicted conceptions occurred between January and July even though the duration of the study would have permitted detection of conceptions as early as mid-December of the previous year and as late as early September of the same year. Nearly 1/2 (48%) of all conceptions were predicted to occur in April and over 3/4 (76%) were predicted to occur between March and May. If breeding activity (as measured by conceptions) had been uniformly distributed over the 6 months when conceptions were predicted, then one would expect about equal numbers of conceptions each month. To test this hypothesis, the observed frequency distribution of predicted conceptions (Fig. 3—8) was compared to a uniform model having 3.5 expected conceptions per month. The actual frequency distribution of predicted conceptions was significantly different from the uniform model (Chi Square = 15.86, df = 5, $p < .01$) which suggests that even though some breeding occurred during each of the first 6 months of the year, there was a definite seasonal peak in the month of April. Furthermore, if an average gestation period of 31 days is added to the April breeding peak, then the highest incidence of pregnant females would be expected to occur in May and this is exactly what was reported by Roest (1984). It's rather ironic that the 4 pregnant females trapped during the present study were probably bred either before or after the April peak.

Although these results certainly indicate that the majority of breeding occurs in early to mid-spring, they do not imply that Morro Bay kangaroo rats never breed after June. For example, a pregnant female caught in August (Roest 1984) was probably conceived in July, which is beyond the breeding period found in the present study. When we applied our technique of estimating conception dates to the 10 immature animals caught by Dixon in late September of 1918, we estimated that 2 were conceived in June, 6 were conceived in July, and 2 were conceived in August. The females involved in these incidents of summer breeding activity may have been adults producing their second litters or females born early enough in the year to have reached reproductive maturity by late summer. The fact that some of the female Morro Bay kangaroo rats housed at Cal Poly have exhibited estrus in every month of the year and even have had litters in October, November, and December (Roest 1987) suggests that the seasonal nature of breeding activity observed in the wild population at Bayview is probably a consequence of exogenous factors such as moisture, temperature, or food supply influencing endogenous reproductive processes in the animals themselves.

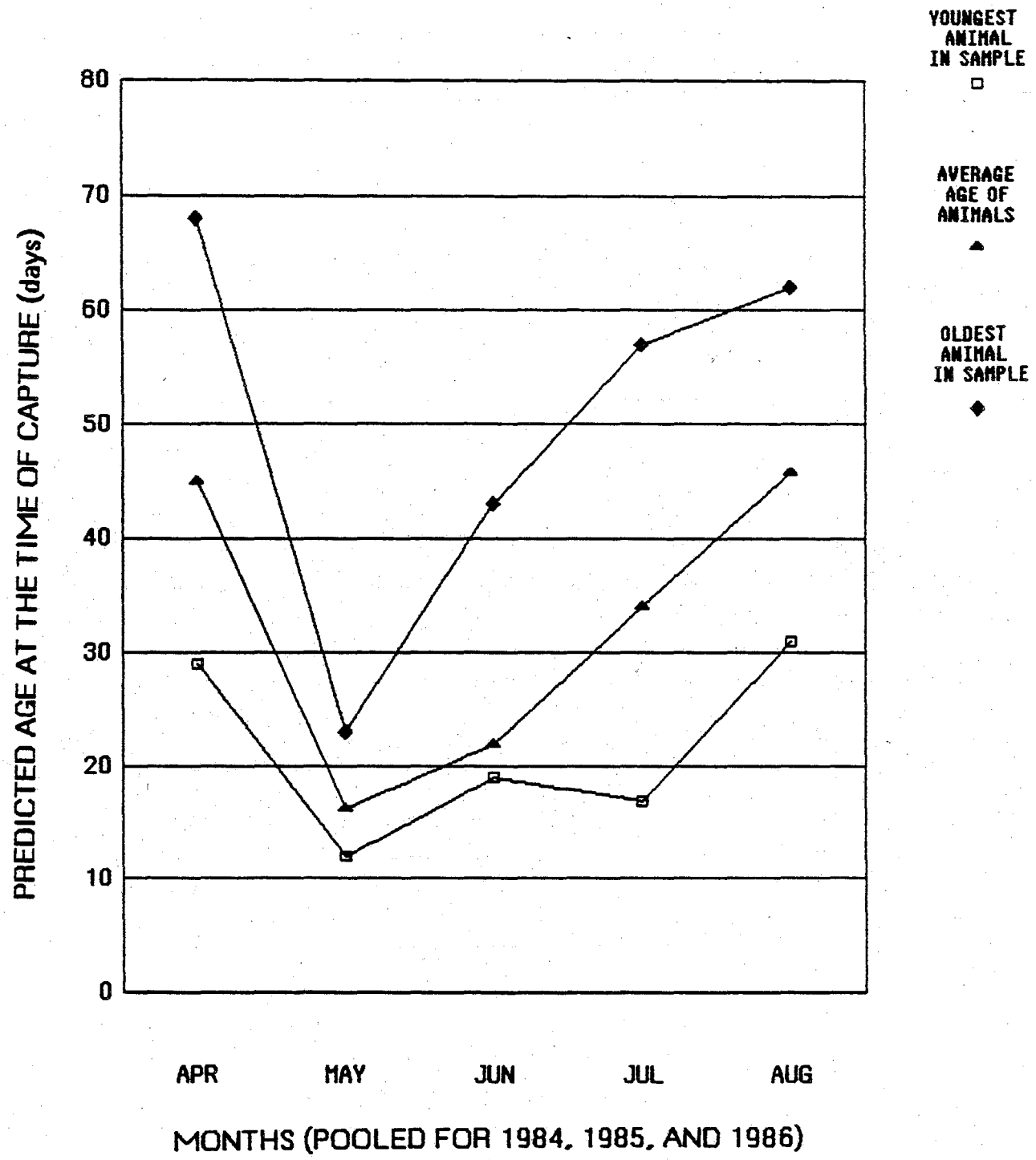


Figure 3—7. Frequency distribution of minimum, maximum, and average predicted ages of immature Morro bay kangaroo rats on the month when they were first caught at the Bayview site. Monthly captures were pooled over the 3 years of the study.

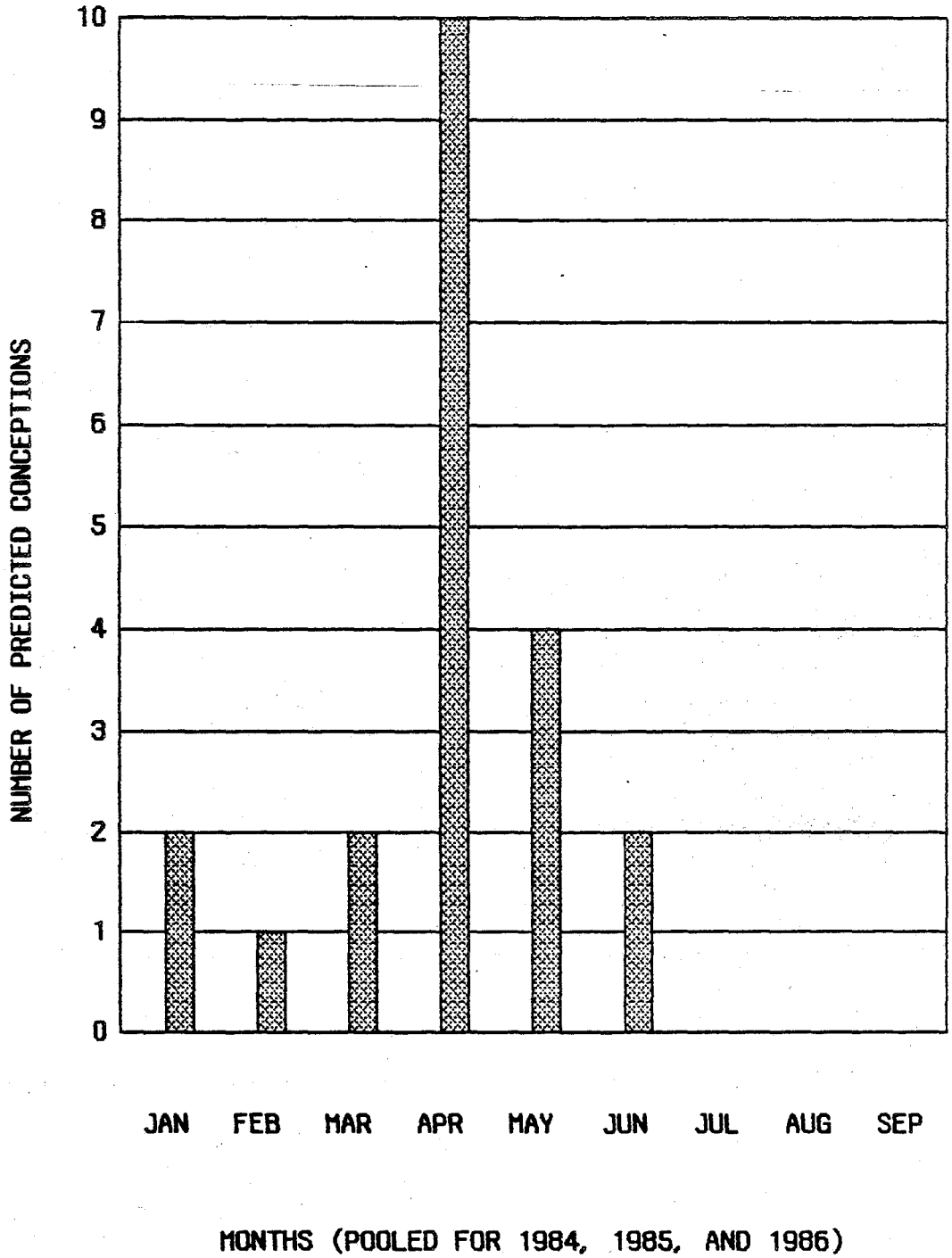


Figure 3—8. Number of Morro Bay kangaroo rats conceived during those months when conception dates could be estimated from capture data. The sample consists of 21 immature animals (2 in 1984, 16 in 1985 and 3 in 1986) which were caught at the Bayview site. The procedures used to estimate the date of conception are given in the text.

RELATIONSHIPS BETWEEN POPULATION CHARACTERISTICS, PRESENT HABITAT CONDITIONS, AND FUTURE HABITAT REQUIREMENTS OF MORRO BAY KANGAROO RATS

In the past, the total population of Morro Bay kangaroo rats probably consisted of a number of subpopulations distributed over a heterogeneous mosaic of habitat fragments within their historic range. Natural habitat perturbations (eg. climatic extremes, fire, sand movement, poor seed set, or severe predator pressure) combined with intrinsic population events (ie. low fecundity, high mortality, or a high rate of emigration) probably resulted in periodic extinctions in some subpopulations. A habitat fragment which had lost its subpopulation probably could have been repopulated by immigrants from neighboring subpopulations, provided the distances between subpopulations were not greater than the average dispersal distance of individuals and the intervening habitat did not prevent such short-term dispersals (Wilcox and Murphy 1985). Over the years, significant landscape and habitat changes have occurred over the rat's historic range which have dramatically reduced the size of their habitat fragments and increased the distance between habitat fragments. The continuing problems of population and habitat fragmentation deserve special consideration because the success or failure of recovery efforts directly hinges upon how well these problems are understood and incorporated into management plans.

In an attempt to provide guidelines for managing nature reserves, Wilcove (1987) argues that fragmentation of natural ecosystems into islands of natural habitat surrounded by areas of alien or unsuitable landscape contributes to or causes at least the following types of biological dysfunction which in turn may lead to extinction:

(a). increased vulnerability of each fragment and the individuals therein to severe natural catastrophes such as fire, flooding, disease epidemics, predator outbreaks, etc.

(b). increased vulnerability of populations to random population imbalances resulting from extremely low reproductive success and / or extremely low survivorship among the individuals of one or more population fragments.

(c). loss of genetic variability in a population resulting from inbreeding among few individuals may result in reduced fertility, the appearance of deleterious genetic disorders in morphology, physiology or behavior, and / or reduced ability to tolerate or adapt to sudden environmental change.

(d). increased vulnerability to abnormal social behavior resulting from diminished social facilitation involved in activities such as breeding or feeding when population size falls below a threshold number.

In addition to these factors, Wilcove (1987) also points out that as a consequence of the interdependency of several species in a habitat fragment, the loss of one species may result in the loss of other, dependent species in the same area. The success of each species in a habitat fragment is further complicated by the influence of adverse factors surrounding it (eg. predators, competitors, parasites, water, soil, weather conditions, etc.) as well as the proportion of edge area to the area actually incorporated in the habitat fragment.

Successful management of fragmented populations on habitat islands may be enhanced by increasing the number of habitat islands and / or linking islands together with suitable habitat corridors (Quinn and Hastings 1987). Increasing the size of habitat islands would also be expected to enhance management success because larger areas would be more likely to incorporate a more complete set of internal ecosystem elements and processes which should promote the stability of the ecosystem (White 1987). In addition to size, the shape of a habitat fragment may also be an important property of any fragment. Circular fragments would seem to be preferable to non-circular ones because adverse encroachment from outside and adverse edge effects would be minimized with fragments having circular dimensions (Wilcove and Wilcox 1987). Furthermore, as the size of habitat fragments decreases and their shapes become more irregular, the intensity of management is expected to increase because of increased perturbation to the fragments from surrounding areas (White 1987). It appears that large, circular preserve areas would be most effective in terms of both habitat management and promoting the survival and dispersal of a species such as the Morro Bay kangaroo rat.

We had originally hoped to collect sufficient life table and dispersal data to allow us to investigate models which have been developed to analyze effective population size and minimum habitat size. Unfortunately, the limited distribution and low numbers of Morro Bay kangaroo rats did not enable us to collect the information necessary to estimate such parameters as net replacement rate, average generation length, intrinsic population growth rate, or one-way variances of dispersal distance between parents and offspring. The results of our population estimates during the last 2 years of the study (51 individuals in 1985 and 50 in 1986) suggest that the intrinsic rate of population growth at Bayview over this period was essentially 0, which would give a net replacement rate of 1 offspring per adult. Of the 38 different individuals caught during the study (11 immatures and 27 adults), we were able to monitor 9 animals for 2 years and 1 for 3 years. The fact that 9 of these 10 individuals (4 adult males, 4 adult females, and 1 immature female) remained on the same plots where they were originally caught suggests that "long-range" dispersal among adults was uncommon. Dispersal among the immatures remains unclear because fewer immatures (18 %) than adults (30 %) were caught in subsequent years and, while one of the two immatures did not change residence, the other moved 400 m to a different plot. Although our data do not permit us to directly determine whether the lower return rate of immatures was a consequence of more "long-range" dispersals or higher mortality rates, we suspect that "long-range" dispersal may be more common in immatures than adults.

By using the limited life history and dispersal information (above) as a basis for making assumptions required to estimate minimum habitat requirements of a territorial species (Lande 1987) it is possible to at least obtain a rough approximation of the minimum habitat requirements of a non-territorial species such as the Morro Bay kangaroo rat. Lande developed a means of estimating minimum habitat areas required for territorial species which occur in regions where patches of suitable habitat are randomly or evenly interspersed with patches of unsuitable habitat. He demonstrated that the minimum critical size of a region must be substantially larger than merely the root-mean-squared dispersal distance (d_0) for the population.

For a two-dimensional landscape, the minimum critical diameter (D) of a circular area required to successfully support a population would be one in which:

$$D > 4.81\, d_0\, (2 r_0 T_0)^{-1/2}$$

Where: d_0 = root-mean-squared dispersal distance per generation when the proportion of suitable habitats occupied by females approaches 0

r_0 = intrinsic growth rate of the population

T_0 = generation time = mean age of reproducing females when the stable age distribution has been attained in the population

Assuming $d_0 \approx 200$ m and $r_0 T_0 \approx \ln R_0$ (where: R_0 = net lifetime production of female offspring per female), it is possible to make a crude estimate of D if a realistic value of $\ln R_0$ can be obtained. Assuming an average female in the population produces 4 litters of 3 pups each, 3/4 of all pups fail to survive, and 50% of all surviving offspring are female, a rough estimate of R_0 would be (4 X 3 X .25 X .5) = 1.5 and $\ln R_0$ = .405. In this scenario, D would have to be > 4.81 X 200 m X 1.115 = 1068 m. The area of such a "minimum" circle = 90 ha. Assuming an average density of 4 individuals per ha, this area would support a population of approximately 360 rats. It should be noted that an increase in dispersal distance would increase the diameter and thus the area of the "minimum" circle. Conversely, if dispersal distance were held at 200 m, but R_0 were increased to 3.0 because of greater reproductive success or a female-biased sex ratio, the diameter of the "minimum" circle would be reduced to 649 m (area = 33 ha). In view of the population estimates obtained during the last two years of our study, the net number of female offspring produced per female is probably near 1. A population having d_0 = 200 m and R_0 = 1.0001 would require at least 363,439 ha of habitat in order to be considered above its "extinction threshold".

RELATIVE ABUNDANCE AND DENSITY OF SMALL MAMMALS AT THE PECHO AND BAYVIEW SITES

In addition to Morro Bay kangaroo rats, Gambs (1986g) reported a total of 7 other species of small mammals caught on study plots at the Pecho or Bayview sites: Dusky-footed woodrats, *Neotoma fuscipes;* California pocket mice, *Perognathus californicus;* brush mice, *Peromyscus boylii;* California mice, *Peromyscus californicus;* deer mice, *Peromyscus maniculatus;* western harvest mice, *Reithrodontomys megalotis;* and California ground squirrels, *Spermophilus beecheyi.* Various other vertebrate species also occurred on the plots (refer to Appendix A). With the exception of California mice and brush mice, all species encountered in the field could be readily identified using external characteristics. The external characteristics of brush mice and California mice were analyzed in a separate study so that these two species could be positively identified in the field (refer to Appendix A).

The population characteristics of small mammal species on undisturbed plots at the Pecho site represent a set of "controls" which then can be used to assess the effects of habitat modification performed on other ("experimental") plots at the Pecho site. All plots at the Bayview site were undisturbed and the small mammal populations on these plots (the only ones supporting Morro Bay kangaroo rats) can be used to assess the potential for experimental plots at Pecho to support Morro Bay kangaroo rats in the future. This report will focus on annual small mammal population characteristics at each plot, overall effects of brush removal and burning on small mammal populations at the Pecho site, and the major similarities and differences in small mammal populations occurring at the Pecho and Bayview sites.

The average relative abundance and density of small mammal populations occurring on all plots at both the Pecho and Bayview sites throughout the study are presented in Table 3—9. For convenience, the average population data collected for one year on one plot will be referred to as data for one plot year (eg. population data collected from plot ABC in 1983, 1984, 1985, and 1986 represent 4 plot years of small mammal population data). Thus there are 12 plot years of data available for undisturbed plots at Pecho (ABC, 1983 — 86; JKL, 1983 — 86; TUVWX, 1984; AA-EE, 1985 — 86; and FF-JJ, 1985); 8 plot years of data for manually cleared plots at Pecho (DEF, 1983 — 86 and GHI, 1983 — 86); 3 plot years of data for burned plots at Pecho (TUVWX, 1985 — 86 and FF-JJ, 1986); and 8 plot years of data for undisturbed plots at Bayview (NOP, 1984 — 86; QRS, 1984 — 86; and KKLLMM, 1985 — 86). Although population data for plots ABC, JKL, DEF, and GHI are provided for 2 different periods in 1983 (JAN-FEB was before manual brush removal on plots DEF and GHI), only those data for the MAY-AUG period (after clearing was completed) will be considered in this report because they are most comparable to data collected in subsequent years.

Casual inspection of Table 3—9 reveals that species composition as well as relative abundance and density vary from year to year on the same plot. Furthermore, these same measures of small mammal community structure differ widely from plot to plot during the same year. In order to develop a general picture of small mammal community structure on both undisturbed and manipulated habitat over the period of the study, two methods of summarization were employed. First, the average densities of all small mammals (except California ground squirrels) which occurred on 12 undisturbed plot years at Pecho, 8 cleared plot years at Pecho, 3 burned plot years at Pecho, and 8 undisturbed plot years at Bayview were pooled and the mean densities of each species were calculated for each of the 4 groups. Second, the relative abundances

Table 3– 9. Summary of small mammal trapping results from 1983 to 1986 on all study plots located at the Pecho and Bayview sites. Jan. - Feb. 1983 data are included for plots ABC,JKL, DEF, and GHI to enable comparisons of small mammal populations on these 4 plots before brushed was removed from plots DEF and GHI. In an attempt to hold seasonal variation in small mammal populations constant, only those data collected during the spring and summer months are included in this and other analyses.

A "-" in a cell indicates that no individuals of that species were captured during the indicated time period. A "0(NA)" in a cell indicates that individuals of that species were captured, but lack of recaptures prevented estimating population density during the indicated time period. Brush clearing on plots DEF and GHI occurred from March to April, 1983. Prescribed burns occurred on plot TUVWX in October, 1984, and on plot FF-JJ in October, 1985.

<STUDY AREA> & PLOT	YEAR	PERIOD OF STUDY	MANIPULATION OF HABITAT	# OF TRAP NIGHTS	MORRO BAY KANGAROO RAT		DUSKY-FOOTED WOODRAT		CALIFORNIA POCKET MOUSE		CALIFORNIA MOUSE		DEER MOUSE		WESTERN HARVEST MOUSE		CALIFORNIA GROUND SQUIRREL	
					AVG. #/ 100TN	AVG. DEN. (#/ha)	AVG. #/ 100TN	AVG. DEN. (#/ha)	AVG. #/ 100TN	AVG. DEN. (#/ha)	AVG. #/ 100TN	AVG. DEN. (#/ha)	AVG. #/ 100TN	AVG. DEN. (#/ha)	AVG. #/ 100TN	AVG. DEN. (#/ha)	AVG. #/ 100TN	AVG. DEN. (#/ha)
<PECHO>																		
ABC	1983	JAN-FEB	NONE	532	-	-	-	-	-	-	-	-	7.3	4.4	7.7	10.4	-	-
ABC	1983	MAY-AUG	NONE	735	-	-	-	-	2.0	1.0	-	-	6.8	3.8	6.1	13.0	-	-
ABC	1984	MAY-AUG	NONE	399	-	-	-	-	4.0	1.5	-	-	16.0	7.5	5.0	3.6	-	-
ABC	1985	JUL	NONE	155	-	-	-	-	1.3	.6	-	-	17.4	10.8	-	-	.6	0(NA)
ABC	1986	AUG	NONE	158	-	-	-	-	10.8	6.3	1.9	1.2	23.4	30.2	-	-	-	-
JKL	1983	JAN-FEB	NONE	328	-	-	.3	0(NA)	-	-	3.6	1.8	10.1	4.1	6.7	3.3	-	-
JKL	1983	MAY-AUG	NONE	691	-	-	3.3	2.1	.7	.4	3.9	2.2	11.3	7.7	10.7	13.3	-	-
JKL	1984	MAY-AUG	NONE	421	-	-	1.7	.4	5.9	2.2	4.5	1.6	18.5	8.7	5.5	4.1	-	-
JKL	1985	AUG	NONE	149	-	-	2.7	2.4	.7	0(NA)	1.3	0(NA)	18.1	8.7	1.3	0(NA)	.7	0(NA)
JKL	1986	JUL	NONE	156	-	-	1.3	.6	9.6	4.1	3.8	2.7	9.6	7.6	1.3	0(NA)	.6	0(NA)
DEF	1983	JAN-FEB	NONE	534	-	-	1.5	1.5	1.5	.6	.9	1.1	7.3	4.2	7.3	5.4	-	-
DEF	1983	MAY-AUG	CLEARED	726	-	-	.4	.1	2.2	2.1	1.5	.9	6.6	3.1	3.7	8.4	-	-
DEF	1984	MAY-AUG	CLEARED	406	-	-	.5	.1	2.2	1.0	2.0	.6	17.5	8.4	5.4	6.5	-	-
DEF	1985	AUG	CLEARED	151	-	-	.7	0(NA)	9.9	5.8	1.3	.6	25.2	11.4	-	-	-	-
DEF	1986	AUG	CLEARED	154	-	-	-		24.7	16.2	3.2	2.2	21.4	16.7	.6	0(NA)	-	-
GHI	1983	JAN-FEB	NONE	424	-	-	1.4	1.2	-	-	.7	.3	9.7	6.2	6.6	5.6	-	-
GHI	1983	MAY-AUG	CLEARED	725	-	-	.5	.1	1.1	.9	2.2	.6	15.0	5.4	6.3	10.9	-	-
GHI	1984	MAY-AUG	CLEARED	414	-	-	.2	0(NA)	3.1	.9	1.0	.3	21.0	9.3	5.1	3.1	-	-
GHI	1985	AUG	CLEARED	153	-	-	-	-	8.5	3.9	1.3	0(NA)	24.2	12.7	-	-	1.3	0(NA)
GHI	1986	JUL	CLEARED	156	-	-	-	-	6.4	7.7	-	-	14.7	7.8	.6	0(NA)	-	-
TUVWX	1984	MAY-AUG	NONE	383	-	-	6.3	2.7	11.2	5.3	3.1	1.1	6.3	2.3	5.3	2.6	-	-
TUVWX	1985	MAY-AUG	BURNED	563	-	-	-	-	9.4	7.9	-	-	22.6	16.4	.2	0(NA)	.5	0(NA)
TUVWX	1986	APR-AUG	BURNED	524	-	-	-	-	22.5	11.9	-	-	23.9	17.4	.2	0(NA)	2.0	0(NA)
AA-EE	1985	JUL	NONE	144	-	-	-	-	-	-	2.1	0(NA)	20.8	17.3	-	-	-	-
AA-EE	1986	JUL	NONE	143	-	-	-	-	14.0	5.8	4.9	4.6	24.5	15.2	7.0	17.9	-	-
FF-JJ	1985	JUL	NONE	145	-	-	-	-	-	-	-	-	15.2	7.9	2.8	0(NA)	-	-
FF-JJ	1986	JUL	BURNED	150	-	-	-	-	2.0	.6	-	-	20.7	18.3	-	-	-	-
<BAYVIEW>																		
NOP	1984	MAR-AUG	NONE	434	.5	0(NA)	-	-	3.0	1.2	1.2	0(NA)	-	-	-	-	-	-
NOP	1985	APR-JUN	NONE	222	-	-	-	-	7.7	2.8	-	-	1.8	.4	-	-	-	-
NOP	1986	APR-MAY	NONE	260	7.3	4.7	-	-	10.4	6.5	.4	-	.4	0(NA)	-	-	-	-
QRS	1984	MAR-AUG	NONE	445	1.8	2.0	-	-	.4	0(NA)	-	-	-	-	-	-	-	-
QRS	1985	APR-JUN	NONE	264	5.7	2.3	-	-	1.5	0(NA)	-	-	-	-	-	-	-	-
QRS	1986	APR-MAY	NONE	260	13.1	5.0	-	-	.4	0(NA)	-	-	.4	.1	-	-	-	-
KKLLMM	1985	AUG	NONE	158	13.3	4.9	-	-	16.5	7.8	-	-	-	-	-	-	-	-
KKLLMM	1986	APR-MAY	NONE	465	14.2	2.1	.2	0(NA)	12.5	3.6	1.7	.6	1.1	.4	.4	0(NA)	-	-

of small mammals from all 31 plot years were subjected to several multivariate statistical analyses in order to evaluate the similarity of plots and sites based upon small mammal communities present on each plot year.

Densities Of Small Mammals On Undisturbed Plots At Pecho

Overall species richness on undisturbed plots exhibited the following patterns: 2 species on plots ABC, AA-EE, and FF-JJ, 3 species on plot ABC, 4 species on plot AA-EE, and 5 species on plots JKL and TUVWX (Table 3—10). Although species composition changed over time on some plots, Morro Bay kangaroo rats were never found on any of the undisturbed plots. Dusky-footed woodrats and California mice were always at fairly low densities; whereas California pocket mice, deer mice and western harvest mice were more abundant on most years of the study (Fig. 3—9). The density of deer mice progressively increased during the study and they were the dominant species (had the highest density) during the last 3 years of the study. In 1983, western harvest mice were the dominant species and deer mice were subordinate (had the second highest density). Western harvest mice declined to extremely low densities in 1985 and then increased somewhat in 1986. California pocket mouse densities varied from low to moderate levels, however their overall density was always less than that of deer mice. Thus, the general pattern of small mammal community structure on undisturbed habitat at Pecho was one in which deer mice were the dominant species in 3 of the 4 years and western harvest mice were dominant in 1 of the 4 years.

Table 3—10. Average annual densities (# / ha) of small mammal species occurring on undisturbed plots at the Pecho site. Complete absence of a species during a plot year is indicated with a "—". Densities indicated by "0(NA)" indicate that a species was present during a plot year, but low capture rates prevented estimating its density. Species abbreviations are as follows: **Dh. mor.** = *Dipodomys heermanni morroensis* (Morro Bay kangaroo rat), **Nt. fus.** = *Neotoma fuscipes* (dusky-footed woodrat), **Pg. cal.** = *Perognathus californicus* (California pocket mouse), **Pm. cal.** = *Peromyscus californicus* (California mouse), **Pm. man.** = *Peromyscus maniculatus* (deer mouse), and **Rd. meg.** = *Reithrodontomys megalotis* (western harvest mouse).

PLOT	YR.	MONTH(S)	Dh. mor.	Nt. fus.	Pg. cal.	Pm. cal.	Pm. man.	Rd. meg.
ABC	1983	MAY-AUG	-	-	1.0	-	3.8	13.0
JKL	"	MAY-AUG	-	2.1	.4	2.2	7.7	13.3
ABC	1984	MAY-AUG	-	-	1.5	-	7.5	3.6
JKL	"	MAY-AUG	-	.4	2.2	1.6	8.7	4.1
TUVWX	"	MAY-AUG	-	2.7	5.3	1.1	2.3	2.6
ABC	1985	JUL	-	-	.6	-	10.8	-
JKL	"	AUG	-	2.4	0(NA)	0(NA)	8.7	0(NA)
AA-EE	"	JUL	-	-	-	0(NA)	17.3	-
FF-JJ	"	JUL	-	-	-	-	7.9	0(NA)
ABC	1986	AUG	-	-	6.3	1.2	30.2	-
JKL	"	JUL	-	.6	4.1	2.7	7.6	0(NA)
AA-EE	"	JUL	-	-	5.8	4.6	15.2	17.9

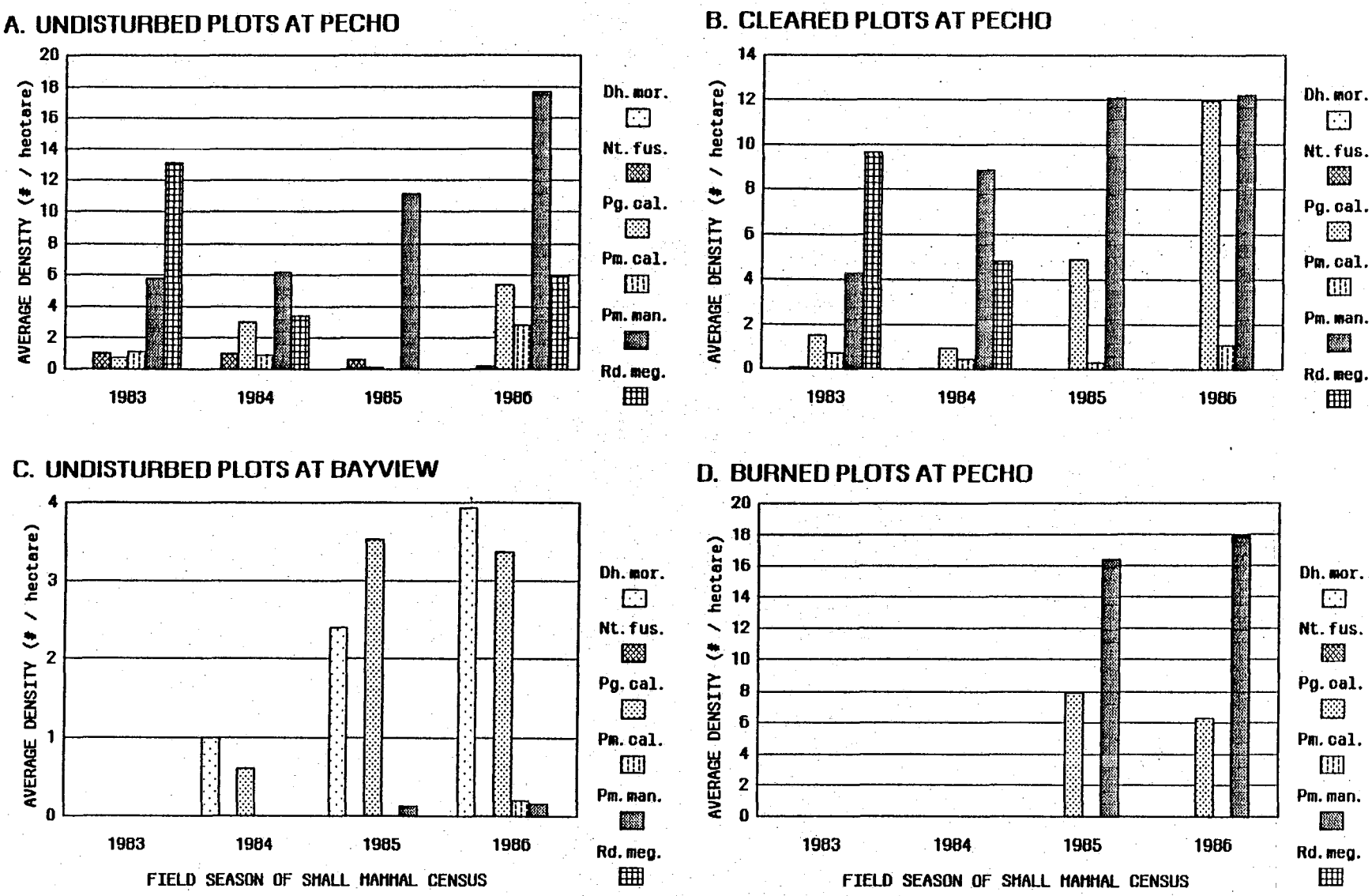


Figure 3-9. Average annual densities of small mammal species occurring on undisturbed and artificially modified forms of Coastal Sage Scrub habitat at the Pecho and Bayview sites. A: average densities taken from 12 plot years of sampling on 5 different undisturbed plots at the Pecho site. B: average densities taken from 8 plot years of sampling on 2 different plots at the Pecho site which were subjected to manual brush removal. C: average densities taken from 8 plot years of sampling on 3 different undisturbed plots at the Bayview site. D: average densities taken from 3 plot years of sampling on 2 different plots at the Pecho site which were subjected to prescription burns.

SPECIES ABBREVIATIONS:
Dh. mor. = *Dipodomys heermanni morroensis*
Nt. fus. = *Neotoma fuscipes*
Pg. cal. = *Perognathus californicus*
Pm. cal. = *Peromyscus californicus*
Pm. man. = *Peromyscus maniculatus*
Rd. meg. = *Reithrodontomys megalotis*

Densities Of Small Mammals On Manually Cleared Plots At Pecho

Overall species richness on the 2 cleared plots (DEF and GHI) dropped from 5 species in 1983 and 1984 to essentially 2 or 3 species in 1985 and 1986 (Table 3—11). Like the undisturbed plots, no Morro Bay kangaroo rats were found on either of the cleared plots. Dusky-footed woodrats were present at extremely low densities during the first 2 years, but disappeared during the last 2 years of the study. California mice persisted at fairly low densities throughout the study; whereas California pocket mice, deer mice and western harvest mice occurred at substantially higher densities during most years of the study (Fig. 3—9). The changes in densities of deer mice and western harvest mice on the cleared plots closely mirrored the changes seen on the undisturbed plots. Deer mice increased throughout the study and they were the dominant species during the last 3 years. Western harvest mice were dominant and deer mice were subordinate in 1983, but after declining to a low level in 1985, western harvest mice failed to recover on the cleared plots in 1986. In addition to the dramatic decline in western harvest mice and the disappearance of dusky-footed woodrats during the last 2 years of the study, the other major difference between the cleared and undisturbed plots was a sharp rise in the density of California pocket mice on cleared plots. The general pattern of small mammal community change seen on the cleared habitat was quite similar to that seen on undisturbed habitat during the first 2 years of the study (ie. either western harvest mice or deer mice were the dominant and subordinate species). However, during the last 2 years of the study, California pocket mouse densities greatly exceeded western harvest mouse densities on the cleared habitat which resulted in California pocket mice replacing western harvest mice as a strong subordinate species to deer mice (the dominant species).

Table 3—11. Average annual densities (# / ha) of small mammal species occurring on cleared plots at the Pecho site. Refer to Table 3—10 for definitions of abbreviations.

PLOT	YR.	MONTH(S)	Dh.mor.	Nt.fus.	Pg.cal.	Pm.cal.	Pm.man.	Rd.meg.
DEF	1983	MAY-AUG	-	.1	2.1	.9	3.1	8.4
GHI	"	MAY-AUG	-	.1	.9	.6	5.4	10.9
DEF	1984	MAY-AUG	-	.1	1.0	.6	8.4	6.5
GHI	"	MAY-AUG	-	0(NA)	.9	.3	9.3	3.1
DEF	1985	AUG	-	0(NA)	5.8	.6	11.4	-
GHI	"	AUG	-	-	3.9	0(NA)	12.7	-
DEF	1986	AUG	-		16.2	2.2	16.7	0(NA)
GHI	"	JUL	-	-	7.7	-	7.8	0(NA)

Although there were no substantial differences in the community structure of small mammals occupying the cleared and undisturbed plots in 1983 and 1984, several significant differences appeared in 1985 and 1986. These latter differences probably reflect a gradual change in community structure in response to brush removal. Thus, it appears that the removal of brush was responsible for the disappearance of dusky-footed woodrats and the extremely low densities of western harvest mice during the last two years of the study. Brush removal had no noticeable effects on deer mouse populations, however the cleared habitat appeared to be more favorable to California pocket mice later in the study. The appearance of California ground squirrels on plots ABC, JKL, and GHI in 1985 (Table 3—9) does not appear to be related to brush removal, but it could be related to a prescribed burn in the immediate vicinity of these plots.

Densities Of Small Mammals On Burned Plots At Pecho

Before the 1984 burn, plot TUVWX was dominated by California pocket mice (Table 3—9). Dusky-footed woodrats, western harvest mice, and deer mice were moderately abundant and California mice were least abundant. Before the 1985 burn, plot FF-JJ was dominated almost completely by deer mice (Table 3—9). A few western harvest mice were caught and California ground squirrels were seen but not trapped on the plot that year.

Overall species richness on these 2 plots was diminished to essentially 2 species after they were burned (Table 3—12). Like all other plots at the Pecho site, no Morro Bay kangaroo rats were found on either of the burned plots. Although dusky—footed woodrats and California mice were found only on plot TUVWX before it was burned, it was not surprising to find that neither plot supported these 2 species after the prescription burns (Tables 3—9, 3—10, and 3—12). Prior to burning, western harvest mice had been moderately abundant on both plots; afterwards, their numbers either fell to very low levels (plot TUVWX) or they were completely absent (plot FF-JJ). It is interesting to note that while harvest mice were not found on plot FF-JJ after the fire; the average annual density of harvest mice on a neighboring, undisturbed plot (AA-EE) was higher than that of any other plot during the entire study (Table 3—9). This sharp contrast suggests that the recently burned habitat of plot FF-JJ must have been quite unfavorable for any western harvest mouse that dispersed away from the high density conditions only 150 m away on plot AA-EE. The 2 species which continued to thrive on the burned plots were deer mice and California pocket mice and deer mice were numerically dominant to California pocket mice on both plots (Fig. 3—9). California ground squirrels were seen on plot FF-JJ the year after it was burned and they were caught on plot TUVWX both years after it was burned. Except for the absence of California mice on the burned plots, the general pattern of small mammal community change seen on the burned habitat was quite similar to that seen on cleared habitat in 1985 and 1986.

Although the effects of burning were more immediate than those of brush removal, the general outcomes were comparable (ie. deer mice and California pocket mice persisted, dusky-footed woodrats and western harvest mice disappeared, and California ground squirrels appeared). The 1984 burn may have created a corridor of open habitat which enabled California ground squirrels living at the base of the dunes to invade plot TUVWX and then spread into the cleared and undisturbed plots in the vicinity of the burn. The spread of California ground squirrels into manipulated habitat represents a serious obstacle to the future introduction of Morro Bay kangaroo rats at these sites.

Table 3—12. Average annual densities (# / ha) of small mammal species occurring on burned plots at the Pecho site. Refer to Table 3—10 for definitions of abbreviations.

PLOT	YR.	MONTH(S)	Dh.mor.	Nt.fus.	Pg.cal.	Pm.cal.	Pm.man.	Rd.meg.
TUVWX	1985	MAY-AUG	-	-	7.9	-	16.4	0(NA)
TUVWX	1986	APR-AUG	-	-	11.9	-	17.4	0(NA)
FF-JJ	"	JUL	-	-	.6	-	18.3	-

Densities Of Small Mammals On Undisturbed Plots at Bayview

Previous studies of small mammals at the Bayview site in 1978/79 (Toyoshima 1983) revealed 4 species living in association with Morro Bay kangaroo rats — deer mice *(Peromyscus maniculatus)*, western harvest mice *(Reithrodontomys megalotis)*, California pocket mice *(Perognathus californicus)*, and California voles *(Microtus californicus)*. California voles were not captured during the present study; however deer mice, western harvest mice, and California pocket mice were found living in association with Morro Bay kangaroo rats on one or more of the study plots (Tables 3—9 and 3—13). The appearance of dusky-footed woodrats *(Neotoma fuscipes)* and California mice *(Peromyscus californicus)* during the present study may indicate that the structure and/or composition of plant cover at the Bayview site has become less suitable for Morro Bay kangaroo rats. It is important to note that in 1978/79, Morro Bay kangaroo rats also were found at the Pecho, Buckskin, and Santa Ysabel/Junior High sites, but the only site that supported Morro Bay kangaroo rats during the present study was Bayview.

Although 6 different species of small mammals were caught on one or more plots during the course of trapping at the Bayview site, 4 of these species (dusky-footed woodrats, California mice, deer mice, and western harvest mice) occurred at very low annual densities (Table 3—13). Morro Bay kangaroo rats were the dominant species and California pocket mice were subordinate in 1984 and 1986, whereas California pocket mice were dominant and Morro Bay kangaroo rats were subordinate in 1985 (Fig. 3—9). Thus, the general small mammal community at Bayview was essentially composed of Morro Bay kangaroo rats and California pocket mice living at fairly low densities. A few dusky-footed woodrats, California mice, and western harvest mice occupied scattered patches of dense plant cover and deer mice occurred sporadically throughout the Bayview site. Comparison of the Bayview small mammal community to the small mammal communities on undisturbed and manipulated plots at Pecho (Fig. 3—9) indicates that the Bayview site was markedly different from the others. In addition to the obvious differences in the species composition between Bayview and Pecho, the combined densities of all small mammals inhabiting the Bayview site on any given year were markedly less than those found on either the undisturbed or manipulated areas at Pecho. It could be that Morro Bay kangaroo rats adversely affect populations of other small mammals such that few other seed-eating rodents can coexist with them on the same habitat. Alternatively, it could be that the habitat at Bayview simply cannot support as many rodents as that at Pecho. This latter possibility seems unlikely because dusky-footed woodrats, California pocket mice, California mice, and deer mice were all found living at much higher densities (10.7 / ha — 15.0 / ha) in areas immediately

adjacent to the Bayview site which were not occupied by Morro Bay kangaroo rats (Gambs 1986c). In the absence of other explanations, it appears that there is at least circumstantial evidence indicating that some sort of negative interaction exists between Morro Bay kangaroo rats and other species (eg. California pocket mice, deer mice, and western harvest mice) normally found in habitat similar to that occupied by the rats.

Table 3—13. Average annual densities (# / ha) of small mammal species occurring on undisturbed plots at the Bayview site. Refer to Table 3—10 for definitions of abbreviations.

PLOT	YR.	MONTH(S)	Dh.mor.	Nt.fus.	Pg.cal.	Pm.cal.	Pm.man.	Rd.meg.
NOP	1984	MAR-AUG	0(NA)	-	1.2	0(NA)	-	-
QRS	1984	MAR-AUG	2.0	-	0(NA)	-	-	-
NOP	1985	APR-JUN	-	-	2.8	-	.4	-
QRS	1985	APR-JUN	2.3	-	0(NA)	-	-	-
KKLLMM	1985	AUG	4.9	-	7.8	-	-	-
NOP	1986	APR-MAY	4.7	-	6.5	-	0(NA)	-
QRS	1986	APR-MAY	5.0	-	0(NA)	-	.1	-
KKLLMM	1986	APR-MAY	2.1	0(NA)	3.6	.6	.4	0(NA)

If one makes the extreme assumption that differences in small mammal communities occupying different habitats are completely dependent upon differences in the plant cover on these sites; it follows that a habitat manipulation procedure which suppressed or eliminated populations of other species (ie. dusky-footed woodrats, California Mice, deer mice, western harvest mice, and, to a lesser extent California pocket mice) might be considered to have successfully created potentially suitable habitat for Morro Bay kangaroo rats. That is, with the exception of Morro Bay kangaroo rats, such a procedure would have promoted a small mammal community similar to that found at Bayview. Conversely, if a habitat manipulation procedure enhanced populations of other local small mammals, then such a procedure might be judged to have been unsuccessful in creating potentially suitable habitat for Morro Bay kangaroo rats. If habitat manipulation produced no noticeable effect on populations of other local small mammals, then factors other than the vegetative composition of the habitat might be involved in regulating populations of local small mammals. As an example, *if* interspecific competition was important in influencing populations of local small mammals, then the mere presence or absence of one or more species from one of several very similar habitats could explain any remaining differences between the habitats. Since the present study was designed to evaluate changes in small mammal populations related to artificial changes in plant cover and not competition, little can be said of the significance of interspecific competition in this study.

Burning and, after several years, manual brush removal both suppressed populations of dusky-footed woodrats and western harvest mice; whereas burning was more detrimental than clearing to populations of California mice. It is important to note than neither brush removal nor burning significantly reduced populations of deer mice or California pocket mice to levels even remotely similar to those found at Bayview. In summary, burning produced stronger negative effects than clearing and these effects were most pronounced on species typically living in stands of dense brush. Deer mice and California pocket mice certainly were not affected by either procedure and in some cases their densities actually increased after their habitat was altered. Even though neither method of habitat manipulation produced a numerically depauperate small mammal community like that seen at Bayview, the burned areas are probably more suitable for reintroducing Morro Bay kangaroo rats simply because the burns cover more area and the two common species there also occur on habitat already occupied by Morro Bay kangaroo rats at Bayview.

MULTIVARIATE ANALYSIS OF THE SIMILARITIES AND DIFFERENCES AMONG STUDY PLOT BASED UPON SMALL MAMMAL ABUNDANCE

The previous sections focused on summarizing the general effects of habitat manipulation as well as the differences between the small mammal communities at Bayview that include Morro Bay kangaroo rats and those at Pecho that do not. Annual means and grand means were used in the summaries because it was too confusing to integrate the independent patterns of variation in small mammal populations for each of the plot years. Multivariate statistical analysis provides a means of examining the overall relationships among the plot years as well as the importance of each species in shaping these relationships.

The relative abundances (# / 100 TN, Table 3—9) of all small mammals (except California ground squirrels) caught on all plot years (except the Jan—Feb sessions for plots ABC, DEF, GHI, and JKL) comprised the raw data used in these analyses. The resulting 31 plot years were treated as individuals (rows) and the 6 small mammal species were treated as variables (columns). The variables were standardized to z scores because of broad differences in both the regularity of captures and the range of densities found for several of the species. The main question we sought to answer was whether or not there were recognizable multivariate differences between the undisturbed, cleared, and burned plots at the Pecho site. We expected that there would be conspicuous differences between the plots at Bayview and those at Pecho because of the exclusive presence of Morro Bay kangaroo rats at Bayview. If there were consistent differences in the small mammal communities occupying the 3 habitat types at Pecho, then the appropriate plot years of each habitat type should form separate aggregations in the graphical output of the multivariate analyses.

UPGMA cluster analysis (Fig. 3—10) reveals some interesting if not unexpected results. Instead of all the Bayview plot years falling into one main part of the dendrogram as expected, they fell into 2 separate clusters. It should be noted that vertical linkages to the left of the dendrogram incidate a high degree of similarity between plot years or groups, whereas vertical linkages to the right of the dendogram indicate a low degree of similarity between plot years or groups. One fairly tight cluster included Bayview plots NOP 84 and 85, QRS 84 and 85, and an undisturbed Pecho plot (AA—EE 85). The other more loosely linked cluster included the remainder of the Bayview plots.

CLUSTER ANALYSIS DENDROGRAM DERIVED FROM GOWER GENERAL SIMILARITY COEFFICIENTS

COPHENETIC CORRELATION COEFFICIENT = .648870

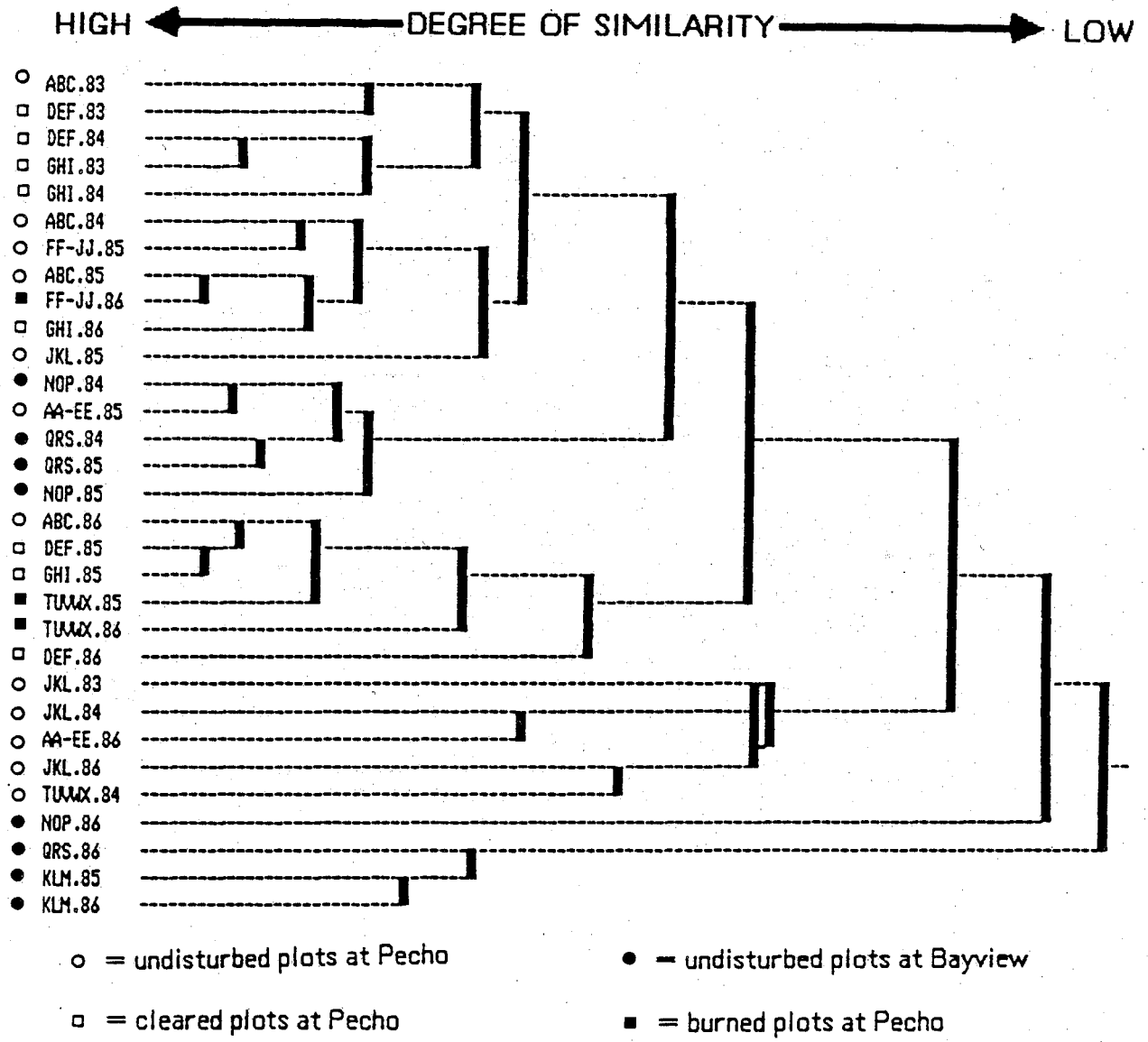


Figure 3—10. Dendrogram of 31 plot years of small mammal sampling at the Pecho and Bayview sites based upon the relative abundance of 6 species of small mammals. Raw data (number of individuals captured / 100 trap nights) were standardized to z scores before conducting the cluster analysis. The association matrix used in the analysis was formed from Gower general similarity coefficients. Unweighted pair group averages (UPGMA) were used to construct linkages between individual plot years and/or groups of plot years in the dendogram.

The close linkage between plots NOP 84 and AA–EE 85 could be because they both supported only 2 species; however only one of the species was common to both plots. The remainder of the data points for undisturbed, cleared, and burned plots form an almost haphazard array of linkages which form 4 general clusters containing either all undisturbed plots (1 cluster), undisturbed and cleared plots (1 cluster), or undisturbed, cleared, and burned plots (2 clusters). These mixed results from cluster analysis suggest several possible explanations: Either the small mammal communities on these 4 habitat types were not sufficiently different to permit discrete aggregations in the cluster analysis or the within group variation of small mammal communities on each habitat type was too large to permit discrete aggregations in the dendrogram.

Unlike cluster analysis, the plot of the first and second principal component axes of single group PCA (Fig. 3–11) provides a more comprehensive view of the same data set. The first principal component axis accounts for 34 % of the total variance and the first and second axes combined account for 59 % of the total variance. The major variables and their component correlations for the first principal component axis were: Morro Bay kangaroo rats, −.67; California mice, +.77, western harvest mice, +.71, and deer mice, +.66. The separation of the Bayview plots from all but one of the Pecho plots along the first axis (Fig. 3–11) is consistent with the fact that the Bayview plots had low to moderate numbers of Morro Bay kangaroo rats and few California mice, western harvest mice, and deer mice; whereas the Pecho plots had no Morro Bay kangaroo rats, and generally larger numbers of the other three species. The major variables and their component correlations for the second principal component axis were: California pocket mice, −.74; deer mice, −.57; dusky-footed woodrats, +.66; and western harvest mice, +.40. Apparently the amount of variation in the abundances of these latter 4 species over all the plots was so large that no discrete aggregations were revealed among the 4 habitat categories along the second axis. Even though it was not particularly surprising, PCA did reveal fairly good segregation between the relative abundance data of small mammals at Bayview and those at Pecho. Like cluster analysis, PCA failed to show any consistent pattern of segregation among the 3 different habitat categories at Pecho which lends support to the earlier conclusion that populations of the two dominant small mammal species (deer mice and California pocket mice) were not significantly altered by brush removal or burning on the Coastal Dune Scrub habitat in that area.

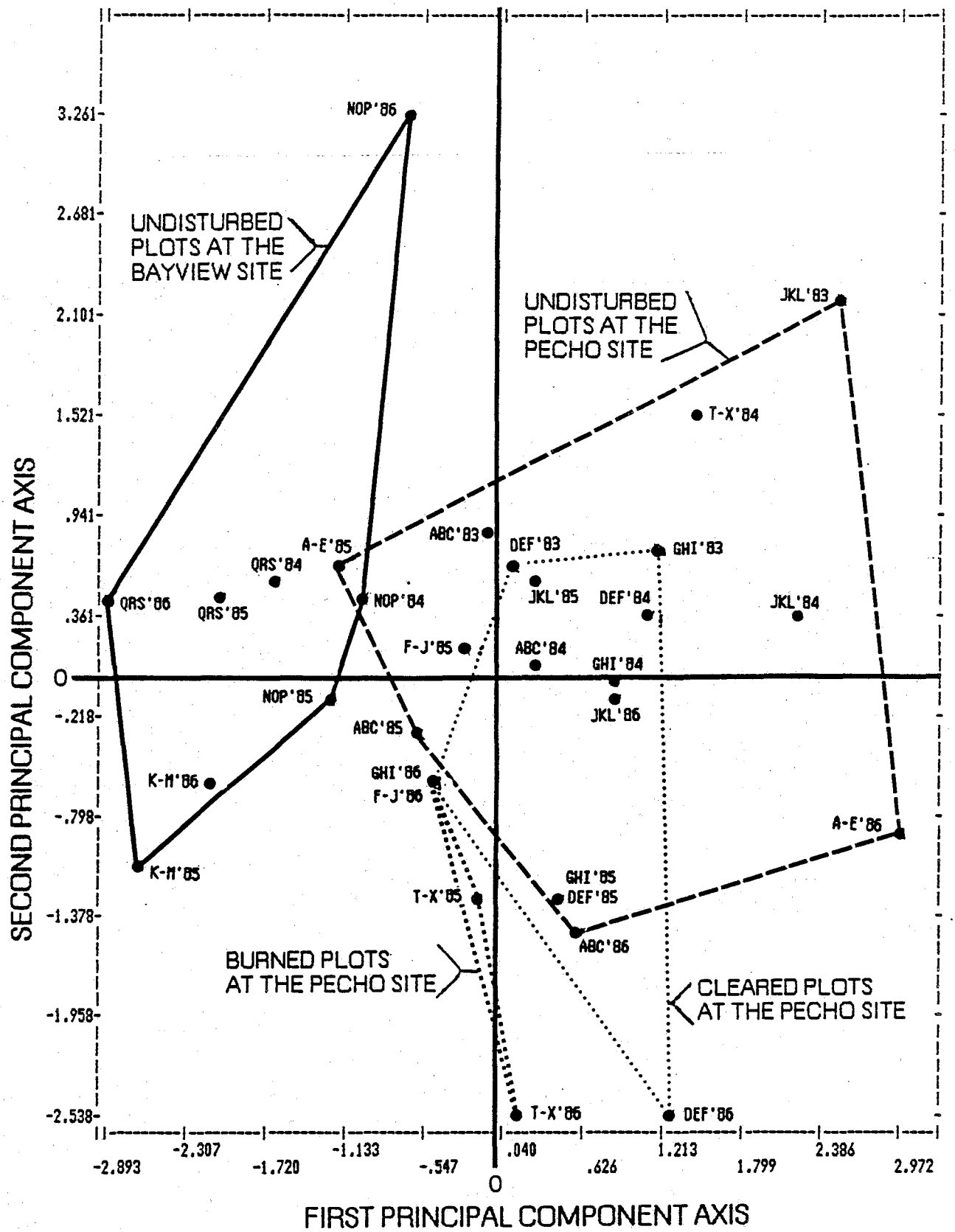


Figure 3—11. Single group Principal Component Analysis of 31 plots years of small mammal sampling at the Pecho and Bayview sites based the relative abundance of 6 species of small mammals. Raw data (number of individuals captured / 100 trap nights) were standardized to z scores before conducting the analysis. The origins of both princial component axes are indicated by solid vertical and horizontal lines. The cumulative percentage of total variance accounted for in the first 2 principal components was 58.535 %.

ZOOLOGICAL CONCLUSIONS

1. At this time, it appears that the only viable wild population of the endangered Morro Bay kangaroo rat *(Dipodomys heermanni morroensis)* is the one inhabiting the Bayview site.

2. The present distribution of Morro Bay kangaroo rats now encompasses only 12 — 15 ha at the Bayview site. Although highly unlikely, a few isolated individuals still may occur in the vicinity of the the Buckskin or Junior High site. Despite extensive trapping efforts, no Morro Bay kangaroo rats were found on Critical Habitat at the Pecho site.

3. There are about 34 ha of suitable but unoccupied habitat distributed over 13 isolated localities within the historic range of the Morro Bay kangaroo rat. Six of the 13 localities cover less than one ha each, 4 of the 13 localities cover less than 2 ha each, 2 of the 13 localities cover less than 7 ha each, and the largest of the 13 localities covers about 13 ha.

4. Virtually all lands within the historic range of the Morro Bay kangaroo rat lacking permanent structures and having suitable soil and slope could probably be made suitable for Morro Bay kangaroo rats given appropriate habitat modifications.

5. The density of Morro Bay kangaroo rats over their occupied range at Bayview was no more than 1.5 animals / ha in 1984. Their total population was estimated at 21 individuals in 1984.

6. The density of Morro Bay kangaroo rats over their occupied range at Bayview was no more than 3.8 animals / ha in 1985. Their total population was estimated at 51 individuals in 1985.

7. The density of Morro Bay kangaroo rats over their occupied range at Bayview was no more than 4.0 animals / ha in 1986. Their total population was estimated at 50 individuals in 1986.

8. The average home range size of Morro Bay kangaroo rats during our study period was .23 ha (95 % confidence interval = .20 — .26 ha). Male home range size did not differ from that of females. Home ranges of different animals overlapped considerably in both time and space.

9. Morro Bay kangaroo rats tend to confine the majority of their movement to an area having a radius of 20 to 40 m. The longest dispersal recorded during the study was 400 m which occurred sometime between 2 capture dates separated by a period of 728 days.

10. Using the regression equation for age (vs) body weight derived from captive, known-aged Morro Bay and Lompoc kangaroo rats; the predicted age of an immature Morro Bay kangaroo rat is:

$$\text{PREDICTED AGE (days)} = 10^{[\text{body weight(g)} + 36.7299] / 50.5566}.$$

11. The predicted date of conception of an immature Morro Bay kangaroo rat is:

PREDICTED CONCEPTION DATE = DATE OF CAPTURE - PREDICTED AGE - 31 DAYS

12. Breeding activity of Morro Bay kangaroo rats (inferred by backdating the estimated ages of immature animals) occurred during the first 6 months of the year; however 76% of the immatures were conceived between March and May. The peak month of breeding occurred in April when 48 % of the immatures were conceived.

13. There are several ways of estimating the amount of habitat required to support the preliminary recovery goal of 2,500 Morro Bay kangaroo rats. One way is to extrapolate required habitat using density estimates derived from the wild population at Bayview. Assuming a density of 4 animals / ha, the amount of habitat required to support 2,500 individuals would be 625 ha (= 2.4 square miles). Caution should be taken in interpreting this habitat estimate because it is completely dependent upon the expected density of animals living in the area. If the density estimate was decreased, then the estimated area of habitat would be increased and vice versa.

14. Another method of estimating required habitat (Lande 1987) is to obtain a rough approximation of the minimum habitat required to successfully support a population using demographic and dispersal characteristics of existing populations. For example, if the net lifetime production of female offspring per female Morro Bay kangaroo rat (R_0) was equal to 1.5 and the root-mean-squared dispersal distance per generation (d_0) was 200 m, then the minimum habitat required to successfully support a population of Morro Bay kangaroo rats would be 90 ha (= 1/3 square mile). From the standpoint of a preliminary recovery goal of 2,500 animals, 90 ha appears to be too small because the rats would have to live at a density of 28 animals/ha which is 7 times higher than the present density at Bayview. Judging from the nearly static population estimates obtained during the last 2 years of our study, the value for R_0 used in the example above is probably too high. If one reduced R_0 to 1.0001 and held the value of d_0 constant at 200 m, then the minimum habitat required to successfully support a population of Morro Bay kangaroo rats would be 363,439 ha (= 1,403 square miles!). Obviously this latter habitat estimate is too high, but it illustrates the important fact that this method of estimating minimum habitat requirements is extremely sensitive to population demographic characteristics (e.g. R_0) as well as dispersal distances (d_0). Since the values of R_0 and d_0 are only crude approximations and have not been measured in Morro Bay kangaroo rats, results of this method, like the results from the density extrapolation method (above) must be regarded as only crude approximations to the problem of estimating habitat requirements for the Morro Bay kangaroo rat.

15. Only 6 small mammal species were regularly caught at the Pecho or Bayview sites — Morro Bay kangaroo rats, dusky-footed woodrats, California pocket mice, California mice, deer mice, and western harvest mice. California ground squirrels and immature rabbits were caught from time to time at the Pecho site.

16. In addition to domestic dogs and cats, other potential Morro Bay kangaroo rat predators in the area include: coyote, gray fox, long-tailed weasel, badger, bobcat, southern alligator lizard, gopher snake, common kingsnake, western rattlesnake, northern harrier, Cooper's hawk, red- shouldered hawk, red-tailed hawk, American kestrel, barn owl, and great horned owl.

17. The species richness of the the small mammal communities occupying undisturbed habitat at the Pecho site ranged from 2 species (deer mice and California pocket mice or deer mice and western harvest mice) on some plots to 5 species (dusky-footed woodrats, California mice, California pocket mice, deer mice, and western harvest mice) on other plots. Although western harvest mice had the highest densities on undisturbed habitat at Pecho in 1983, deer mice had the highest densities in 1984, 1985, and 1986. The general pattern of small mammal community structure on undisturbed habitat at Pecho was one in which deer mice were usually the species with the highest density and either western harvest mice or California pocket mice had the second highest density. Dusky-footed woodrats and California mice were typically found in scattered patches of dense brush and small trees.

18. The species richness of the small mammal communities occupying cleared habitat at the Pecho site gradually dropped to either 3 or 4 species (California pocket mice, California mice, deer mice, and western harvest mice). The removal of brush was responsible for the disappearance of dusky-footed woodrats and the extremely low densities of western harvest mice during the last two years of the study. Brush removal had no noticeable effects on deer mouse populations, however the cleared habitat appeared to be more favorable to California pocket mice later in the study. The appearance of California ground squirrels on one of the cleared plots appears to be related to a prescribed burn in the immediate vicinity of this plots.

19. The species richness of small mammal communities occupying burned habitat at the Pecho site sharply dropped to 3 species (deer mice, California pocket mice, and western harvest mice) after the fires. Although the effects of burning were more immediate than those of brush removal, the general small mammal population responses were comparable (ie. deer mice and California pocket mice persisted, dusky-footed woodrats and western harvest mice disappeared, and California ground squirrels appeared). The 1984 burn may have created a corridor of open habitat which enabled California ground squirrels living at the base of the dunes to invade the burned plot and then spread eastward into the cleared and undisturbed plots in the vicinity of the burn. The spread of California ground squirrels into manipulated habitats represents a serious obstacle to the future introduction of Morro Bay kangaroo rats at these sites.

20. The species richness of small mammal communities occupying undisturbed habitat at the Bayview site ranged from 2 — 6 species (Morro Bay kangaroo rats, dusky-footed woodrats, California pocket mice, California mice, deer mice, and western harvest mice); however the predominant small mammal community at Bayview was composed of Morro Bay kangaroo rats and California pocket mice living at fairly low densities. A few dusky-footed woodrats, California mice, and western harvest mice occupied scattered patches of dense plant cover and deer mice occurred sporadically throughout the Bayview site. In addition to the obvious differences in the species composition between Bayview and Pecho, the combined densities of all small mammals inhabiting the Bayview site on any given year were markedly less than those found on either the undisturbed or manipulated areas at Pecho. It could be that Morro Bay kangaroo rats adversely affect populations of other small mammals or it could be that the habitat at Bayview simply cannot support as many rodents as that at Pecho. The former rather than the latter possibility seems more likely because dusky-footed woodrats, California pocket mice, California mice, and deer mice were all found living at much higher densities in areas immediately adjacent to the Bayview site which were not occupied by Morro Bay kangaroo rats.

In the absence of other explanations, it appears that there is at least circumstantial evidence indicating that some sort of negative interaction exists between Morro Bay kangaroo rats and other species (eg. California pocket mice, deer mice, and western harvest mice) normally found in habitat similar to that occupied by the rats.

21. Even though burning and clearing did not produce a numerically depauperate small mammal community like that seen at Bayview; burning and, after several years, brush removal did suppress populations of dusky-footed woodrats, California mice, and western harvest mice. The burned areas are probably more suitable for reintroducing Morro Bay kangaroo rats simply because they cover more area and the two common species there (deer mice and California pocket mice) also occur on habitat already occupied by Morro Bay kangaroo rats at Bayview.

22. Principal Component Analysis revealed fairly good segregation of the small mammal communities at Bayview from those at Pecho. However, both cluster analysis and PCA failed to show a clear pattern of segregation among the 3 different habitat categories (undisturbed, cleared, and burned) at Pecho. This supports the earlier conclusion that populations of the two dominant small mammal species (deer mice and California pocket mice) were not significantly altered by brush removal or burning on the Coastal Dune Scrub habitat in that area.

IV. BOTANICAL STUDIES

Although the overall botanical objective was to quantitatively describe the vegetative components of habitat preferred by Morro Bay kangaroo rats, a substantial body of information also was collected on the variation in plant community structure and interactions between plant communities in the area. Detailed study of plant succession processes following brush clearing and burning experiments also were possible during the course of the study. A number of Rare, Endangered, or Threatened plants were found during the study and these are given special consideration at the end of this chapter. Methods, summary results, and conclusions of these studies are all incorporated in this chapter. Additional analyses of habitat relationships of Morro Bay kangaroo rats are presented in Chapter V.

METHODS

Quantitative sampling of the vegetation on the Pecho site was carried out on 7 study plots from 1983 to 1987. Plots ABC, JKL, and AA–EE were used as undisturbed, control plots; plots DEF and GHI were used to assess the effects of manual brush removal; and plots TUVWX and FF–JJ were used to assess the effects of fire.

Vegetation sampling was carried out using both the line intercept and the quadrat methods (Cox 1980). The line intercept method involved stretching a 10 m tape out from a station marker along a line and taking measurements on the plants which intercepted the tape. For plots ABC, DEF, GHI, and JKL, data were collected at five stations (0+00, 0+50, 1+00, 1+50, and 2+00) along each line resulting in a total of 50 m sampled per line and 150 m per plot (Fig. 2–5). For plots TUVWX, AA–EE, and FF–JJ, sampling was conducted at every marker. Since these plots contained five lines, a total of 50 m per line and 250 m per plot were sampled. The layout of the sample lines is illustrated in Holland (1986).

Control plots ABC and JKL were sampled in 1983, 1984, and 1986 while plot AA–EE was sampled in 1985, 1986, and 1987. Cleared plots DEF and GHI were sampled before they were cleared in 1983 and afterwards in 1983, 1984, and 1986. Plot TUVWX was sampled before it was burned in 1984 and afterwards in 1985 and 1986 (the 1985 sampling consisted of the quadrat method only). Plot FF–JJ was sampled before it was burned in 1985 and afterwards in 1986 and 1987.

Quantitative vegetation sampling at Bayview included 3 plots (NOP, QRS, KKLLMM) and 5 transect lines (S, T, U, V, and X). All sampling at the Bayview site was carried out using the line intercept method as described above. Plots NOP and QRS were sampled in 1984 and 1986. Plot KKLLMM and lines S, T, U, V, and X were sampled in 1985. For plots NOP and QRS, all 5 stations along the lines were sampled for a total of 50 m per line and 150 m per 1/2 ha plot. Every other station was sampled along the lines of plot KKLLMM resulting in 50 m per line and 150 m for the 1 ha plot. Lines S, T, and U were 200 m long and each consisted of 9 marked stations. All 9 stations were sampled for lines T and U (90 m sampled) and 8 were sampled for line S (80 m sampled). Line X was 300 m long and consisted of 13 stations. All 13 stations were sampled for a total of 130 m sampled. Line V was 125 m long and consisted of 6 stations. Five stations were sampled on line V for a total of 50 m sampled (Holland 1986).

Measurements recorded at each sampling station included actual intercept distance along the tape, crown diameter perpendicular to the tape, height of the plant and clearance of the plant above the soil surface. From these measurements, relative and absolute density, cover, and frequency as well as importance values (the sum of the relative values) were calculated for each plant species using a Macintosh computer program written by Rosemary Bowker, Biological Sciences Department, Cal Poly, San Luis Obispo, CA.

The quadrat method (1 m^2) also was used to sample the herbaceous vegetation from April — June in 1985 and 1986 on plot TUVWX following the controlled burn of October, 1984. One cleared plot (DEF) and one control plot (ABC) also were sampled using the quadrat method in spring, 1985. In order to get a more detailed representation of the plots, two additional stakes were added to subdivide the 25 m intervals into 8.33 m intervals. These stakes were marked like the others (e.g. 0+8.33, 0+16.67, etc.). Therefore, each line had stakes placed the entire length at 8.33 m intervals resulting in 25 sample stations per line and 75 stations for the 50 m X 200 m plots. The 100 m X 100 m plot (TUVWX) had 13 sample stations per line and 65 stations per plot.

The square meter sampling quadrat was placed on the south side of the stake towards the next highest numbered stake (except for line F). On line F, the quadrat was placed on the north side of the stakes because a sharp habitat border between uncleared brush and the cleared plot was located immediately to the south of line F. In areas where the shrubs were large and dense, the quadrat was placed in its proper location on top of the shrubs and the understory plants below were measured.

Plots ABC, DEF, and TUVWX were sampled using the one square meter quadrat at all stations in March and April, 1985. Plot TUVWX was sampled again in late May — early June, 1985. The two sampling periods were used to evaluate vegetational changes with season during the first year. All the species rooted within the quadrat were counted and their percent cover within the quadrat was estimated visually. In 1986, all of the plots at the Pecho site (ABC, DEF, GHI, JKL, TUVWX, AA—EE, and FF—JJ) were sampled again with the square meter quadrat following the same methodology as used in 1985. Quadrat placement in 1986 was as close as possible to that used in 1985. Photographs of each quadrat were taken both years in order to document visual estimates and follow succession in subsequent years. These data were then used to calculate absolute and relative density, frequency, and cover. The relative values were then averaged to derive an importance value (refer to Holland 1986 for detailed accounts of the methods and results of these procedures).

Because the Bayview study plots were sampled using only the line intercept method, we decided to use only the line intercept data for comparisons among plots. The only exception is that quadrat data for TUVWX also were included so that plant succession following the fire could be evaluated in more detail. We also decided that plant cover and frequency of occurrence were the best quantitative means of describing the habitat of Morro Bay kangaroo rats. The amount of a plot covered by each plant species seemed to us to be a more important habitat measure than the density of plants found on the plot.

Morro Bay kangaroo rat food plants were considered to be those species which were reported to have a relative preference (REL. PREFER.) of high (H), medium (M), or low (L) when offered to 6 captive Morro Bay kangaroo rats (Stewart 1958). The species list below [modified from Table 5, pages 44-45, in Stewart (1958)] is included here in an attempt to distribute it to a wider audience of readers.

SCIENTIFIC NAME	COMMON NAME	REL. PREFER.	PARTS EATEN
Abronia spp.	sand-verbena	H	seed, pod
Arctostaphylos morroensis	Morro manzanita	L	seed, berry
Bromus spp.	brome	H	seed, leaf, stem
Ceanothus cuneatus	buckbrush	L	seed, leaf
Cirsium occidentale var. *occidentale*	thistle	H	seed
Corethrogyne filaginifolia	California aster	H	seed
Croton californicus	croton	M	seed
Cryptantha clevelandii var. *hispidissima*	cryptantha	H	seed
Dudleya caespitosa	dudleya	H	seed, leaf, stem
Eriastrum densifolium	wolly gilia	H	seed, pod
Ericameria ericoides	mock heather	H	seed
Eriogonum parvifolium	coastal buckwheat	M	seed, flower
Eriophyllum confertiflorum	common golden-yarrow	M	seed
Erodium cicutarium	redstem filaree	H	seed, leaf
Hemizonia increscens	tarweed	M	seed
Horkelia cuneata	silverweed	H	seed, pod, leaf
Lotus scoparius	deerweed	H	seed, leaf, stem
Lupinus arboreus	tree lupine	H	seed, leaf, stem
Lupinus chamissonis	coastal silver lupine	H	seed, leaf, stem
Mimulus aurantiacus	sticky monkeyflower	M	seed
Mucronea californica	spineflower	H	seed
Salvia mellifera	black sage	H	seed
Stephanomeria virgata	wire-lettuce	H	seed

RESULTS AND DISCUSSION

PECHO UNDISTURBED PLOTS

Overall, the Pecho area averaged about 59% living vegetation cover, 12% cover by dead standing plants, and 29% bare ground (Table 4–1). All of the study plots had at least 50% living vegetation cover; however, plant cover and bare ground varied from plot to plot and from year to year. The most densely vegetated plot from 1983-86 was ABC with 63–73% cover by living vegetation and 17–32% bare ground. The least densely vegetated plots were JKL and GHI. Plot JKL had 52–66% living vegetation cover and 25–36% bare ground. Before GHI was cleared, it had 53% living vegetation cover and 37% bare ground. All plots, except ABC in 1983, had between 25 and 37% bare ground. Standing dead vegetation covered about 12% of the Pecho site with a range of 5% (ABC, 1986) to 17.5% (FF–JJ, 1985).

The composition and structure of the vegetation at the Pecho site was variable even within plots. In some places shrubs formed a complete canopy; whereas, in other places they were widely spaced. In general, the vegetation was composed of scattered shrubs with an understory of subshrubs, herbs, and bare ground under and between the shrubs. The percentage of living plant cover composed of shrubs varied considerably (33–68%) from plot to plot and year to year. The largest coverage of shrubs was on plots AA–EE and TUVWX (before it was burned) where shrubs accounted for almost 2/3 of the living plant cover. The only other plots where shrubs comprised over 50% of the living vegetation were GHI (before it was cleared) and FF–JJ (before it was burned). The lowest shrub cover (32–47%) was found on plot ABC where the vegetation was composed mostly of subshrubs and herbs (53–67%).

During the four years of the study, there was a weak trend toward increased cover by shrubs on some of the undisturbed plots. For example, relative shrub cover on plot ABC increased from 33% in 1983 to 47% in 1986 and from 39% to 48% on plot JKL during the same period. In contrast, Plot AA–EE showed a slight decrease in relative shrub cover from 1985 to 1986. Almost 60% of the living vegetation cover at the Pecho site was composed of plants known to be used as food by Morro Bay kangaroo rats. In fact, food plants accounted for over 50% of the living vegetation cover on all but plot GHI in 1983 (Table 4–1).

All of the Pecho plots were more or less similar in species composition, but the actual cover values for individual species varied from plot to plot and year to year. Overall, the dominant plants in terms of coverage were *Artemisia californica* (10.6%) *Ericameria ericoides* (9.8%), *Lotus scoparius* (8.1%), and *Salvia mellifera* (6.5%). All of these plants were found in every plot; however some had low cover values in a few places. Only *Ericameria ericoides* had cover values of over 5% in every plot (range: 5.1% to 16.2%). *Artemisia californica* was one of the dominants in every plot except JKL and *Lotus scoparius* was a dominant in every plot except GHI before it was cleared and TUVWX before it was burned. *Salvia mellifera* was among the dominants on three of the plots: ABC, JKL, and AA–EE. *Carpobrotus* spp. were among the dominants on two of the plots (ABC and JKL), but was uncommon or absent on the other plots. *Dudleya caespitosa* was found on every plot and was a dominant on some in 1983. It is interesting to note that *Dudleya caespitosa* showed a general decline in the Pecho area from 1983 to 1986. *Prunus fasciculata* var. *punctata* had a patchy distribution and was found on about half of the plots; however, it was a dominant on AA–EE as well as TUVWX and FF–JJ before they were burned. *Prunus ilicifolia* was found on only 42% of

Table 4-1. Line intercept coverage values (%) for plant species found on Pecho undisturbed study plots including the cleared and burned plots (DEF, GHI, TUVWX, FF-JJ) before they were disturbed

Plant Species	ABC 83	ABC 84	ABC 86	DEF 83	GHI 83	JKL 83	JKL 84	JKL 86	TUVWX 84	AA-EE 85	AA-EE 86	FF-JJ 85	Mean	Freq. %
Achillea borealis	0.2	-	-	0.4	0.3	0.6	-	-	-	0.3	*	*	0.2	58
Artemisia californica	8.8	12.5	12.5	13.7	11.1	3.0	4.4	4.1	25.1	12.9	12.4	6.7	10.6	100
Cardionema ramosissmum	9.4	5.4	5.3	4.1	1.7	2.5	0.6	1.7	0.3	0.1	0.1	0.1	2.6	100
Carpobrotus spp.	11.6	15.1	12.8	1.2	*	12.2	8.7	9.1	-	-	-	-	5.9	67
Ceanothus cuneatus	7.6	4.5	10.1	2.5	*	16.9	12.1	12.5	0.8	-	-	-	5.6	75
Corethrogyne filaginifolia	4.2	8.9	4.3	4.4	3.8	4.6	4.6	3.8	7.4	3.2	4.4	13.5	5.6	100
Croton californicus	4.0	4.3	3.8	6.6	1.2	5.8	2.5	3.1	3.5	2.5	3.7	2.4	3.6	100
Dudleya caespitosa	11.3	3.3	4.5	9.8	8.1	6.5	2.0	2.4	2.0	2.3	4.7	1.6	4.9	100
Ericameria eriocoides	5.1	6.9	7.4	8.7	9.2	7.0	5.8	5.6	14.0	15.8	16.2	15.1	9.8	100
Eriogonium parvifolium	0.5	0.5	0.2	2.3	1.8	0.8	1.2	2.1	3.1	3.4	3.8	4.6	2.0	100
Eriophyllum confertiflorum	0.3	*	*	0.5	0.2	2.8	*	0.1	1.9	2.2	2.0	1.2	1.0	75
Eschscholzia californica	-	-	-	1.2	2.2	0.6	*	0.1	1.1	-	0.7	0.2	0.5	50
Helianthemum scoparium	0.2	0.2	0.9	-	0.1	0.6	0.6	0.7	-	-	-	-	0.3	58
Horkelia cuneata	1.0	0.7	0.5	1.9	0.1	0.8	0.6	0.6	-	-	-	0.4	0.6	75
Lotus scoparius	12.3	10.0	11.2	6.7	4.3	9.8	9.5	9.1	4.0	8.3	7.4	5.2	8.1	100
Lupinus chamissonis	2.2	2.6	1.5	*	-	-	-	-	1.4	2.0	2.2	4.2	1.3	67
Prunus fasciculata	-	-	-	*	2.5	0.1	-	-	5.3	13.3	15.5	8.9	3.8	58
Prunus ilicifolia	-	-	-	6.7	10.8	0.4	5.8	1.5	4.1	-	-	-	2.3	42
Salvia mellifera	7.6	2.5	9.7	1.9	2.6	10.4	8.6	9.6	3.2	9.7	10.8	0.4	6.5	100
Solanum xanti	-	-	-	-	0.1	-	-	-	0.8	0.2	0.3	-	0.1	33
Misc. herbaceous plants	8.8	3.1	3.2	8.2	6.0	8.5	7.5	6.6	2.2	2.3	2.7	2.5	5.1	100
Misc. shrubs	-	-	-	0.1	-	2.9	-	-	2.4	-	-	-	0.5	25
% Living vegetative cover	65.0	72.9	63.4	54.5	53.2	65.7	52.2	55.0	65.6	55.1	56.2	51.7	59.2	100
% Non-living plant cover	8.5	10.4	5.1	16.2	9.6	9.8	13.9	8.6	11.6	15.0	16.5	17.5	11.9	100
% Bare ground	26.5	16.7	31.5	29.3	37.2	24.5	33.9	36.4	22.8	29.9	27.3	30.8	28.9	100
% Veg. cover by shrub	32.9	36.0	46.9	41.5	54.8	39.0	49.3	47.7	65.3	68.4	65.7	52.7	49.6	100
% Veg. cover by subshrub/herb	67.1	64.0	53.1	58.5	45.2	61.0	50.7	52.1	34.7	31.6	34.3	47.3	50.4	100
% Cover in food plants	59.0	54.9	60.6	56.1	47.4	67.6	63.0	56.9	50.0	62.9	63.5	72.5	59.7	100
% Cover non-food plants	41.0	45.1	39.5	43.9	52.6	32.4	37.0	43.1	50.0	37.1	36.5	27.5	40.3	100

_ Not present on sampled line * Present at less than 0.1% cover

the plots but often covered large areas where it was found. It was a dominant on DEF and GHI before these plots were cleared of brush and ice plant (Table 4—1).

BAYVIEW PLOTS AND LINES

The Bayview plots and lines tended to be quite similar in structure and composition (Table 4—2). Overall, the Bayview area had about 56% living plant cover, 8% cover by dead standing plants, and 35% bare ground; although there was variation from place to place and year to year. The most densely vegetated plot was KKLLMM which had 66% cover by living plants and only 28% bare ground. The least densely vegetated sample site was line V where living plants covered 45% and bare ground 54%. Plots NOP and QRS had about 60% living plant cover in 1984 and 50% in 1986. Overall, subshrubs and herbs made up over 60% of the living plant cover at Bayview compared to less than 40% by shrubs. The only exceptions were plot KKLLMM, line S, plot QRS in 1986, and line U. Shrub cover was about equal to subshrub and herb cover on these latter plots and lines.

Bare ground covered an average of 35% of the Bayview site. Only line V had more than 50% bare ground. Cover by standing dead vegetation was extremely variable over the Bayview site. The average cover of standing dead vegetation on all plots and lines was 8.4% with a range of 1.5% (line V, 1985) to 20.4% (plot QRS, 1986). The percentage of plant cover composed of plants known to be used as food by Morro Bay kangaroo rats was extremely high at Bayview (72—80% on plots QRS and NOP and over 90% on plot KKLLMM as well as all the lines).

The two species that were consistently dominant or co-dominant over the entire study site were *Horkelia cuneata* and *Lotus scoparius*. They covered 19.6% and 17.1% of the area, respectively, accounting for over 1/3 of the total plant cover. They were also found on every plot and line. *Horkelia cuneata* was the dominant species on every plot and line except NOP. It covered 24—30% of plots QRS and KKLLMM, 16—28% of the lines, but only 2—3% of plot NOP. *Lotus scoparius* was the dominant on NOP, covering 31% and 24% of the plot in 1984 and 1986, respectively. It was also co-dominant with *Horkelia cuneata* on every plot and line except plot KKLLMM and line S. On these, *Lotus scoparius* was common, but its absolute cover was only 6% and 4%, respectively.

Other plants that were found on at least 80% of the plots and lines with average cover values of 5% or more were: *Salvia mellifera* (7.3%), *Ceanothus cuneatus* (6.9%), *Artemisia californica* (6.4%), and *Ericameria ericoides* (6.4%). *Salvia mellifera* was found on every plot and line with cover values over 5%, except plot QRS in 1984 and lines T and V. *Ceanothus cuneatus* was found on 90% of the plots and lines and had absolute cover values of over 9% on plots NOP and KKLLMM and lines S and T. It was not one of the dominants on either plot QRS or line V and it was not found at all on line U. *Ericameria ericoides* was found on 90% of the plots and lines and had coverage values of over 6% on plots QRS and KKLLMM as well as lines S, T, and U. It was not common on plot NOP and line V. *Artemisia californica* was found on 80% of the plots and lines and was the dominant plant on plot QRS. It also was one of the dominants on NOP but not on KKLLMM or on any of the lines (Table 4—2).

COMPARISON OF UNDISTURBED PECHO AND BAYVIEW PLOTS

Although the overall species diversity of the Pecho plots was higher than that of the Bayview plots, a comparison of the two sites (Table 4—3) reveals several similarities in overall vegetation characteristics. The two areas were covered by about the same

Table 4-2. Line intercept coverage values (%) for plant spceis on Bayview study plots NOP, QRS, KLM and lines S, T, U, V fron 1984 to 1986.

Plant Species	NOP 84	NOP 86	QRS 84	QRS 86	KLM 85	S 85	T 85	U 85	V 85	Mean	Freq. %
Arctostaphylos morrensis	2.6	1.4	-	-	7.3	3.9	3.1	8.6	4.3	3.5	77.8
Artemisia californica	7.0	4.8	13.4	26.1	1.7	3.9	-	0.4	-	6.4	77.8
Cardionema ramosissmum	0.2	1.4	0.2	0.1	0.6	-	1.4	0.7	1.7	0.7	88.9
Carpobrotus spp.	3.7	4.4	-	-	-	-	-	-	-	0.9	22.2
Ceanothus cuneatus	9.1	12.1	0.8	3.1	13.0	9.1	13.5	-	1.6	6.9	88.9
Corethrogyne filaginifolia	2.7	3.7	0.8	0.6	*	-	0.1	-	-	0.9	66.7
Croton californicus	8.1	10.3	5.5	0.4	2.9	2.8	2.0	4.7	0.4	4.1	100.0
Dudleya caespitosa	-	-	0.5	0.4	0.4	-	*	-	0.2	0.2	55.6
Ericameria eriocoides	-	0.3	6.2	10.8	10.7	12.7	8.6	6.8	1.9	6.4	88.9
Eriogonium parvifolium	0.3	2.0	4.8	4.2	-	4.1	3.3	5.9	1.2	2.9	88.9
Eriophyllum confertiflorum	0.1	0.2	0.2	0.1	0.9	-	0.7	-	-	0.2	66.7
Eriophyllum multicaule	-	-	0.4	0.1	-	-	-	-	-	0.1	22.2
Helianthemum scoparium	-	0.4	-	-	0.3	-	0.4	-	-	0.1	33.3
Horkelia cuneata	1.9	3.1	23.9	30.0	27.6	22.9	23.1	16.0	28.3	19.6	100.0
Lotus scoparius	31.2	24.0	18.4	13.9	6.0	4.3	16.0	9.5	10.7	17.1	100.0
Prunus fasciculata	-	3.2	-	-	-	-	-	3.1	-	0.7	22.2
Prunus ilicifolia	-	0.5	-	-	-	-	-	-	-	0.1	11.1
Salvia mellifera	5.0	7.3	0.6	7.6	17.1	11.7	1.6	14.5	0.5	7.3	100.0
Solanum xantii	-	-	0.1	0.1	-	-	-	-	-	*	22.2
Misc. herbaceous plants	4.6	3.5	1.2	1.4	0.9	0.5	0.6	0.5	0.7	1.5	100.0
% Living vegetation cov.	60.1	49.9	62.4	47.1	66.0	61.4	58.0	56.3	44.8	56.2	100.0
% Non-living plant cover	6.0	15.5	9.1	20.4	5.9	6.3	2.1	6.4	1.5	8.4	100.0
% Bare ground	31.9	34.6	28.5	32.4	28.1	32.3	39.9	37.3	53.7	35.4	100.0
% Living veg. in shrubs	31.0	36.0	27.3	48.1	55.7	54.4	35.0	47.2	16.1	39.3	100.0
% Living veg. herb/sub	69.0	64.0	72.7	51.9	44.3	45.6	64.0	52.8	83.9	60.7	100.0
% Cover in food pants	79.7	78.0	80.3	71.9	96.1	94.2	96.8	93.4	95.3	86.8	100.0
% Cover in non-food plts	20.3	22.0	19.7	28.1	3.9	5.8	3.2	6.6	4.7	13.2	100.0

- Not present
* Present but cover less than 0.1%

Table 4-3. Comparison on mean cover and frequency values (%) for plant species found in the undisturbed plots in the Bayview and Pecho study sites.

	BAYVIEW CONTROL PLOTS		PECHO CONTROL PLOTS	
	Cover %	Freq. %	Cover %	Freq. %
Achillea borealis	-	-	0.2	58
Arctostaphylos morroensis	3.5	22	-	-
Artemisia californica	6.4	78	10.6	100
Cardionema ramosissmum	0.7	89	2.6	100
Carpobrotus spp.	0.9	22	5.9	67
Ceanothus cuneatus	6.9	89	5.6	75
Corethrogyne filaginifolia	0.9	67	5.6	100
Croton californicus	4.1	100	3.6	100
Dudleya caespitosa	0.2	56	4.9	100
Ericameria eriocoides	6.4	89	9.8	100
Eriogonium parvifolium	2.9	89	2.0	100
Eriophyllum confertiflorum	0.2	67	1.0	75
Eriophyllum multicaule	0.1	22	-	-
Erysimum suffrutescens	0.1	22	0.3	25
Eschscholzia californica	-	-	0.5	50
Helianthemum scoparium	0.1	33	0.3	58
Horkelia cuneata	19.6	100	0.6	75
Koeleria cristata	-	-	0.6	25
Lotus scoparius	17.1	100	8.1	75
Lupinus chamissonis	*	11	1.3	67
Marah fabaceus	0.1	22	-	-
Prunus fasciculata	0.7	22	3.8	58
Prunus ilicifolia	0.1	11	2.3	42
Salvia mellifera	7.3	100	6.5	100
Senecio blochmanae	-	-	0.1	25
Solanum xanti	*	22	0.1	33
Toxicodendron diversilobum	-	-	0.6	25
Misc. herbaceous plants	1.5	100	5.1	100
% Total living vegetative cover	56.2	100	59.2	100
% Total bare ground	35.4	100	28.9	100
% Shrub cover	39.2	100	48.5	100
% Subshrub/herbaceous cover	60.8	100	51.5	100
% Vegetation cover by food plants	86.6	100	58.5	100
% Vegetation cover by non-food plants	13.4	100	41.5	100

_Not present on sampled line
* Present at less than 0.1% cover

percentages of living vegetation, non-living vegetation, and bare ground. The vegetation cover at the Pecho site was composed of a slightly higher percentage of shrubs and lower percentage of subshrubs and herbs than that at the Bayview site. Shrubs accounted for 49% of the vegetative cover at Pecho compared to 39% at Bayview. The major difference between the two study areas was in the coverage of plants used for food by Morro Bay kangaroo rats (Stewart 1958). Food plants averaged 86.6% of the total living vegetative cover at Bayview and only 58.5% at Pecho.

The two study areas also were similar in terms of species cover and composition. Most of the dominant plants were common in both areas. For example, the Pecho and Bayview sites had 5 species in common that covered at least 5% of the sites and occurred on at least 75% of the plots and lines: *Artemisia californica, Ceanothus cuneatus, Ericameria ericoides, Lotus scoparius,* and *Salvia mellifera.* While the percent cover of these 5 species varied from plot to plot, their overall combined coverage was 44.1% at Bayview and 40.6% at Pecho. Three species were dominant at Pecho but not at Bayview: *Carpobrotus* spp., *Corethrogyne filaginifolia,* and *Dudleya caespitosa.* All of these plants had absolute cover values of 4.9–5.9% at Pecho compared to 0.2–0.9% at Bayview. Only one species, *Horkelia cuneata,* was dominant at Bayview but relatively insignificant at Pecho. *Horkelia cuneata* had an average cover of almost 20% at Bayview but less than 1% at Pecho. These differences may be significant in terms of identifying preferred habitat for Morro Bay kangaroo rats. Stewart (1958) rated *Horkelia cuneata* as a plant having a high acceptance rat as food by Morro Bay kangaroo rats.

Cover values of the dominant plants at the Pecho and Bayview study sites were quite different (Fig. 4–1). *Horkelia cuneata* (19.6%) and *Lotus scoparius* (17.1%) combined to cover 36.7% of the Bayview site but only 8.7% of the Pecho site. Of this combined cover at Pecho, *Lotus scoparius* accounted for 8.1%. Both species were rated high as food sources for Morro Bay kangaroo rats. The two dominant plants at Pecho were *Artemisia californica* (10.6%) and *Ericameria ericoides* (9.8%) which had a combined cover of 20.4% compared to 12.8% at Bayview. Of these, *Ericameria ericoides* was rated high as a food source for Morro Bay kangaroo rats whereas *Artemisia californica* was not rated. Another interesting difference was that *Arctostaphylos morroensis* was common at the Bayview plots but absent from the Pecho plots (Table 4–3). *Arctostaphylos morroensis* occurs at Pecho, but not within the boundaries of our study plots. It is very common on the hillsides east of the study plots

EFFECTS OF BRUSH REMOVAL ON PECHO PLOTS

The density of vegetation on the undisturbed plots was variable; some areas were fairly open and others were so dense that the canopies of individual shrubs overlapped and were interlaced. This was especially true along drainage areas. Bare ground and/or herbaceous ground cover were extensive on some sites and nearly nonexistent on others. Subligneous species such as *Corethrogyne filaginifolia* and *Lotus scoparius* experience significant seasonal dieback, the former during the winter and the latter during the summer. Heavily woody sclerophyllous shrubs such as *Ceanothus cuneatus* and *Prunus ilicifolia* sometimes completely dominated the areas on which they occurred, casting a dense shade and adding significant annual increments of coarse litter to the ground below.

Vegetation on the cleared plots was obviously more open after the clearing operation. Most individuals and patches of shrubs were cut and the accumulated wood and foliage

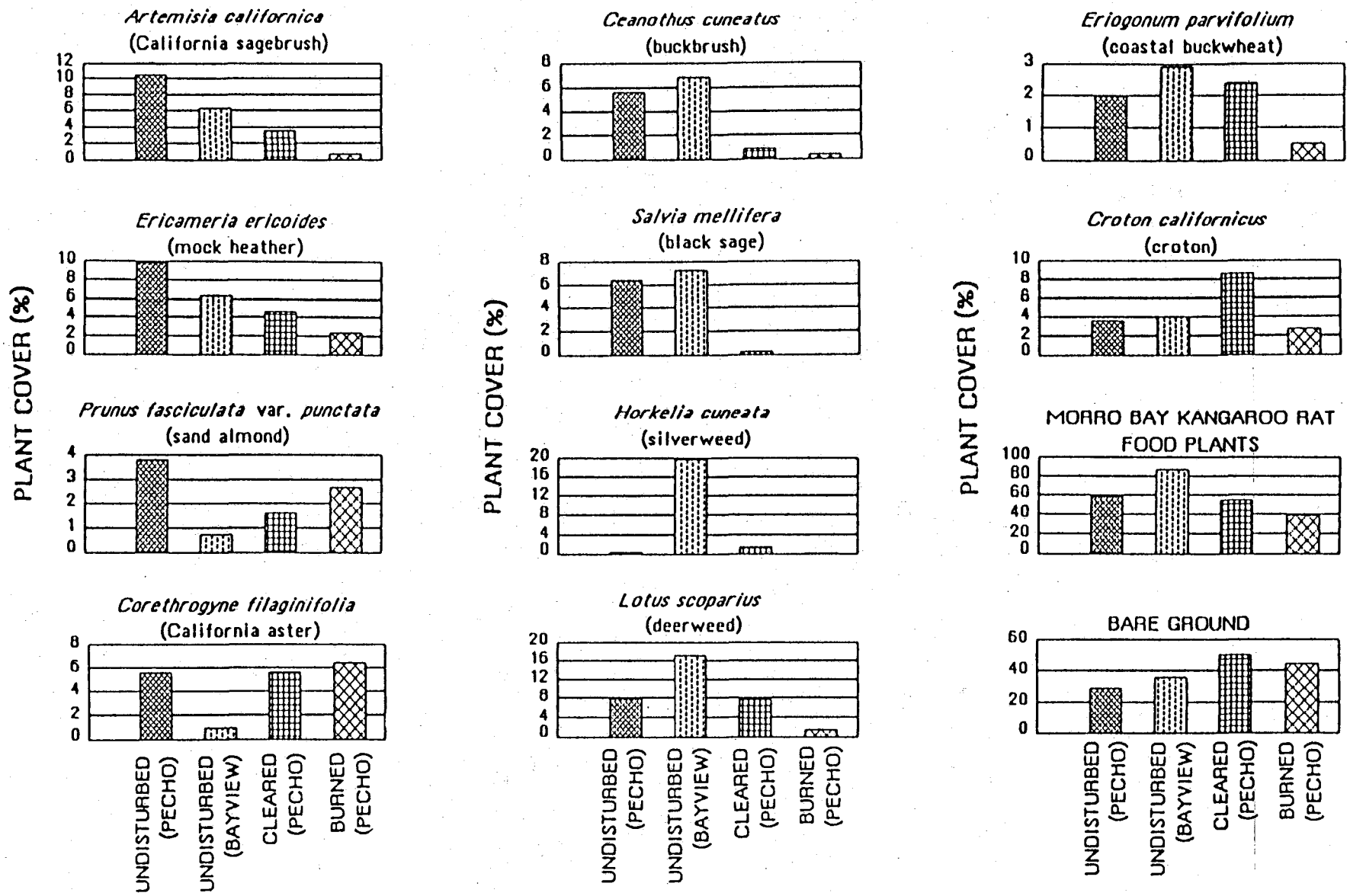


Figure 4—1. Comparison of average cover values (%) of common plant species, bare ground, and Morro Bay kangaroo rat food plants that occur on undisturbed plots at both the Pecho and Bayview sites, cleared plots at the Pecho site, and burned plots at the Pecho site. Note the differences in scale for the cover values of different species.

were hauled away. Some intact shrubs, cut stumps, small branches, and other litter were left on each plot. Overall, about 10–25% of the large shrubs remained, however plot GHI was cleared more than plot DEF. As of 1986, these plots were still more open that the control plots, but the amount of bare ground had decreased and the amount of coverage by living vegetation had increased (Table 4–4). The shrubs also regained a more dominant role on the plots. Many of the cut shrubs resprouted from remaining branches or stumps, but not all species reacted in the same way. Some appeared to have been killed by the cutting (e.g. *Lupinus chamissonis*). Others sprouted back and rapidly returned to their former size (e.g. *Ericameria ericoides, Artemisia californica,* and *Eriogonum parvifolium*). Some, such as *Salvia mellifera,* stump sprouted but showed little evidence of seedling establishment; whereas others, such as *Lotus scoparius* and *Artemisia californica,* had numerous seedlings.

As of 1986, most of the shrubs in the cleared plots had not yet returned to either their former density or their former size. The result was a much greater expanse of bare ground or ground covered by low herbs on these plots. Both gradually decreased with time; however, even at the present time, not all of the shrubs show overlapping canopies. Herbaceous and subligneous species, especially *Croton californicus, Eschscholzia californica, Galium californicum, Gnaphalium bicolor, Cardionema ramosissimum, Senecio californicus,* and *Corethrogyne filaginifolia* appear to have benefited greatly with the opening of the shrub overstory. Individuals of these species were larger and denser after the clearing. They also were larger and denser on the cleared plots than on adjacent uncleared areas and on the control plots. Growth of herbaceous species benefited least in areas formerly covered by dense thickets of *Prunus ilicifolia.* Only *Solanum xanti* appeared to be growing well in these areas immediately after clearing. The litter from the *Prunus ilicifolia* plants may have had an allelopathic effect on herbaceous species. In subsequent years, *Prunus ilicifolia* sprouted back vigorously and rapidly eliminated the opening for invasion by herbs.

The cleared plots had mostly low-growing, scattered shrubs with a greater number and cover of annual and perennial herbs following the clearing. There does not seem to have been any substantial invasion of European weed species in the cleared areas. Succession had involved the species already present on the sites. *Lotus scoparius, Croton californicus,* and *Corethrogyne filaginifolia* have been major beneficiaries of the disturbance. All three are fast-growing subligneous species with a subshrub profile and all three were present in greater numbers on the cleared sites than on undisturbed sites.

Herbaceous vegetation increased at least partly because of the enhanced insolation and decreased competition provided by the clearing of the shrubby overstory. Several herbs were found in more abundance in the cleared plots than in uncleared areas. The most common were *Camissonia micrantha, Mucronea californica, Eschscholzia californica, Gnaphalium bicolor, Cirsium occidentale, Cryptantha californica, Senecio californicus,* and *Galium californicum.* Of these, *Eschscholzia californica,* because of its large, bright flowers, took on an aspect dominance in some cleared areas in late spring.

Total living plant cover was reduced on plot DEF from 55% to 45% by the clearing operation. Dead plants were reduced from 16.2% to 0.2% and bare ground increased from 29% to 55%. The shift from shrubs to herbs and subshrubs as a result of clearing was quite pronounced. Before clearing, the percentage of plant cover composed of shrubs was over 40% compared to 17% immediately after clearing. *Artemisia californica* covered 14% of the plot before clearing and only 3% afterwards. Cover of *Ericameria ericoides* dropped from 9% to 1% while *Prunus ilicifolia* decreased from

Table 4-4. Comparison of cover values for plant species found on Pecho study plots DEF and GHI before (1983) and after hand clearing of brush and ice plant (1983-86). Small p indicates the results of sampling after clearing.

PLANT SPECIES	DEF 83	DEF 83 p	DEF 84 p	DEF 86 p	GHI 83	GHI 83 p	GHI 84p	GHI 86p
Achillea borealis	0.4	0.4	0.1	0.2	0.3	0.2	0.1	*
Artemisia californica	13.7	3.3	2.5	2.7	11.1	2.2	2.1	8.2
Cardionema ramosissmum	4.1	6.4	3.0	3.4	1.7	2.0	2.2	0.8
Carpobrotus spp.	1.2	*	0.2	0.6	*	-	0.6	2.1
Ceanothus cuneatus	2.5	1.7	1.5	2.0	*	-	-	0.2
Chenopodium californicum	0.8	2.5	-	-	0.1	1.6	-	-
Cirsium occidentale	-	-	-	0.2	-	-	-	0.6
Corethrogyne filaginifolia	4.4	2.9	6.0	4.1	3.8	4.1	8.5	8.7
Croton californicus	6.6	5.6	14.7	15.1	1.2	2.1	5.7	8.8
Dudleya caespitosa	9.8	4.3	0.3	0.9	8.1	3.7	1.5	1.0
Ericameria ericoides	8.7	1.0	4.8	5.7	9.2	3.5	5.0	7.9
Eriogonum parvifolium	2.3	2.1	3.2	5.5	1.8	1.7	0.3	1.5
Eriophyllum confertiflorum	0.5	0.1	0.1	-	0.2	0.7	0.3	2.0
Erysimum suffrutescens	1.7	0.1	-	-	2.1	0.3	-	-
Eschscholzia californica	1.2	1.6	*	0.2	2.2	5.8	*	1.3
Helianthemum scoparium	-	-	-	-	0.1	0.6	0.5	1.2
Horkelia cuneata	1.9	2.6	1.5	3.3	0.1	0.2	0.1	0.8
Lotus scoparius	6.7	4.1	4.0	15.8	4.3	3.2	6.0	13.1
Marah fabaceus	0.5	0.3	*	-	-	3.0	-	-
Prunus fasciculata	-	1.1	1.1	0.6	2.5	2.8	2.6	1.6
Prunus ilicifolia	6.7	2.7	2.2	5.3	10.8	1.7	2.0	10.8
Salvia mellifera	1.9	-	-	-	2.6	0.3	0.6	1.0
Senecio californicus	*	1.2	-	-	*	-	*	1.6
Solanum xanti	-	-	-	0.3	0.1	-	0.3	*
Misc. herbaceous plants	5.8	13.6	12.1	9.5	3.2	13.2	6.7	7.2
% Living vegetation cover	54.5	45.0	44.7	49.2	53.2	47.6	45.5	56.3
% Non-living veg. cover	16.2	0.2	1.3	1.5	9.6	0.3	2.5	4.5
% Bare ground	29.3	54.8	54.0	49.3	37.2	52.1	52.0	39.2
% Veg. cov. in shrubs	41.5	16.9	19.8	21.0	54.8	16.7	27.5	36.9
% Veg. cov. in subshrubs/herb	58.5	83.1	81.1	79.0	45.2	83.3	72.5	63.1
% Cover by food plants	56.1	42.8	63.0	70.4	47.4	38.3	62.1	56.7
% Cover by non-food plants	43.9	57.2	37.0	29.6	52.6	61.7	37.9	43.3

_ Not present on sampled line
* Present at less than 0.1% cover

7% to 3% and *Salvia mellifera* decreased from 2% to nearly 0%. Some of the dominant plants before clearing, such as *Dudleya caespitosa*, *Croton californicus* and *Lotus scoparius*, were still dominant immediately afterwards, but their absolute cover percentage decreased. Clearing of the plot resulted in an increase in herbaceous plants such as *Eschscholzia californica*, and *Senecio californica*. One herbaceous species, *Cardionema ramosissimum*, increased in density and cover and was one of the dominants immediately following clearing in 1984 (Table 4—4).

From 1983 to 1986, the vegetation of plot DEF went through secondary succession which resulted in a gradual recovery of dominant shrubs and a gradual decrease in bare ground, herb, and subshrub cover. Percent relative cover by standing dead plants changed very little. The major change was that some of the shrubs resprouted and covered a larger percentage of the plot resulting in an increase in shrub cover from 17% immediately after clearing to 21% in 1986. For example, *Ericameria ericoides* resprouted vigorously and increased from about 1% cover in 1983 to 6% cover in 1986, and again became one of the dominants on the plot. There also were some shifts in dominance among the subshrubs and herbs. *Croton californicus* increased from about 6% in 1983 to about 15% in 1986 and *Lotus scoparius* increased from 4% to 16% and was co-dominant with *Croton californicus* in 1986. Together, these two species covered nearly 1/3 of the plot. *Dudleya caespitosa*, which occurs primarily under shrubs, was reduced to a level where it was no longer a dominant on the plot. Its cover value went from 10% before clearing to 4% immediately after clearing to less than 1% in 1984 and 1986. The diversity and coverage of herbaceous plant species increased significantly after clearing (Table 4—4).

The vegetation on plot GHI responded to clearing in much the same way as that on plot DEF. After the plot was cleared, the total plant cover on plot GHI was reduced from 54% to 47%. Dead plant coverage was reduced from 10% to 0.3% and bare ground increased from 37% to 52%. The percentage of living plant cover composed of shrubs decreased from 55% to about 17%, showing the shift from shrubs to herbs and subshrubs as a result of clearing. The dominant shrubs on the plot decreased markedly as a result of clearing. *Artemisia californica* covered 11% of the plot before it was cleared and only 2% afterwards. Similarly, the cover of *Ericameria ericoides* dropped from 9% to 4%, *Prunus ilicifolia* dropped from 11% to 2%, and *Salvia mellifera* dropped from 3% to less than 1%. Some of the dominants on the plot before it was cleared were still dominant after clearing, but their absolute percent cover decreased. For example, *Ericameria ericoides*, *Dudleya caespitosa*, and *Lotus scoparius* were among the dominants before and after clearing, but all had lower cover values after the plot was cleared (Table 4—4).

The vegetation of plot DEF underwent secondary succession after clearing which resulted in a gradual increase in shrub cover and a concomitant decrease in bare ground, herb, and subshrub cover. Many of the common shrubs resprouted resulting in an increase of relative shrub cover from about 17% immediately after clearing to about 27% in 1984 and 37% in 1986. Cover by bare ground during the same period decreased from 52% to 39% which approached pre-clearing conditions. Standing dead plant cover also increased from less than 1% in 1983 to 5% in 1986 (Table 4—4).

Plot GHI, like plot DEF, showed a gradual shift in relative cover by herbs and subshrubs to shrubs. *Ericameria ericoides* and *Prunus ilicifolia* resprouted vigorously. *Ericameria ericoides* covered 3.5.% of the plot immediately after clearing, but increased to 5% cover in 1984 and 8% cover in 1986. *Prunus ilicifolia* increased from

about 2% cover to almost 11% cover over the same period. There also were some shifts in dominance among the subshrubs and herbs. *Lotus scoparius* showed the largest increase; from 3% cover immediately after clearing to over 13% in 1986. *Croton californicus* increased from about 2% to 9% and *Corethrogyne filaginifolia* increased from 4% to 9% during this same period and was among the dominants in 1986. *Dudleya caespitosa* cover decreased and it was no longer a dominant on the plot. Its cover value went from 8% before clearing to 4% afterwards and less than 2% thereafter. The diversity and cover of herbaceous plant species increased significantly after clearing but gradually decreased as the shrub cover increased on the plot (Table 4—4).

The following is a general summary of the effects of brush clearing:

1. Reduction in number of shrubs, some of which were killed
2. Reduction in size (both height and diameter) of shrubs
3. Reduction in overlap of shrub canopies
4. Increase in amount of bare ground
5. Selective elimination of non-sprouting species
6. Selective enhancement of certain species of herbs and subshrubs

Gradually the two plots are returning to their pre-clearing condition. Most shrubs are both resprouting from the base and/or reproducing by seeds and appear to be approaching their original cover values.

EFFECTS OF FIRE ON PECHO PLOTS

Plot TUVWX

Before the prescribed burn, plot TUVWX was rather densely covered by shrubs and dead plant material. Most of the low, sparse brush carried the fire and was burned completely, but some of the tall, dense brush resisted the fire and was not completely burned. Thus, plot TUVWX included areas that were completely burned and other areas that were not. Before the fire, the plot was covered by 65% living vegetation, 12% dead vegetation, and 23% bare ground (Table 4—5). Of the living vegetation cover, 65% was shrubs and 35% was herbs and subshrubs. After the fire, the overall composition of the plot was obviously very different even though there were some small islands of vegetation that escaped the fire. Quadrat sampling in 1985 showed that the living vegetative cover of the plot had decreased to 44% (from 65%) and almost all (96%) of the vegetative cover was composed of herbs and subshrubs. Thus, as a result of the fire, composition of the plant cover shifted from a dominance by shrubs to a dominance by herbs and subshrubs. Shrubs decreased from 65% to 4% and the herb/subshrub cover increased from 35% to 96% following the fire. The fire burned almost all of the dead vegetation and the percentage of bare ground increased from 23% to over 55% after the burn. From spring 1985 to spring 1986, the living plant cover on the plot increased from 44% to 60% and bare ground decreased from 55% to 25%. However, the vegetation was still dominated by herbs and subshrubs (11% in 1986 compared to 4% in 1985).

The dominant plants in terms of cover before the fire were *Artemisia californica* (25%), *Ericameria ericoides* (14%), *Corethrogyne filaginifolia* (7.4%), *Prunus fasciculata* var. *punctata* (5.3%), and *Prunus ilicifolia* (4%) (Table 4—5). Note that all except *Corethrogyne filaginifolia* were well developed shrubs. About 6 months after the fire (late winter/early spring, 1985), the dominant cover plants were *Senecio*

Table 4-5. Cover values (%) for plant species found on Pecho study plot before and after the October, 1984 control burn.

PLANT SPECIES	TUVWX 84i	TUVWX 85qW	TUVWX 85qSp	TUVWX 86q	TUVWX 86i
Achillea borealis	-	0.8	-	0.9	0.1
Amsinckia spectabilis	-	7.7	10.6	9.9	3.1
Artemisia californica	25.1	0.1	1.2	2.4	0.8
Bromus diandrus	-	*	*	0.1	*
Bromus rubens	-	*	0.1	1.1	0.6
Camissonia micrantha	-	2.9	3.6	1.3	-
Cardionema ramosissmum	0.3	4.2	1.4	2.1	1.2
Carex pansa	-	-	-	0.1	0.1
Carpobrotus spp.	-	*	0.5	0.1	0.1
Ceanothus cuneatus	0.8	0.5	1.7	-	-
Chenopodium californicum	-	1.7	6.6	4.1	1.6
Chorizanthe angustifolia	-	1.1	0.5	1.7	1.6
Cirsium occidentale	-	*	0.3	0.3	2.1
Corethrogyne filaginifolia	7.4	1.2	0.8	0.8	3.4
Croton californicus	2.6	3.5	0.8	2.2	3.5
Cryptantha clevelandii	-	*	0.7	4.0	0.7
Dudleya caespitosa	2.0	0.2	0.3	0.7	0.5
Ericameria ericoides	14.0	1.2	0.9	0.6	2.9
Eriogonum parvifolium	3.1	0.4	*	0.2	0.6
Eriophyllum confertiflorum	1.9	*	0.9	2.2	0.3
Eriophyllum multicaule	-	0.1	4.7	7.9	8.9
Erysimum suffrutescens	-	*	0.2	0.3	0.8
Eschscholzia californica	1.1	0.9	0.5	1.8	5.0
Horkelia cuneata	-	*	0.1	0.1	0.1
Lotus scoparius	4.0	1.1	0.7	2.3	2.9
Lupinus chamissonis	1.4	0.1	0.1	*	*
Marah fabaceus	-	2.8	2.2	1.6	0.3
Melica imperfecta	-	-	-	0.8	0.8
Mucronea californica	-	*	0.1	0.2	0.8
Orthocarpus purpurascens	-	*	*	0.4	*
Phacelia distans	-	2.0	0.9	2.9	2.1
Prunus fasciculata	5.3	*	*	1.2	3.9
Prunus ilicifolia	4.1	1.6	1.1	3.1	2.7
Salvia mellifera	3.2	0.1	*	*	*
Senecio blochmanae	1.3	*	*	0.3	*
Senecio californicus	-	9.3	*	0.1	0.1
Solanum xanti	0.8	*	1.5	1.3	3.6
Stephanomeria virgata	-	*	*	3.1	5.5
Toxicodendron diversilobum	2.4	*	0.1	0.1	0.8
Vulpia myuros	-	-	-	0.6	*
Misc. herbaceous plants	1.1	3.1	1.1	3.8	1.4

continued on next page...

Table 4-5 Cont.	TUVWX 84i	TUVWX 85qW	TUVWX 85qSp	TUVWX 86q	TUVWX 86i
% Living vegetation cover	65.6	44.3	27.6	60.0	53.1
% Non-living vegetation cover	11.6	0.3	15.3	15.5	3.8
Bare ground	22.8	55.4	57.1	24.5	44.8
% Living veg. in shrubs	65.3	4.0	18.9	11.3	5.0
% Living veg. in subshr/herbs	34.7	96.0	81.1	88.7	95.0
% Veg. cover, food plants	50.0	26.6	41.1	26.8	26.4
% Veg. cover, non-food plants	50.0	73.4	58.9	73.2	73.6

_ Not present on sampled line
* Present at less than 0.1% cover

W-Sampled during Feb.-March, 1985
Sp-Sampled during April-May, 1985

i- Sampled using Line Intercept Method
q-Sampled using Quadrat Method

californicus (9.3%), *Amsinckia spectabilis* (7.7%), *Cardionema ramosissimum* (4.2%), *Croton californicus* (3.5%), and *Camissonia micrantha* (2.9%). Just 1—2 months later (late spring, 1985) the dominants were *Amsinckia spectabilis* (10.6%), *Chenopodium californicum* (6.6%), *Eriophyllum multicaule* (4.7%), and *Camissonia micrantha* (3.6%). *Senecio californicus*, an herbaceous annual, dried up in that short period of time and was no longer among the dominants. In the spring of 1986, the dominants on the plot were the same as those in the late spring of 1985; *Amsinckia spectabilis*, *Eriophyllum multicaule*, and *Chenopodium californicum*. *Cryptantha clevelandii* was among the dominants in 1986; whereas *Camissonia micrantha*, which had been among the dominants in 1985, dropped to about a 1% cover in 1986 (Table 4—5). In 1986, Plot TUVWX also was sampled using the line intercept method. The results of this sampling were similar to those of the quadrat sampling that year except for minor shifts in relative cover of the individual species. The differences were partly attributable to the time of sampling (late spring/early summer for the line intercept and early spring for the quadrat) as well as differences in methodologies.

The shrubs that were dominant before the fire were reduced significantly by the fire, as one would expect. *Artemisia californica* dropped from a cover of 25% in 1984 to about 1% in 1985, *Ericameria ericoides* dropped from 14% to about 1%, *Corethrogyne filaginifolia* dropped from 7.4% to 1%, *Prunus fasciculata* var. *punctata* dropped from 5.3% to less than 1% and *Prunus ilicifolia* dropped from 4.1% to 1 % (Table 4—5). By 1986, all of the shrubs had increased somewhat in their cover values, but the plot was still dominated by herbaceous plants. The species diversity increased following the fire as shown by the increased number of species encountered in the line intercept samples (32 in 1984 and 46 in 1986). This increase was due largely to an increase in the number of herbaceous species that were able to occupy the site.

Following the fire, many of the shrubs resprouted from the base and gradually produced a canopy similar to pre-burn conditions. The dominant shrubs before the fire; *Artemisia californica*, *Ericameria ericoides*, *Prunus fasciculata* var. *punctata* and *Prunus ilicifolia* all resprouted and developed extensive growth near their bases. *Ericameria ericoides* resprouted and grew more vigorously than the others and became good-sized shrubs by the fall of 1986. Some seedlings of *Artemisia californica*, *Lupinus chamissonis*, and *Ericameria ericoides* also became established on the plot, but no seedlings of *Prunus* were noted.

Seeds of a number of plants are known to germinate better if they are heat scarified or exposed to residues from charred wood. Some seeds may germinate following the removal of allelopathic substances from the soil. Others may germinate better because of the higher soil nutrient level or because the area has been opened up to more insolation and less competition. This complexity of changes has resulted in a much richer and diverse flora, dominated by herbaceous species, following the fire. The number of plant species found on the site after the fire increased significantly. The complete species list for the plot following the fire reveals about 60 species present within the boundaries of the plot compared to less than 30 species before the fire. It is interesting to note that the few introduced Eurasian weeds that invaded the plot following the fire were mostly restricted to areas along roads and trails, places where these weeds were common before the burn. Weeds penetrated into the fringe areas of the burned site, but few moved into the study plot. The dominant plant cover after the fire was composed of native herbs and subshrubs.

In order to assess the effects of the fire on the soils and soil nutrient levels, the following soil characteristics were measured in control, cleared, and burned areas: sulfate, chloride, phosphate, magnesium, sodium, potassium, calcium, and pH. These measurements were made from soils collected in plots ABC (control), DEF (cleared), and TUVWX (burned) in the spring of 1985 (refer to Holland 1986 for details on sampling and analytical methods). The results revealed that the soil pH of the burned plot was considerably less acidic (6.7) than either the control plot (5.6) or cleared plot (5.7). The burned plot also had higher levels of all nutrients measured: sulfate, chloride, phosphorous, magnesium, calcium, sodium, and potassium. The biggest increases were noted in chloride, phosphorous, calcium, and potassium (Table 4–6). The control and cleared plots showed little differences in soil nutrient levels except that potassium was higher in the control plot.

The effects of the fire on the soil of the plot were that the foliage, stems and litter of most of the plants were consumed in place, leaving a layer of inorganic ash in the sandy soil. Non-volatile nutrients formerly incorporated in the vegetation were released and subsequently incorporated into the upper layers of the soil during the winter rains. As a result, soil fertility in the burned area was much higher than in unburned areas. The pH of the soil became less acidic as a result of the salts present in the ash. It is difficult to predict how long this increased fertility and reduced acidity will last; but, because of the sandy soil, probably not more than a few years. Plants that survived the fire by underground stems such as rhizomes, bulbs, lignotubers, etc. and those that started as seedlings after the fire, appeared to grow more rapidly and to be more productive than those in unburned areas. It appears that any soil chemicals that produce allelopathic effects were inactivated by burning.

Plot FF–JJ

After the fire, vegetation on the plot was obviously different from what it had been before the burn. The most significant changes recorded on the plot were the differences in dominant species, species composition, and the amounts of vegetative cover, bare ground, and dead vegetation. Overall, the vegetation changed from mostly established perennial shrubs and subshrubs to mostly herbaceous annuals. After the burn in October, 1985, the first plants to become established were annuals that are known to be highly adapted to fire and disturbance. It addition to the annuals, several of the perennials and woody shrubs on the plot (e.g. *Croton californicus, Prunus fasciculata* var. *punctata*, and *Ericameria ericoides)* were sprouting from their burned remains but were still quite small. By far, the most dominant species after the fire were the fire-enhanced and other invasive annuals such as *Phacelia distans, Camissonia micrantha, Amsinckia spectabilis, Bromus diandrus,* and *Stephanomeria virgata.*

Probably the biggest change caused by the fire was the increased diversity of species found on the plot after the burn. Of the 24 species found before the fire, 19 survived and re-established themselves after the fire. Five of the 24 species did not become re-established; however, 26 new species were found on the plot after the fire. All of the new species were annual herbs. Contributing to the success of the vegetative growth on the plot was the very large increase in the total number of individual plants after the fire. After a few growing seasons, the large number of annual plants probably will decrease as the shrub and subshrub cover increases. In a few years, one would expect the plot to have a vegetative cover similar to that found before the fire.

Table 4-6. Comparison of soil nutrients from undisturbed (ABC), cleared (DEF) and burned (TUVWX) plots on the Pecho site in spring, 1985. Data are expressed in ppm of dry soil.

	ABC Control Plot	DEF Cleared Plot	TUVWX Burned Plot
Sulfate	1.6	2.8	4.0
Chloride	1.0	1.0	6.3
Phosphorous	9.0	7.5	27.0
Magnesium	74.0	73.0	88.0
Calcium	33.8	32.0	139.6
Sodium	87.0	91.0	95.0
Potassium	140.0	92.0	200.0
pH	5.6	5.7	6.7
Texture	fine sand	fine sand	fine sand

Before it was burned, 52% of plot FF—JJ was covered by living vegetation, 18% by dead vegetation, and 31% by bare ground. Of the living vegetation, 53% was shrubs and 47% subshrubs and herbs. The burn destroyed almost all of the living vegetation leaving only the charred remains of some of the larger shrubs. Fall and winter rains enhanced germination and regrowth of numerous subshrubs and herbs so that by spring, 1986, the plot was again covered by about 52% living vegetation. However, the composition and structure of the vegetation after the fire was very different in that 95% of the plant cover consisted of subshrubs and herbs. The fire also reduced the cover by dead plants and increased the amount of bare ground. In the spring of 1987 (2 years after the fire), cover by living vegetation increased to 62% of the plot, dead plant cover increased to 6% and bare ground decreased to 32%. The plot was still dominated by herbaceous plants and scattered subshrubs which accounted for 85% of the living vegetation. Shrubs continued to resprout and grow but still made up only 15% of the plant cover (Table 4—7).

Before the fire, the dominant plants were *Ericameria ericoides* (15.1%), *Corethrogyne filaginifolia* (13.5%), *Prunus fasciculata* var. *punctata* (8.9%), *Artemisia californica* (6.7%), and *Lotus scoparius* (5.2%). All except *Corethrogyne filaginifolia* are well developed shrubs. When combined, these 5 species made up about 1/2 of the plant cover on the plot. In the first spring following the fire (1986), the dominants were all herbaceous species that were uncommon before the fire; *Eriophyllum multicaule* (36.9%), *Phacelia distans* (16.4%), *Camissonia micrantha* (10.8%), *Amsinckia spectabilis* (9.8%) and *Bromus diandrus* (9.4%). The rest of the plot was covered by miscellaneous herbs and scattered subshrubs. In the second spring after the fire (1987), some of the subshrubs had increased significantly. In fact, *Corethrogyne filaginifolia* became the dominant at 17.6% cover and *Croton californicus* increased to 5.2%. The other dominants were annual herbs that had been dominant the previous spring such as *Amsinckia spectabilis* and *Bromus diandrus.*

Table 4-7. Cover values (%) for plant species found in the Pecho north study plot FF-JJ before and after the controlled burn, October, 1985.

Plant Species	FF-JJ 85	FF-JJ 86p	FF-JJ 87p
Abronia umbellata	0.1	1.8	0.4
Achillea borealis	*	0.5	-
Amsinckia spectabilis	-	9.8	7.4
Artemisia californica	6.7	0.3	0.6
Artemisia dracunculus	1.1	2.1	-
Bromus diandrus	-	9.4	7.4
Bromus rubens	-	1.0	2.5
Camissonia micrantha	-	10.8	-
Camissonia strigulosa	-	2.0	-
Cardionema ramosissmum	0.1	1.5	2.9
Carex pansa	0.3	2.3	0.7
Chenopodium californicum	-	0.8	2.2
Chorizanthe angustifolia	-	2.8	*
Cirsium occidentale	-	0.6	0.3
Corethrogyne filaginifolia	13.5	3.8	17.6
Croton californicus	2.4	1.6	5.2
Cryptantha clevelandii	-	1.5	0.7
Dudleya caespitosa	1.6	0.3	0.4
Ericameria ericoides	15.1	1.2	4.6
Eriogonum parvifolium	4.6	0.1	1.4
Eriophyllum confertiflorum	1.2	-	-
Eriophyllum multicaule	-	36.9	1.1
Eschscholzia californica	0.2	1.0	0.2
Galium nuttallii	0.1	2.1	-
Horkelia cuneata	0.4	0.3	-
Lotus scoparius	5.2	0.3	1.6
Lupinus chamissonis	4.2	-	-
Marah fabaceus	-	2.1	-
Melica imperfecta	-	2.4	1.2
Mucronea californica	-	0.6	-
Orthocarpus purpurascens	-	0.1	-
Phacelia distans	-	16.4	1.4
Prunus fasciculata	8.9	2.1	4.9
Rhamnus crocea	0.9	0.4	0.8
Salvia mellifera	0.4	-	-
Senecio californicus	-	0.3	0.1
Solanum xanti	-	0.3	0.7
Stephanomeria virgata	0.3	0.5	4.1
Toxicodendron diversilobum	1.8	0.7	0.8
Vulpia myuros	-	0.5	-
Misc. Herbs plants	1.1	4.5	5.9

Table 4-7 is continued on next page...

Table 4-7 cont.	FF-JJ 85	FF-JJ 86p	FF-JJ 87p
% Living vegetation cover	51.7	51.9	62.4
% Non-living vegetation cover	17.5	3.3	5.9
% Bare ground	30.8	44.8	31.7
% Veg. cover in shrubs	52.7	5.0	14.6
% Veg. cover in subshr/herb	47.3	95.0	85.4
% Veg. Cov. in food plants	72.5	26.4	63.1
% Veg. Cov. in non-food plants	27.5	73.6	36.9

- Not present on sampled line
* Present at less than 0.1% cover
p-After prescribed burn of October, 1985

SPECIES DIVERSITY

Species diversity of an ecosystem is a measurable biological characteristic that may provide some relationship to the area's suitability as habitat for Morro Bay kangaroo rats. It has been suggested that species diversity reflects organizational features important to the functioning of the ecosystem and may be related to the stability of the ecosystem. Clearly, a plant community with a high species diversity has a more complex network of trophic pathways along which density-dependent animal population control mechanisms may operate. One might expect that the higher the plant species diversity, the higher the animal species diversity because of the variety of habitat and food sources within the site. In addition, clearing and burning will change species diversity of the area as will plant succession following such disturbances. In order to investigate these predictions, the species diversity of all study plots was measured and compared before and after clearing and burning using the following methods: Simpson's Index of Diversity, Shannon-Wiener Diversity Index, and Hulburt's Probability of Interspecific Encounter (Cox 1980 and Barbour et. al. 1980). In every case the diversities were obtained by using cover values of the plants derived from line intercept sampling. Some of the herbaceous species were lumped together for purposes of calculating these diversity indices.

The results (Table 4—8) indicate that all the Pecho plots before clearing and burning had very similar species diversity characteristics. Simpson's Index values for these plots ranged from 0.88 to 0.92. The Bayview plots and lines had lower species diversities with Simpson's Index values that ranged from 0.65 to 0.86. Very similar results were obtained using the Shannon-Wiener Index. The Pecho plots ranged from values of 0.98 to 1.10, whereas the Bayview plots and lines had lower species diversities that ranged from 0.62 to 0.90. Results using Hulbert's Interspecific Encounter Index also were similar, but showed greater variations and differences among the plots than the other two methods. The Pecho plots ranged from values of 7.10 to 11.46; whereas the Bayview plots and lines again had lower species diversities that ranged from 2.85 to 7.24.

The first spring after clearing, plots DEF and GHI showed an increase in species diversity; however after two years, the species diversity on these two plots decreased back to pre-clearing values. In contrast, the burned plots (TUVWX and FF—JJ) showed an increase in species diversity the first spring after the fire and an even greater increase on the second spring after the fire. This indicates that fire more completely opens up and modifies the habitat allowing more species to become established. After a few years, the shrub cover will probably regain full dominance and gradually produce a decrease in species diversity to pre-burn conditions.

All indices indicated that the Pecho plots had a greater species diversity than the Bayview plots. This of great interest since Morro Bay kangaroo rats have only been trapped on the Bayview site where plant species diversity is low. Zoological results showed that Morro Bay kangaroo rats seem to occur on sites where there are fewer species of small mammals present. Perhaps an increased diversity of animal species occurs where there is also an increased diversity of plant species and vice versa. If this is the case, then plant species diversity indices may provide valuable information in assessing the suitability of habitat for Morro Bay kangaroo rats. Plant species diversity indices also may provide valuable information in evaluating the efficacy of clearing and burning as methods to improve habitat for Morro Bay kangaroo rats. If one ignores species composition and cover for the time being and considers only species diversity, then it appears that habitats (either undisturbed or manipulated) having lower species

Table 4-8. Results of species diversity measurements for the Pecho and Bayview study sites including control, cleared and burned plots.

Plots	Simpson's Index	Shannon-Weiner Index	Hulbert's Intraspecific Encounter Index
ABC, 1983	0.91	1.04	10.87
ABC, 1984	0.89	1.00	9.45
ABC, 1986	0.89	0.98	9.21
DEF, 1983	0.91	1.06	10.87
DEF, 1983*	0.94	1.14	16.10
DEF, 1984*	0.86	0.94	7.10
DEF, 1986*	0.87	0.97	7.71
GHI, 1983	0.89	1.00	9.09
GHI, 1983*	0.94	1.16	17.78
GHI, 1984*	0.90	1.00	9.64
GHI, 1986*	0.90	1.07	10.27
JKL, 1983	0.91	1.10	11.46
JKL, 1984	0.90	1.01	10.05
JKL, 1986	0.90	1.02	8.87
TUVWX, 1984	0.86	1.01	7.10
TUVWX, 1985**	0.92	1.16	12.66
TUVWX, 1986**	0.95	1.33	19.16
FF-JJ, 1985	0.88	1.01	8.62
FF-JJ, 1986**	0.87	1.13	9.74
FF-JJ, 1987**	0.91	1.15	10.67
NOP, 1984	0.79	0.83	4.76
NOP, 1986	0.86	0.90	7.05
QRS, 1984	0.81	0.79	5.13
QRS, 1986	0.80	0.79	5.10
KKLLMM, 1985	0.83	0.85	5.82
LINE S, 1985	0.84	0.85	6.21
LINE T, 1985	0.81	0.81	5.37
LINE U, 1985	0.86	0.88	7.24
LINE V, 1985	0.65	0.62	2.85
BAYVIEW AVERAGE	0.86	0.96	7.03
PECHO AVERAGE	0.93	1.17	14.28

*after plot was cleared
**after plot was burned

diversity values (ie. similar to Bayview) would be potentially more suitable for Morro Bay kangaroo rats than other habitats having higher species diversity values so long as the plants could be used by Morro Bay kangaroo rats.

COMMUNITY SIMILARITY AMONG THE PECHO AND BAYVIEW PLOTS

In order to determine why Morro Bay kangaroo rats occur at Bayview but no longer at Pecho, we evaluated the degree of vegetation similarity among sample sites within these two areas. The degree of similarity among the various plots should be an indication of habitat similarity as far as their present environmental conditions and/or histories are concerned. The two most commonly used methods of calculating community similarity coefficients, Sorenson and the Jaccard coefficients (Barbour et. al. 1980), were used to compare the Pecho plots and the Bayview plots and lines. Community coefficients were calculated using cover values because we felt that cover would provide a better indication of the degree of similarity/dissimilarity among the plots. Since both the Jaccard and Sorenson coefficients showed nearly identical results, we present only the Sorenson Indices of Similarity (Table 4—9).

Similarity analyses showed that the vegetation over the two study sites varied considerably from plot to plot. In general, Bayview showed more variation from plot to plot that did Pecho. As a result, the Pecho plots showed a higher degree of similarity with one another than did the Bayview plots. For example, comparisons of the undisturbed Pecho plots showed a range of Community Coefficients (CC) of 49—75 (a value of 0 indicates no similarity whereas a value of 100 indicates identity between two plots). In contrast, the range of CC values at Bayview was 29—82.

Similarity results generally indicated that the Pecho plots were more similar to themselves than to the Bayview plots and lines and, conversely, the Bayview plots and lines were more similar to themselves that to the Pecho plots. However, there were some interesting exceptions. For example, Bayview plot NOP showed a higher degree of similarity with Pecho plots ABC and JKL than with any Bayview plot. In contrast, plots ABC and JKL showed a higher degree of similarity with each other than with NOP or the other Pecho plots.

Effects of Brush Clearing on Index of Similarity

Pecho plots DEF and GHI were very similar (CC = 75) in 1983, before they were cleared. After clearing, these two plots showed a slight decrease in similarity (CC = 61 in 1983 and CC = 66 in 1986). The two undisturbed plots, ABC and JKL also showed a high degree of similarity in 1983 (CC = 71) and maintained this same level of similarity throughout the study. The two undisturbed plots also were similar to the cleared plots before brush removal occurred (CC ranged from 42—63). However, after DEF and GHI were cleared, their similarity with the undisturbed plots decreased (CC ranged from 35—55).

As the vegetation on the two cleared plots went through succession, their similarity to the undisturbed plots increased and by 1986, some of the cleared plots were more similar to undisturbed plots than they were before clearing. For example, before clearing, plot GHI and undisturbed plots ABC and JKL had CC values of 50 and 42, respectively. Immediately after clearing, the CC values decreased to 35 and 37, but in 1986, the CC values increased to 55 and 51, respectively. Cleared plot DEF gradually became more similar to the undisturbed plots, but did not regain the same level of

Table 4-9. Comparison of overall plant cover on Pecho and Bayview study plots and lines using the Sorenson Index of Similarity analysis. Refer to text for details on loacation, experimental manipulation an sampling methods pertinent to each plot or line. A similarity value of 100 indicates that the two sites are identical; whereas a 0 value indicates no similarity.

Stands	ABC 83	ABC 84	ABC 86	DEF 83	DEF 83	DEF 84	DEF 86	GHI 83	GHI 83	GHI 84	GHI 86	JKL 83	JKL 84	JKL 86	T-X 84	T-X 85	T-X 86	FF-JJ 85	FF-JJ 86	FF-JJ 87	NOP 84	NOP 86	QRS 84	QRS 86	KLM 85	S 85	T 85	U 85
ABC84	77																											
ABC86	79	83																										
DEF83	63	65	63																									
DEF83	45	44	41	60																								
DEF84	40	45	38	57	63																							
DEF86	48	48	46	62	56	77																						
GHI83	50	52	54	75	47	45	45																					
GHI83	35	37	38	47	61	53	43	53																				
GHI84	43	54	47	56	57	69	58	52	63																			
GHI86	51	59	55	67	47	56	66	64	44	63																		
JKL83	71	64	69	54	41	41	46	42	37	46	49																	
JKL84	70	64	66	57	40	45	53	50	40	50	57	74																
JKL86	72	66	69	54	44	47	51	46	44	51	51	78	92															
T-X84	40	52	48	60	38	44	40	61	42	49	56	39	44	41														
T-X85	12	13	10	17	22	20	17	14	26	19	15	14	15	17	13													
T-X86	22	22	22	30	39	36	31	32	52	41	33	23	26	26	32	36												
F-J85	37	49	41	47	34	44	40	49	42	53	52	36	38	38	66	10	29											
F-J86	9	9	9	11	15	13	12	12	19	15	12	10	9	10	12	33	37	14										
F-J87	24	32	25	29	34	41	32	27	37	48	35	26	23	25	34	28	50	46	37									
NOP84	54	47	45	42	33	35	48	27	20	32	48	48	53	54	27	9	15	25	6	14								
NOP86	57	47	48	44	42	47	59	33	32	42	52	58	65	68	32	13	24	31	11	23	79							
QRS84	43	48	47	52	35	39	57	40	26	37	50	34	38	39	41	10	18	38	6	21	47	47						
QRS86	43	43	46	46	23	26	41	39	19	23	40	35	41	41	54	9	11	35	4	11	37	41	74					
KLM85	38	32	35	34	23	26	29	27	20	28	28	48	49	52	29	9	12	14	4	13	36	43	52	62				
S85	40	34	38	38	29	34	35	34	23	27	30	45	51	54	39	9	15	39	4	15	40	44	60	66	82			
T85	40	37	33	38	26	31	48	29	24	29	39	46	48	51	27	11	15	29	5	15	45	53	70	63	72	74		
U85	37	34	43	36	29	35	45	31	27	38	37	42	43	45	31	7	22	34	7	24	34	44	58	53	68	69	60	
V85	27	27	25	26	27	26	36	19	20	24	27	24	28	29	14	12	13	17	5	12	29	31	63	60	62	58	70	57

100 = Complete similarity (indentity); 0 = No similarity

similarity it had with them before it was cleared. The differences between the two cleared plots is attributed to differences in the degree of brush removal; DEF was more thoroughly cleared than GHI.

Effects of Fire on Index of Similarity

Fire modified the Pecho vegetation so significantly that the burned plots (TUVWX and FF–JJ) shared little similarity with any of the Pecho or Bayview study plots. Before burning, TUVWX and FF–JJ were most similar to each other (CC = 66) and to plots DEF and GHI before they were cleared (CC = 47–49). After burning, the similarity of TUVWX and FF–JJ to each other and to all other plots decreased to extremely low levels. Not only did fire produce different effects at different sites, but its effects on Coastal Dune Scrub vegetation were much different than the effects of manual brush removal.

RARE AND ENDANGERED PLANTS

Several plants that occur on the Pecho and Bayview sites are considered to be rare and/or endangered. The status of these was determined from the California Native Plant Society's Inventory of Rare and Endangered Vascular Plants of California (3rd. ed. 1984), the California Department of Fish and Game's list of Designated Rare or Endangered Plants (1982), the California Department of Fish and Game's Natural Diversity Data Base List of Special Plants (updated), and the U. S. Fish and Wildlife Service's list of Endangered and Threatened Wildlife and Plants (1980 and 1983). None of these species is currently federally listed as Endangered or Threatened. However, two are candidates for such listing: *Arctostaphylos morroensis* and *Eriodictyon altissimum*. One, *Eriodictyon altissimum*, is listed by the California Department of Fish and Game as Endangered.

Arctostaphylos morroensis (Morro manzanita) is endemic to San Luis Obispo County. Its entire distribution is limited to the sandy soils of the South Bay (Morro Bay) area where it occurs from Turri Road to the lower slopes of the hills above Los Osos. At the crest of the ridge above Los Osos, where the soil changes abruptly from sand to shale derivatives, there is a sharp boundary beyond which the Morro manzanita does not grow. *Arctostaphylos morroensis* is locally abundant on the hills above Los Osos, but has been strongly affected by development in other areas of the South Bay. Continued development pressure could bring about its extinction.

This species is a dominant component of the old-growth Chaparral on both the Bayview and Pecho sites. As a general rule, the density of the manzanitas on the Bayview site increases from north to south with increasing elevation on the site. There is also some east-west variation in this pattern. In the eastern portion of Bayview, *Arctostaphylos morroensis* occurs from the southern to the northern borders of the site. West of Broderson Ave., manzanitas occur mostly in the southern portion of the site. On the Pecho site, the Morro manzanita is found at higher elevations near Pecho Road. To the east of Pecho Road, it becomes very dense and forms almost pure stands in the Chaparral on the hillsides. To the west of Pecho Road, it is scattered and occurs down to the Pecho study plots only as scattered individuals. The Morro manzanita is listed by the CNPS as both rare and endangered, and it is included in the CDFG list of Special Plants. It is a candidate for listing as rare and endangered by the USFWS (1980 and 1983).

Erigeron foliosus var. *blochmaniae* **(Blochman's leafy daisy)** is a perennial herb that occurs from the South Bay (Morro Bay) area to northern Santa Barbara County on coastal dunes and sandstone hills. In the South Bay area it ranges from the Morro Bay Sand Spit and the hills near the Los Osos Junior High School to the Chaparral-covered hills above Los Osos. Although it is locally common in a few areas, numerous populations have been extirpated by development. It is found in scattered locations on both the Bayview and Pecho sites. It is fairly common on one of the burned sites (plot TUVWX) and on the two cleared sites (plots DEF and GHI) at the Pecho site. This plant is not presently considered to be in danger of extinction, but the CNPS has placed in on its Watch List (Plants of Limited Distribution). It is also included in the CDGF list of Special Plants.

Erigeron sanctarum **(Saint's daisy)** is known from northwestern San Luis Obispo County (in the vicinity of Arroyo de la Cruz Creek) to Santa Barbara County where it occurs both on the mainland and on Santa Rosa Island. In the South Bay area, it has been found only on a ridgetop about 1/4 mile west of the junction of Calle Cordoniz and Bayview Heights Drive along a trail through the Chaparral. Only a few individuals were observed in flower at this site (non-flowering plants are easily overlooked). Its occurrence within the overall boundaries of the Pecho or Bayview sites has not been completely documented, but its presence just outside the Bayview site boundary and the presence of similar habitats within the site support its inclusion in this discussion. Saint's daisy is not at present in danger of extinction, but the CNPS has placed this plant on its Watch List (Plants of Limited Distribution). It is included in the CDFG list of Special Plants.

Eriodictyon altissimum **(Indian Knob mountain balm)** is a slender shrub that is endemic to a very small portion of San Luis Obispo County. It is known to occur in two areas of the San Luis Range. One population occurs on Indian Knob south of San Luis Obispo. Three very small, isolated populations occur in the hills immediately south of Los Osos. The South Bay populations are located (1) west of Calle Cordoniz, south of its junction with Bayview Heights Drive; (2) south of Highland Drive between the extensions of Ravenna and Pallisades Avenues, approximately 100 m west of the the extension of Palisades Avenue at about the 250 ft elevation level; and (3) at a site north of Hazard Canyon below the main crest of the ridge, 1 mile directly south of Cabrillo Estates. An isolated individual discovered by Dr. Dirk Walters in the early 1970's south of the end of Ravenna Avenue could not be relocated by the author during this field survey. Of the documented populations of this species, only South Bay population number 2 (above) is located within the Bayview site. South Bay population number 1 is about 300 m to the east of the site boundary. The plant has not been reported or found on the Pecho site.

Little is known about the ecology of this species. Some species of *Eriodictyon*, including the closely related *Eriodictyon capitatum*, are apparently successional species that follow fires. The lack of fire in recent years in the area occupied by this species may be related to the small present-day populations. These populations consist of only a few individuals and could be easily destroyed by human activity. South Bay number 2 consists of about 25 individuals ranging in size from a few inches to about 8 ft tall. Continued development on the hills above Los Osos would threaten these plants with extinction. Of the rare plant species present on the Bayview site, the Indian Knob mountain balm is the closest to extinction. *Eriodictyon altissimum* is listed by the CNPS as both rare and endangered and it has been designated by the CDFG (1982) as

endangered. It is a candidate for listing as rare and endangered by the USFWS (1980 and 1983).

Erysimum suffrutescens var. *lompocense* **(San Luis Obispo wallflower)** is a low subshrub that occurs on coastal sand dunes from the South bay area to northern Santa Barbara County. In the South bay area it is an occasional to locally common component of Coastal Dune Scrub communities. Small, localized populations are scattered throughout the south bay area including the Pecho and Bayview sites. Numerous individuals of this low shrub have been eliminated by development in the South Bay area. Because most of the sites in the South Bay area where this species occurs are zoned for residential development, this species is becoming rarer. Some of the San Luis Obispo wallflowers are located in the open scrub in the lower half of the Bayview site and also in scattered locations on the Pecho site including the study plots. The San Luis Obispo wallflower is not presently considered to be in danger of extinction, but the CNPS has placed this species on its Watch List (Planted of Limited Distribution). It is also included in the CDFG list of Special Plants.

Monardella undulata **var.** *undulata* **(curly-leafed monardella)** is an annual plant that occurs on coastal sand dunes from Sonoma County to San Luis Obispo County where it reaches its southernmost station in the South Bay area. The closest populations to the north are in Monterey County. In the South Bay area, it occurs as an occasional to locally common component of Coastal Dune Scrub communities. It is found on both the Pecho and Bayview sites, but is not common on either. Numerous individuals of this annual herb have been eliminated by development in the South Bay area. Interestingly, minor disturbance of Coastal Dune Scrub communities sometimes promotes the growth of this species by creating open spots in the vegetation. Because most of the sites in the South Bay area where this species occurs are zoned for residential development, this species is becoming rarer. The curly-leafed monardella is not presently considered to be in danger of extinction, but the CNPS has placed it on its Watch List (Plants of Limited Distribution). It is also included on the CDFG list of Special Plants.

Prunus fasciculata **var.** *punctata* **(dune almond)** occurs on coastal sand dunes from the South Bay area to northern Santa Barbara County. In the South Bay area, it occurs as an occasional to locally common component of Coastal Dune Scrub communities. Numerous individuals of this low shrub have been eliminated by development in the South Bay area. Because most of the sites in the South Bay area where this species occurs are zoned for residential development, this species is becoming rarer. The dune almond is found on both the Pecho and Bayview sites and occurs on some of the study plots. It is among the dominants on at least one of the study plots on the Pecho site. The dune almond is not presently considered to be in danger of extinction, but the CNPS has placed this species on its Watch List (Plants of Limited Distribution). It is also included in the CDFG list of Special Plants.

BOTANICAL CONCLUSIONS

1. The undisturbed plant cover on both the Pecho and Bayview sites is similar in structure and composition. The principal plant community on both sites is Coastal Dune Scrub interspersed with some Chaparral components.

2. The Coastal Dune Scrub community is composed of a mixture of herbaceous, subshrubby and shrubby species. Dominant species are generally soft-stemmed shrubs or subshrubs (obscurely shrubby and usually low growing plants) that have thin, often deciduous leaves. In the mixed mosaic of species characteristic of Coastal Dune Scrub, dominance and relative species cover vary from site to site and year to year. Species often have patchy distributions, with aggregations of individuals occurring at some sites and not at others. This patchiness may be due to environmental factors such as enhanced or decreased moisture availability or to reproductive success of an original colonizer. Some species spread by underground rhizomes and the resulting patch may actually be all one individual. Some species, by virtue of their size or density, locally dominate to the exclusion of other species; but, over the entire area, these species may be relatively unimportant. For example, *Prunus ilicifolia* is found only at a few locations; however, where it occurs, it usually forms almost pure stands.

3. Although the overall structure and appearance of the Coastal Dune Scrub habitat was similar at the two sites, Bayview had slightly more bare ground and less shrub cover than Pecho.

4. The species composition of the two study sites was similar in that the common species were present on both; however, the relative coverage of the common species was markedly different on the two sites. The Bayview site had two co-dominant species: *Horkelia cuneata* and *Lotus scoparius*. These two species were found on every plot and covered 19.6% and 17.1% of the area, respectively. These two species were less common on the Pecho site and covered considerably less area. For example, *Horkelia cuneata* was found on only 75% of the Pecho study plots and was relatively insignificant in terms of actual cover (less than 1%). In contrast, *Lotus scoparius* was found on every Pecho and Bayview plot and was one of the dominants on both sites; however, its cover at Pecho (8%) was less than half that of Bayview. On the Pecho site, *Artemisia californica*, *Ericameria ericoides*, and *Lotus scoparius* were the dominant species. They occurred on every plot and together these three species covered over 20% of the Pecho plots. At Bayview these shrubs were somewhat less common (occurring on 78% and 89% of the plots, respectively) and together they covered less than 13% of the area.

5. Cover by Morro Bay kangaroo rat food plants was significantly higher at Bayview than at Pecho. Almost 87% of the plant cover at Bayview consisted of food plants compared to less than 60% at Pecho. The high coverage of *Horkelia cuneata* and *Lotus scoparius* (both highly favored food plants) at Bayview played an important role in this difference. The percentage of vegetative cover by Morro Bay kangaroo rat food plants was increased by 10% to 15% as a result of brush removal on Pecho plots DEF and GHI. This indicates that clearing may improve habitat quality for the Morro Bay kangaroo rat. By contrast, the burned plots suffered a loss of cover by food plant species listed by Stewart (1958). Unfortunately, many of the plants that appeared on the plots following the fires were not tested by Stewart so it's hard to predict whether or not Morro Bay kangaroo rats would use these species.

6. Plant species diversity was significantly higher at Pecho than at Bayview. This difference was largely because several, co-dominant species had nearly equal cover values on the Pecho plots and species richness was higher at Pecho. The overwhelming dominance of *Horkelia cuneata* and *Lotus scoparius* at Bayview also contributed to the lower species diversity at this site.

7. Brush removal on the two Pecho plots resulted in an obvious reduction in shrub cover and a concomitant increase in bare ground and cover by herbs and subshrubs. In the first spring after clearing, the species diversity increased markedly when herbaceous species became established after the shrub cover had been opened up. However, after two years, the shrub cover increased, herbaceous cover decreased, and species diversity decreased as the shrub canopy recovered.

8. Plant species capable of resprouting after disturbance appear to be favored on the cleared plots while non-sprouting species may be at a selective disadvantage. It is predicted that within a few years, secondary succession will bring the plant cover on the plots back to pre-cleared conditions. However, non-sprouting species may be fewer in numbers and lower in cover than before the clearing. Some species that are closely associated with shrub cover (e.g. *Dudleya caespitosa)* were reduced by the clearing and recovery has been slow. It is difficult to predict how well these species will recover in the future.

9. The overall effects of fire on the two burned plots were that the foliage, stems, and litter of most plants were consumed in place, leaving a layer of inorganic ash on the sandy soil. Non-volatile nutrients and salts formerly incorporated in the plants were released and subsequently incorporated into the upper layers of the soil during the winter rains. As a result, soil fertility in the burned area was much higher and the pH of the soil was less acidic as a results of the salts in the ash. It is difficult to predict how long this increased fertility and elevated pH will last, but, because of the sandy soil, probably not more than a few seasons. Species that survived the fire by underground stems such as rhizomes, bulbs, lignotubers, etc., as well as those that started as seedlings after the fire, appeared to grow more rapidly and to be more productive than those in unburned areas. Any soil chemicals that produce allelopathic effects appeared to have been inactivated by the burning.

10. The shrubs that were dominant before the fire were obviously reduced significantly by the fire. Within a few weeks after the fire, many of the shrubs resprouted from the base and gradually began regenerating a new canopy. The dominant shrubs before the fire, *Artemisia californica*, *Ericameria ericoides*, *Prunus fasciculata* var. *punctata*, and *Prunus ilicifolia* all resprouted and developed extensive growth near their bases. Some seedlings of *Artemisia californica*, *Lupinus chamissonis*, and *Ericameria ericoides* also became established on the plot, but no seedlings of *Prunus* were noted.

11. By 1986, the cover of shrubs had increased, but the burned plots were still dominated by herbaceous plants. The increased species diversity following the fire was largely due to the increase in herbaceous species that were able to occupy the site. Seeds of a number of plants are known to germinate after fire because of heat scarification, exposure to residues from charred wood, removal of allelopathic substances in the soil, increased soil nutrients, increased insolation, and/or reduction in competition from shrubs. This complexity of changes resulted in a much richer and diverse flora, dominated by herbaceous species, following the fire.

12. The dominant plant cover after the fire was composed of native herbs and subshrubs. However, a few introduced, Eurasian weed species invaded the plots after the fires. On plot TUVWX, these weedy plants were mostly restricted to areas along the roads and trails, places where they were common before the burn. On plot FF–JJ, weeds such as *Bromus diandrus* moved into the plot from the surrounding trails, became established, and now have assumed a dominant role on the plot. It is hard to predict the permanency of these weedy species, but one might expect that as the shrub canopy continues to regenerate, there will be a gradual reduction in weedy species as well as opportunistic herbs that moved in after the fire. It is noteworthy that Stewart (1958) found that *Bromus* spp. were used as food by Morro Bay kangaroo rats which suggests that the increase in *Bromus diandrus* might actually be somewhat beneficial in providing an additional food source.

13. Results of Sorenson community similarity analysis showed that the the Coastal Dune Scrub vegetation at Bayview was more variable from site to site that was the vegetation at Pecho. Consequently the Pecho plots showed a much higher degree of similarity with one another than did the Bayview plots and lines.

14. Before Pecho plots DEF and GHI were cleared, they shared a high degree of community similarity. Immediately after clearing, the similarity between these two plots decreased somewhat. Gradually, as a result of natural secondary succession, the cleared plots began to return to their pre-cleared condition and they became more similar to the nearby undisturbed plots.

15. Fire modified the Coastal Dune Scrub vegetation so significantly that after the two experimental plots were burned, they showed little similarity to any of the Pecho or Bayview study plots. Not only did fire produce different effects at different sites, but its effects on Coastal Dune Scrub vegetation were much different than the effects of manual brush removal.

16. Several plants that occur on the Pecho and Bayview sites are considered rare and/or endangered by the California Native Plant Society. None of these plants are federally listed, although two are candidate species *(Arctostaphylos morroensis* and *Eriodictyon altissimum).* Only *Eriodictyon altissimum* is listed by the California Department of Fish and Game as endangered. All of the listed species have apparently decreased in numbers over the years as a result of human destruction of their habitat.

V. HABITAT RELATIONS OF MORRO BAY KANGAROO RATS

The original aim of this study was to evaluate the direct effects of brush removal and burning on populations of Morro Bay kangaroo rats living on public land at the Pecho site. Obviously, after finding that the the only viable population available was the one at Bayview, an alternate approach was necessary to study the habitat relationships of Morro Bay kangaroo rats. Systematically collected habitat data from both the Pecho and Bayview sites were used to compare those plant communities that supported Morro Bay kangaroo rats to those that did not. Because Morro Bay kangaroo rats were not uniformly dispersed at Bayview, microhabitats (stations) at Bayview that supported rats could be compared to those that did not. The results of these two levels of analysis should help managers identify habitats which would be most likely to support Morro Bay kangaroo rats now or in the future.

METHODS

Only line intercept data were used in the analyses presented here because: (1) more plot years of data were collected by this method and (2) comparisons between intercept and quadrat data collected simultaneously from the same plots failed to show significant correlation.

Although importance values as well as absolute and relative values for density, cover, and frequency were computed for all species (Holland 1986), absolute cover appeared to be the best, unbiased measure of the influence of each plant species on each plot. A number of plants were either very rare or had extremely low overall cover values in the samples. In order to focus on the major species occurring in the study areas and minimize the statistical difficulties associated with outliers, we arbitrarily deleted a number of species from the analyses. For a species to be included in the analyses, it had to occur in at least 50 % of the samples *or* it had to have an overall cover value of at least 5 % of the combined lengths of all sample lines used in the analyses. Data transformation and all multivariate statistical analysis were accomplished using Apple Macintosh computer programs available in BIOSTAT II (Pimentel and Smith 1986).

OVERALL COMPARISON OF HABITATS AT THE PECHO AND BAYVIEW SITES

Two different levels of analysis were performed on the data collected during the study. The first level of analysis compared the 3 predominant habitat types studied [undisturbed plots at Pecho, manipulated (cleared and burned) plots at Pecho, and undisturbed plots at Bayview] based upon the cover values of plants, dead litter, and bare ground on each. This analysis permitted quantitative evaluations concerning the similarities and differences between the general habitats at Bayview and Pecho as well as the effects of habitat manipulation at Pecho.

The absolute cover (m) of plants, dead litter, and bare ground collected during each plot year comprised the raw data used in the first level of analyses. Plot years were treated as individuals (rows) and the cover of plants, litter and bare ground were treated as variables (columns). The variables then were standardized to z scores because of broad differences in both the occurrence and densities of several of the species. The 4 multivariate analyses used (Pimentel and Smith 1986, Manly 1986) were as follows: (1) Principal Coordinate Analysis (PCORD) using an association matrix formed from Gower's general similarity coefficients and Q mode analysis, (2) Nonmetric Multidimensional Scaling (MDS) using the same association matrix as used in PCORD

and an Euclidian distance matrix calculated from input trial vectors, (3) Principal Component Analysis (PCA) using all plot years as a single group so that the results of PCA could be compared to the first 2 methods, and (4) Cluster Analysis (CLUST) using a dissimilarity index formed from Gower's general similarity coefficients.

The first 2 of these analytical methods (PCORD and MDS) are ordination procedures which, using "multidimensional" mathematical solutions, produce successive, two dimensional graphs that show the degree of association among all of the plot years (points) according to which pair of axes are selected. The axes of the graphs represent the various "dimensions" (up to 4) of the multidimensional dissimilarity space. The axes (dimensions) are ranked such that the first axis accounts for the greatest degree of dissimilarity and subsequent axes account for progressively less dissimilarity among the plot years. Only the first 2 axes were considered because they normally account for the majority of the dissimilarity among "individuals" being compared.

The third method (single group PCA) uses eigenvalues and eigenvectors that are extracted from a variable by variable, variance-covariance (dispersion) matrix to construct "multidimensional" principal component axes. The principal component axes are ranked such that the first axis accounts for the greatest degree of variation and subsequent axes account for progressively less variation among the plot years. The degree and direction of participation of each variable on each principal component axis is given in the analysis so that the overall pattern of relationships among plot years can be interpreted in terms of the variables (species) used in the analysis. Unless substantial discrepancies appear among the results of PCA, PCORD, and MDS analyses, only the PCA results will be shown because, unlike the other 2 methods, PCA permits an examination of the importance of each species in determining the overall pattern of relationships among the various plot years.

The fourth method (CLUST) is an agglomerative, hierarchical, cluster analysis procedure which is used to produce a dendrogram (a one-dimensional summary of relationships among the plot years). The linking procedure used to form the dendrograms was the group average method (UPGMA). The relative "goodness of fit" of the dendrogram to the original dissimilarities is indicated by an overall cophenetic correlation coefficient. Although cluster dendrograms often misrepresent complex relationships, the results of cluster analysis are included because they provide a simplified overview of the relationships.

COMPARISON OF HABITATS AT THE BAYVIEW SITE

The second level of analysis involved detailed comparisons of microhabitats (stations) at the Bayview site based upon the cover values of major plant species, dead litter, and bare ground. This analysis permitted a quantitative definition of the habitat used by Morro Bay kangaroo rats during the period of our study. The data were divided into two groups: stations where no Morro bay kangaroo rats were captured in 1984, 1985, or 1986 and stations where one or more rats were captured on at least one of the three years. This grouping procedure compensated for the marked difference in population estimates for Morro Bay kangaroo rats in 1984 (low) and 1986 (higher). This procedure assumed that if no animals were trapped at a station for 3 years, then the area in the vicinity of the station was probably unsuitable regardless of the population size. The microhabitats surrounding stations where rats were caught may have been either marginal or optimal, but at least these areas had resources which attracted animals sometime during the study. This assumed that usage of a microhabitat reflected

preference for that site by Morro Bay kangaroo rats. The absolute cover data for major plants, dead litter, and bare ground collected from stations with rats and those with no rats in both 1984 and 1986 (Holland 1986) were pooled in order to achieve adequate sample sizes for multivariate analysis. These pooled cover data comprised the raw data used in this study of habitat "preference". Stations were treated as individuals (rows) and the cover of plants, litter and bare ground were treated as variables (columns). The variables were standardized to z scores (when appropriate) because of broad differences in both the occurrence and densities of several of the species. Multigroup discriminant function analysis (MDA) was used to determine whether or not there was a significant statistical difference between the habitat surrounding stations which were used by rats and those which were not used. The Geisser classification procedures used in MDA provide a means of evaluating the relationships within and between the 2 groups. Univariate statistical tests and generalized distance analysis used in MDA enabled us to determine which variables were significant in accounting for differences between the 2 groups. Multigroup PCA also was performed on the same data set to further evaluate the role of each variable in describing relationships within each group.

RESULTS AND DISCUSSION

OVERALL COMPARISONS OF HABITATS AT THE PECHO AND BAYVIEW SITES

These multivariate comparisons were based upon 21 plot years of line intercept data which sampled a total of 3,750 m of habitat. Ten plot years were from the following undisturbed plots at Pecho: ABC and JKL in 1983 and 1984, DEF and GHI before they were cleared in 1983, TUVWX before it was burned in 1984, AA-EE in 1985 and 1986, and FF-JJ before it was burned in 1985. Six plot years were from the following manipulated habitat at Pecho: DEF and GHI after they were cleared in 1983 and again in 1984 and TUVWX and FF-JJ after they were burned in 1986. Five plot years were from the following undisturbed plots at Bayview: NOP and QRS in 1984 and 1986 and KKLLMM in 1986. These 21 plot years were treated as individuals (rows) for purposes of multivariate statistical analysis. Twenty plant species or ground cover characteristics (Table 5—1) satisfied the criteria of occurring on at least 50 % of the plots or having an overall cover value of at least 5 % of the total line intercept length (3,750 m) for all 21 plot years.

The absolute cover values (m) of these 20 habitat variables (Table 5—1) were treated as variables (columns) for purposes of multivariate statistical analysis. The main questions we sought to answer were whether or not there were distinctive multivariate differences between the Pecho and Bayview plots and whether or not the manipulated plots at Pecho were more similar to the Bayview plots than they were to undisturbed plots at Pecho.

Cluster Analysis— Results of CLUST analysis (Fig. 5—1) reveal 4 general cluster sets (indicated by brackets). Undisturbed plots ABC and JKL in 1983 and 1984 form one cluster at the top of the dendrogram. Undisturbed plots TUVWX in 1984, AA-EE in 1985 and 1986, and FF-JJ in 1985 form another cluster at the bottom of the dendrogram. It is surprising to find that before they were cleared in 1983, plots DEF and GHI did not form links with one of the other clusters containing undisturbed plots. Instead, these 2 plots were placed in a third cluster that included all of the plots that had been either cleared or burned (ie. DEF (A) 1983, GHI (A) 1983, TUVWX 1986, and FF-JJ 1986).

All of the Bayview plot years fell into a fourth general cluster of the dendrogram which eventually formed a link with the cluster containing cleared and burned plots. These results suggest that the undisturbed habitat at Bayview was distinctly different from the undisturbed habitat at Pecho. Even though none of the Bayview plots formed close links with manipulated plots at Pecho, the distant link between all Bayview plots and all manipulated plots suggests that habitat manipulation produced a general habitat type which was slightly more similar to Bayview habitat than it was to the undisturbed habitat at Pecho. Although all of the manipulated plots fell into a single cluster, burning and brush removal created somewhat different habitats because the burned and cleared plots fell into separate subsets of the cluster. The general relationships among undisturbed plots is less clear because they fell into 2 separate clusters and several undisturbed plots overlapped with manipulated plots.

Table 5—1. Absolute cover values of the 20 major habitat variables used to compare those plot years at the Pecho and Bayview sites for which there were comparable line intercept data. Plant species that occurred on fewer than 50 % of the plot years or had overall cover values less than 5 % of the sum of all the line intercept lengths were not included here or in subsequent multivariate statistical analysis. Plots DEF and GHI were sampled before they were cleared (B) and after they were cleared (A) in 1983. Plot TUVWX was sampled before it was burned in 1984 and plot FF-JJ was sampled before it was burned 1985. Abbreviations, scientific names, and common names of the variables are given below.

ABBREV.	SCIENTIFIC NAME	COMMON NAME
ACH.BO	Achillea borealis	yarrow
ART.CA	Artemisia californica	California sagebrush
CAR.RA	Cardionema ramosissimum	sandmat
CAR.SP	Carpobrotus spp.	ice plants
CEA.CU	Ceanothus cuneatus	buckbrush
COR.FI	Corethrogyne filaginifolia	California aster
CRO.CA	Croton californicus	croton
DUD.LA	Dudleya lanceolata	live-forever
ERI.ER	Ericameria ericoides	mock heather
ERI.PA	Eriogonin parvifolium	coastal buckwheat
ERI.CO	Eriophyllum confertiflorum	golden yarrow
HOR.CU	Horkelia cuneata	silverweed
LOT.SC	Lotus scoparius	deerweed
LUP.CH	Lupinus chamissonis	coastal silver lupine
PRU.FA	Prunus fasciculata	sand almond
PRU.IL	Prunus ilicifolia	holly-leaf cherry
SAL.ME	Salvia mellifera	black sage
HER.GR	-----	herbaceous vegetative growth
DEA.MA	-----	Dead material (litter)

PLOT/DATE	ACH.BO	ART.CA	CAR.RA	CAR.SP	CEA.CU	COR.FI	CRO.CA	DUD.LA	ERI.ER	ERI.PA	ERI.CO	HOR.CU	LOT.SC	LUP.CH	PRU.FA	PRU.IL	SAL.ME	HER.GR	DEA.MA	BAR.GR
ABC '83	.20	8.80	9.40	11.60	7.60	4.20	4.00	11.30	5.10	.50	.30	1.00	12.30	2.20	•	•	7.60	8.60	8.50	26.50
ABC '84	•	12.50	5.40	15.10	4.50	8.90	4.30	3.30	6.90	.50	•	.70	10.00	2.60	•	•	2.50	3.10	10.40	15.70
JKL '83	.60	3.00	2.50	12.20	•	4.60	5.80	6.50	7.00	.80	2.80	.80	9.80	•	17.00	.40	10.40	2.20	9.80	24.50
JKL '84	•	4.40	.60	8.70	•	4.60	2.50	1.90	5.80	1.20	•	.60	9.50	•	12.10	5.90	8.60	5.50	13.90	14.00
DEF(B)83	.40	13.70	4.10	1.20	2.50	4.40	6.60	9.80	8.70	2.30	.50	1.90	6.70	.01	•	6.70	1.90	7.70	16.20	29.30
DEF(A)83	.40	3.30	6.40	.01	1.70	2.90	5.60	4.30	1.00	2.10	.10	2.60	4.10	•	1.10	2.70	•	18.90	.20	54.80
DEF '84	.10	2.50	3.00	.20	1.50	6.00	14.70	.30	4.80	3.10	.10	1.50	4.00	•	1.00	2.20	•	2.10	•	56.10
GHI(B)83	.30	11.10	1.70	.02	.04	3.80	1.20	8.10	9.20	1.80	.20	.10	4.30	•	2.50	10.90	2.60	6.00	9.60	37.20
GHI(A)83	.20	2.20	2.00	•	•	4.10	2.10	3.70	3.50	1.70	.70	.20	3.20	•	2.80	1.70	.30	20.40	•	52.80
GHI '84	.10	2.10	2.20	.60	•	8.50	5.70	1.50	5.00	.30	.30	.10	6.10	•	2.60	2.00	.60	6.70	2.50	52.00
TUVWX'84	•	25.10	.30	•	.80	7.40	3.50	2.00	14.00	3.10	1.90	•	4.00	1.40	5.30	4.10	3.20	2.20	11.60	23.50
TUVWX'86	.10	.80	1.20	•	•	3.40	3.50	.40	2.90	.60	.30	.10	2.90	.03	3.90	2.70	•	29.50	33.80	33.10
NOP '84	•	7.00	.20	3.70	9.10	2.70	8.10	•	•	.30	.10	1.90	31.20	•	•	•	5.00	4.60	8.00	31.90
NOP '86	•	4.80	1.40	•	12.10	3.70	10.30	•	.30	2.00	.20	3.10	24.00	•	3.20	.50	7.30	4.50	34.60	15.50
QRS '84	•	13.40	.20	•	.80	.80	5.50	.50	6.20	4.80	.20	23.90	18.40	•	•	•	.60	.80	9.10	28.50
QRS '86	•	26.10	.10	•	3.10	.60	6.30	.40	10.90	4.20	.10	30.00	13.90	•	•	•	7.60	.70	20.40	32.40
KK-MM'86	•	1.70	.70	•	13.00	.02	2.90	.40	10.70	•	.90	27.60	6.00	•	•	•	17.10	.70	5.90	28.10
AA-EE'85	.30	12.90	.10	•	•	3.20	2.50	2.30	15.80	3.40	2.20	•	8.30	2.00	13.30	•	9.70	.64	15.00	29.90
AA-EE'86	.02	12.40	.10	•	•	4.40	3.70	4.70	16.20	3.80	2.00	•	7.40	2.20	15.50	•	10.80	1.80	31.00	27.30
FF-JJ'85	.03	6.70	.10	•	•	13.50	2.40	1.60	15.10	4.60	1.20	.40	5.20	4.20	8.90	•	.40	.90	27.50	30.80
FF-JJ'86	.50	.30	1.50	•	•	3.80	1.80	.30	1.20	.10	•	.30	.30	•	2.10	•	•	89.50	3.30	44.80

CLUSTER ANALYSIS DENDROGRAM DERIVED FROM GOWER GENERAL SIMILARITY COEFFICIENTS

COPHENETIC CORRELATION COEFFICIENT = .478795

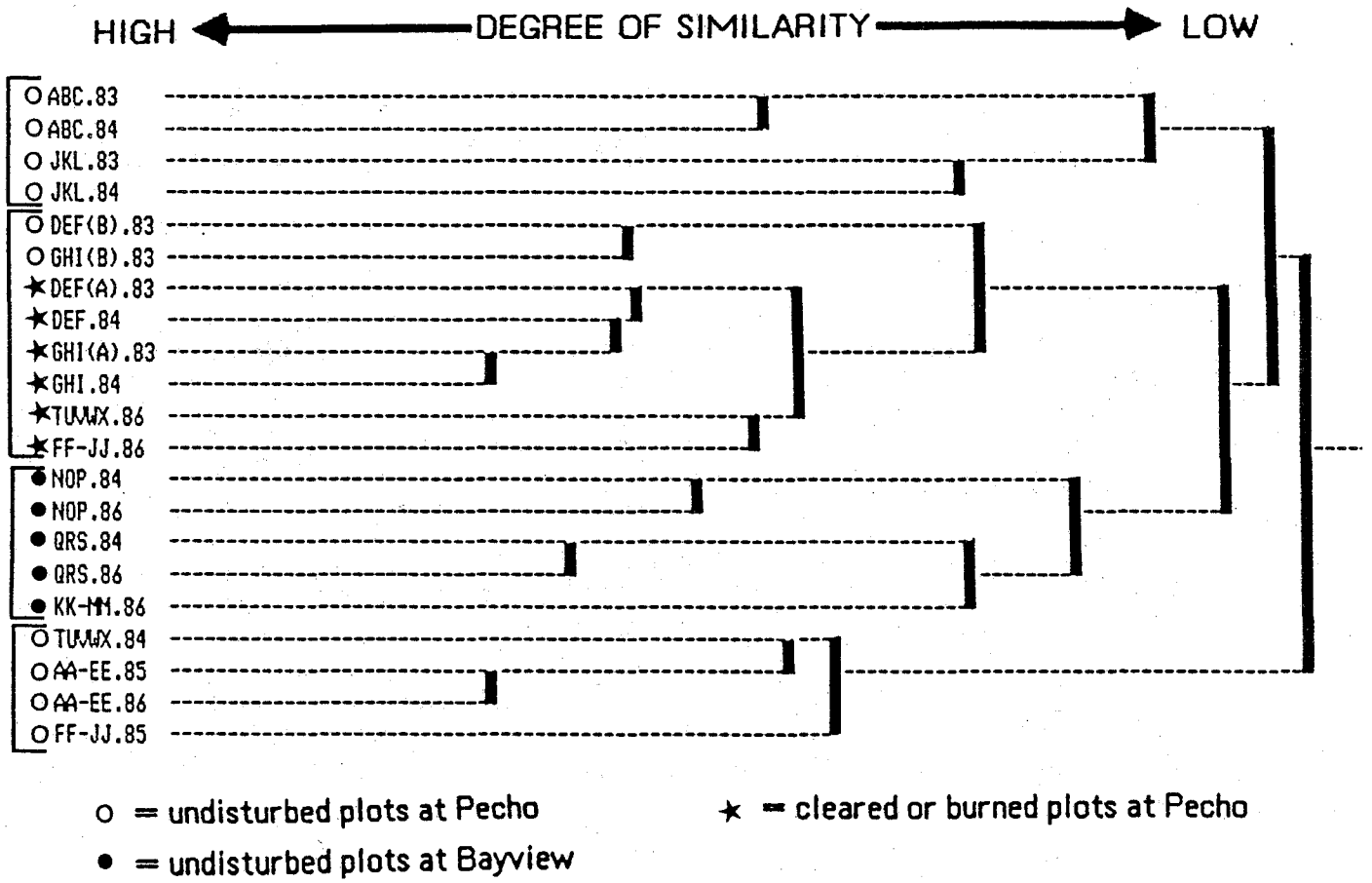


Figure 5–1. Dendrogram of 21 plot years of vegetation sampling at the Pecho and Bayview sites based upon the total line intercept coverage of 20 variables (17 species of plants, vegetative herbaceous growth, dead plant litter, and bare ground). Plots DEF and GHI were sampled twice in 1983; once before brush removal (B) and once after brush removal (A). Raw data (absolute cover values) were standardized to z scores before conducting the cluster analysis. The association matrix used in the analysis was formed from Gower general similarity coefficients. Unweighted pair group averages (UPGMA) were used to construct linkages between individual plot years and/or groups of plot years in the dendogram.

Principal Component Analysis— Unlike cluster analysis, single group PCA provides a more comprehensive view of the same data set (Fig. 5—2). The first principal component axis accounted for 22.1 % of the total variance and the first and second axes combined accounted for 40.4 % of the total variance. The major differentiation along the first principal component axis was between undisturbed plots and manipulated plots at Pecho (Fig. 5—2). The percent of variance and component correlations for the major variables of the first principal component axis and the habitat type where each variable had the greatest influence (cover) are summarized below:

Habitat Variable	Percent of Variance	Component Correlation	Habitat Type at Pecho Where the Variable had Greatest Influence
mock heather	72.4 %	−.85	Undisturbed
golden yarrow	42.6 %	−.65	Undisturbed
coastal silver lupine	37.3 %	−.61	Undisturbed
sand almond	35.7 %	−.60	Undisturbed
dead plant litter	35.3%	−.59	Undisturbed
coastal buckwheat	34.4 %	−.59	Undisturbed
California sagebrush	32.8 %	−.57	Undisturbed
bare ground	37.3 %	+.61	Manipulated
vegetative herbaceous growth	33.9 %	+.58	Manipulated

As might be expected, the cleared and burned plots generally had higher cover values for bare ground and vegetative herbaceous growth and lower cover values for mock heather, golden yarrow, coastal silver lupine, sand almond, dead plant litter, coastal buckwheat, and California sagebrush. Conversely, undisturbed plots generally had lower cover values for bare ground and vegetative herbaceous growth and higher cover values for the other 7 variables. Obviously brush removal and burning influenced the cover values of other habitat variables, but the impact of these 2 procedures was less pronounced than it was on the 9 variables above.

The major differentiation along the second principal component axis was between the Bayview and Pecho plots (Fig. 5—2). The percent of variance and component correlations for the major variables of the second principal component axis and the habitat type where each variable had the greatest influence (cover) are summarized below:

Habitat Variable	Percent of Variance	Component Correlation	Habitat Type Where the Variable had Greatest Influence
buckbrush	56.6 %	−.75	Bayview
deerweed	54.1 %	−.74	Bayview
silverweed	47.1 %	−.69	Bayview
yarrow	32.5 %	+.57	Pecho (Undist. and Manip.)

The Bayview plots generally had higher cover values for buckbrush, deerweed, and silverweed and lower cover values for yarrow; whereas the undisturbed and manipulated plots at Pecho generally had higher cover values for yarrow and lower cover values for buckbrush, deerweed, and silverweed.

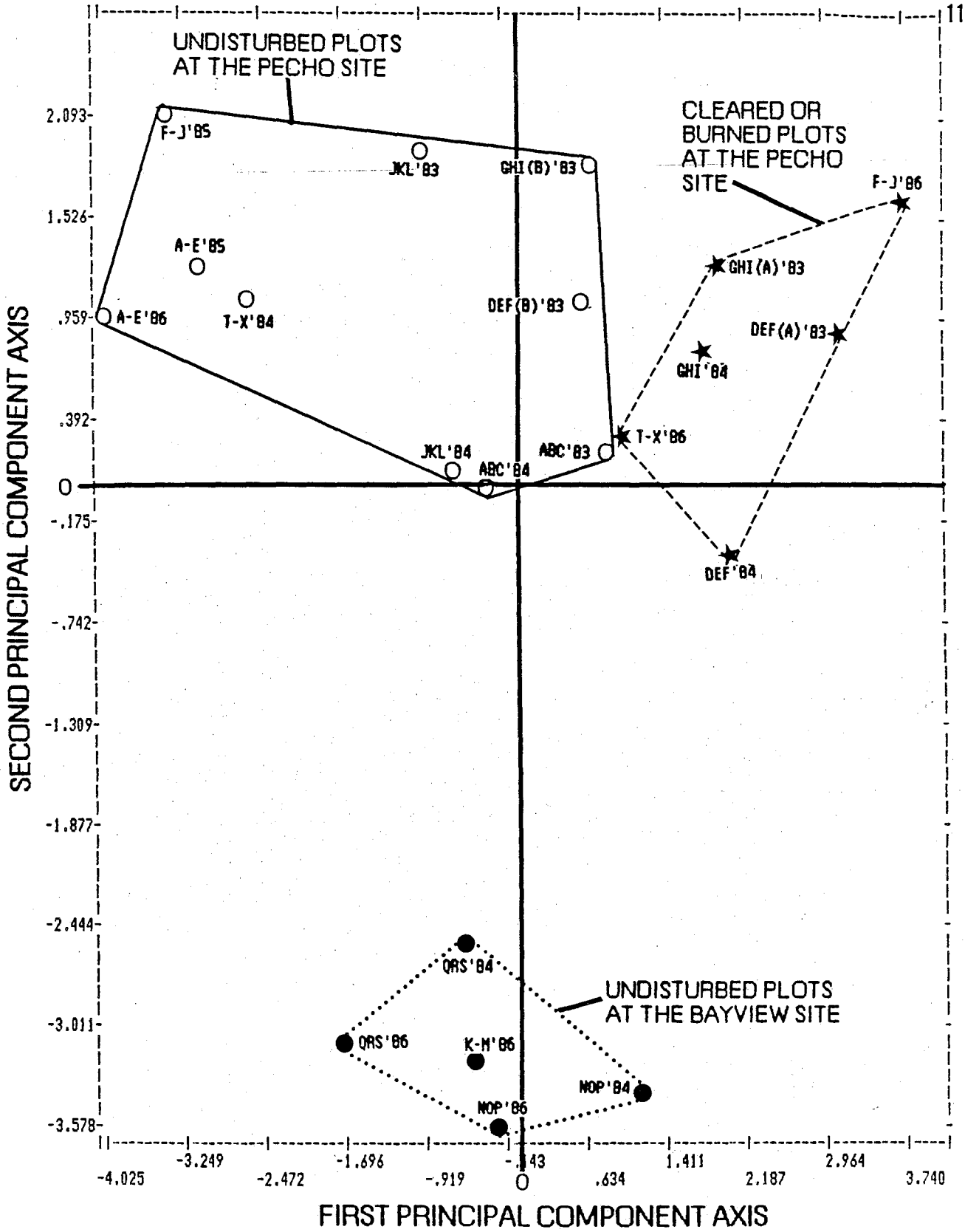


Figure 5—2. Single group Principal Component Analysis of 21 plots years of vegetation sampling at the Pecho and Bayview sites based upon the total line intercept coverage of 20 variables (17 species of plants, vegetative herbaceous growth, dead plant litter, and bare ground). Plots DEF and GHI were sampled twice in 1983; once before brush removal (B) and once after brush removal (A). Raw data (absolute cover values) were standardized to z scores before conducting the analysis.. The origins of both princial component axes are indicated by solid vertical and horizontal lines. The cumulative percentage of total variance accounted for in the first 2 principal components was 40.401 %.

Both cluster analysis and PCA indicate that the habitat occupied by Morro Bay kangaroo rats at Bayview differs substantially from the habitat at Pecho. The Bayview site has more buckbrush, deerweed, and silverweed and less yarrow than the Pecho site. Although the descriptions and comparisons of plant cover at Bayview and Pecho from Chapter IV (Botanical Studies) generally confirmed the large degree of habitat difference between these two sites, several additional differences were revealed in Chapter IV. (1) Both the Bayview and undisturbed Pecho plots had similar overall coverage of living plants, dead plants, and bare ground; however plant species diversity at Bayview was markedly lower than at Pecho. (2) There were more Morro Bay kangaroo rat food plants at Bayview than at Pecho. (3) *Carpobrotus, Corethrogyne,* and *Dudleya* were dominant on some of the Pecho plots, but these three species were never dominant on the Bayview plots and lines. Unfortunately, the lack of comparable vegetation data from past studies has prevented quantitative comparisons of Morro Bay kangaroo rat habitat today with that available when their populations were larger and more widespread. Although a remnant population still persists at the Bayview site, the present habitat there certainly must be different from what it was 30 years ago when they were far more abundant in that area. If the declining numbers and range of Morro Bay kangaroo rats are in any way a function of habitat deterioration over time, then our descriptions of the Bayview habitat should be considered as indicative of habitat conditions which are sufficient, but not necessarily optimal, for the animals there today. It is quite possible that other habitat elements which are absent or obscure today may have been even more beneficial to past populations than the present habitat variables identified in this study.

Our findings suggest the following habitat management activities: (1) potential reintroduction sites having greater coverage of buckbrush, deerweed, and silverweed would be preferable to sites where these 3 species were less abundant, (2) reintroduction sites having both lower plant species diversity and more food plants would be preferable to sites having higher plant species diversity and fewer food plants, and (3) reintroduction sites having little or no *Carpobrotus* (iceplant) would be preferable to sites having iceplant. Obviously, we would expect that reintroduction attempts made on sites which shared an even higher degree of habitat congruency with the Bayview site than just these attributes (above) would be even more likely to succeed.

PCA and, to a lesser extent, CLUST analysis revealed a number of differences in the cover values of habitat variables between undisturbed and manipulated habitat types at Pecho. Manipulated plots had more bare ground and vegetative herbaceous growth and less mock heather, golden yarrow, coastal silver lupine, sand almond, dead plant litter, coastal buckwheat, and California sagebrush. Since both habitat manipulation procedures involved the direct removal of brush and dead litter resulting in more bare ground and the invasion of herbaceous plants, these results serve as much to verify the performance of the multivariate analyses used as they do to provide insights into differences between the habitat types. The real question is whether or not the manipulated habitats would be suitable for reintroduced Morro Bay kangaroo rats. Certainly the reduction in brush cover and dead litter coupled with an increase in bare ground and herbaceous food plants are habitat characteristics which generally have been associated with suitable habitat conditions in past studies (refer to the Introduction). The weak similarity between manipulated habitat and the habitat at Bayview (shown in CLUST analysis) suggests that the manipulated habitat shared more cover characteristics with Bayview than did the undisturbed habitat. However, the fact that both undisturbed and manipulated habitats were strongly grouped at one end of the

second principal axis whereas the Bayview habitat was tightly grouped at the opposite end suggests that the manipulation procedure did not bring the cover characteristics of the manipulated plots into a high degree of congruency with habitat that presently supports Morro Bay kangaroo rats. Had this been the case, then the spatial aggregation of manipulated plots (Fig. 5—2) should have overlapped or at least been positioned closer to the aggregation of Bayview plots.

The results of Community Similarity analysis from Chapter IV (Botanical Studies) generally confirm the results of CLUST and PCA analyses above. Clearing and especially burning caused the manipulated habitats to lose similarity with undisturbed plots at both Pecho and Bayview. Recovery to pre-manipulated conditions was more rapid after clearing than after burning, but the recovering habitat still did not become more similar to Bayview habitat. Both clearing and burning produced an increase in species diversity and a shift in dominance from shrubs to herbs and subshrubs; however the effects of burning were more pronounced than those of clearing. Soils on the burned plots were less acidic and had a higher nutrient content than soils on either the cleared or undisturbed plots.

We conclude that of the two habitat types available for reintroducing Morro Bay kangaroo rats at the Pecho site, the manipulated areas, especially those that were burned, would be preferable to the undisturbed areas; however, at the present time, the manipulated areas are still substantially different from the area now occupied by rats. With time, successional events on the manipulated areas might bring the habitat there "closer" to that at Bayview, but species diversity would have to drop below that of the undisturbed Pecho plots and deerweed, silverweed, and buckbrush coverage would have to rise above present levels on these manipulated sites.

COMPARISON OF HABITATS AT THE BAYVIEW SITE

Absolute cover (m) of major plants, dead material, bare ground, and vegetative herbaceous growth was sampled at 75 Bayview stations in 1984 and 1986. No Morro Bay kangaroo rats were caught at 20 of these stations during the 3 years of the study, however one or more Morro Bay kangaroo rats were caught at 55 of the stations in 1984, 1985, or 1986 (Table 5—2). Stations were grouped according to whether or not rats were caught there and these two groups then were compared in order to assess the nature of habitat use ("preference") exhibited by these animals. Nine plant species or ground cover characteristics (Table 5—2) satisfied the criteria of occurring on at least 50 % of the stations or having an overall cover value of at least 5 % of the total line intercept length (300 m in 1984 and 450 m in 1986) during at least one of two years. The absolute cover of these 9 habitat attributes were treated as variables for purposes of subsequent analyses. The main questions we sought to answer were whether or not unused microhabitats (stations) were different from used microhabitats and if so which habitat variables were responsible for the bulk of the difference.

<u>Multigroup Discriminant Function Analysis</u>— Results of MDA revealed that the group centroid of the 20 stations not used by rats was —.997 whereas the group centroid of the 55 stations used by rats was +.363, a difference of 1.360 standard deviations. Although the individual canonical scores of all used and unused stations showed some

Table 5–2. Sample stations at Bayview ranked according to the total number of Morro Bay kangaroo rat captures from 1984 to 1986. The absolute cover values of 9 major habitat variables at these stations were collected in 1984 and 1986. These cover values represent the raw data used to conduct multivariate analyses of habitat preference in Morro Bay kangaroo rats. The raw data were partitioned into two groups: those stations where no rats were captured (the first 20 stations) and those where at least one animal was caught (the last 55 stations). The designation of lines KK, LL, and MM on plot KKLLMM have been shortened to K, L, and M in the interest of consistency.

ABBREV.	SCIENTIFIC NAME	COMMON NAME
DH.MOR	*Dipodomys heermanni morroensis*	Morro Bay kangaroo rat
ART.CA	*Artemisia californica*	California sagebrush
CEA.CU	*Ceanothus cuneatus*	buckbrush
CRO.CA	*Croton californicus*	croton
ERI.ER	*Ericameria ericoides*	mock heather
HOR.CU	*Horkelia cuneata*	silverweed
LOT.SC	*Lotus scoparius*	deerweed
SAL.ME	*Salvia mellifera*	black sage
DEA.MA	-----	Dead material (litter)
BAR.GR	-----	Bare ground

STA/YR	DH.MOR	ART.CA	CEA.CU	CRO.CA	ERI.ER	HOR.CU	LOT.SC	SAL.ME	DEA.MA	BAR.GR
P100/84	00	24.5	03.5	12.5	00.0	00.0	03.5	00.0	00.0	55.9
O000/84	00	00.0	00.0	05.5	00.0	00.0	53.5	00.0	04.0	16.0
P000/84	00	00.0	00.0	06.0	00.0	02.5	60.5	00.0	00.0	61.0
P075/84	00	24.7	00.0	07.0	00.0	00.1	38.5	25.5	31.0	03.0
N100/84	00	23.0	25.0	00.0	00.0	00.0	00.0	49.0	00.0	15.0
N000/84	00	00.0	11.5	08.5	00.0	02.0	21.0	00.0	00.0	54.0
N050/84	00	00.0	00.0	22.5	00.0	01.5	44.0	00.0	12.0	19.5
N075/84	00	02.5	00.0	19.5	00.0	06.0	32.5	00.0	11.5	17.5
K050/86	00	00.0	00.0	01.6	50.5	50.5	00.0	08.7	19.1	14.4
N075/86	00	05.3	00.0	16.4	00.0	10.7	33.1	00.0	20.6	38.0
N050/86	00	00.0	00.0	37.9	00.0	00.0	41.9	00.0	24.9	34.5
M100/86	00	00.0	49.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0
K150/86	00	00.0	19.7	10.8	00.0	17.3	06.1	00.0	08.9	33.0
M150/86	00	00.0	77.7	05.5	02.9	11.2	00.0	00.0	00.0	16.0
P000/86	00	00.0	00.0	09.4	00.0	00.0	37.6	00.0	00.0	63.9
O000/86	00	00.0	00.0	24.2	00.0	00.0	36.8	00.0	28.7	09.5
P100/86	00	26.5	13.3	03.2	00.0	00.0	14.0	00.0	11.5	51.2
P075/86	00	00.0	00.0	13.1	00.0	00.0	08.4	57.9	19.3	29.0
N100/86	00	22.5	29.3	00.0	00.0	00.0	11.9	51.6	00.0	18.3
N000/86	00	00.0	18.2	18.4	00.0	06.3	17.2	00.0	00.0	46.0
P025/84	01	00.0	00.0	00.0	00.0	04.0	24.5	00.0	01.5	79.0
Q025/84	01	00.0	00.0	17.3	00.0	04.0	46.5	00.0	00.0	53.5
Q075/84	01	51.5	00.0	17.5	00.0	02.5	12.5	00.0	06.0	39.5
L050/86	01	00.0	00.0	00.0	14.9	26.9	07.4	38.4	03.5	33.3
Q025/86	01	19.7	00.0	01.1	00.0	39.3	12.3	00.0	35.9	19.1
Q075/86	01	32.2	00.0	28.9	03.4	18.8	20.3	21.8	23.9	20.0
P025/86	01	00.0	00.0	00.6	04.5	07.2	10.0	00.0	00.0	65.5
K000/86	01	00.0	25.8	00.0	07.9	30.3	24.2	37.4	00.0	04.3
K200/86	01	00.0	22.3	03.9	00.4	20.7	01.4	00.0	26.3	27.7
R075/84	02	00.0	00.0	01.0	00.0	10.5	10.0	08.5	31.0	38.0
P050/84	02	15.0	00.0	04.5	00.0	02.0	42.0	00.0	05.0	19.5
R000/84	02	00.0	00.0	13.0	14.5	21.0	12.5	00.0	06.0	25.0
N025/84	02	20.0	37.5	07.5	00.0	00.0	03.8	00.0	01.2	31.2
Q050/84	02	25.5	00.0	00.0	00.0	27.0	27.5	00.0	14.0	13.0
R075/86	02	09.8	00.0	01.0	00.0	26.7	14.8	33.5	22.3	21.5
R000/86	02	01.3	00.0	00.4	25.4	13.3	00.2	00.0	27.4	39.3
N025/86	02	07.1	48.0	01.3	00.0	03.5	05.0	00.0	71.4	00.0
P050/86	02	01.9	01.6	03.3	00.0	04.4	33.4	00.0	35.2	33.2

STA/YR	DH.MOR	ART.CA	CEA.CU	CRO.CA	ERI.ER	HOR.CU	LOT.SC	SAL.ME	DEA.MA	BAR.GR
Q050/86	02	42.0	37.0	15.1	00.0	27.9	22.3	00.0	45.3	07.1
L100/86	02	00.0	00.0	00.0	07.8	29.2	04.9	00.0	18.2	19.4
O075/84	03	00.0	11.0	05.5	00.0	00.0	55.0	00.0	00.0	44.0
O050/84	03	00.0	51.0	04.0	00.0	00.0	18.5	00.0	00.0	20.0
Q100/84	03	43.5	00.0	05.5	00.0	18.5	09.0	00.0	28.0	09.0
R050/84	03	00.0	12.0	00.5	31.0	32.0	19.0	00.0	03.0	26.0
L000/86	03	00.0	00.0	00.0	17.6	00.0	00.0	32.9	00.0	39.1
O075/86	03	00.0	00.0	10.7	00.0	00.0	53.7	00.0	04.6	19.5
R050/86	03	06.0	00.0	12.3	15.8	34.6	30.2	00.0	14.7	26.4
O050/86	03	00.0	51.2	02.4	00.0	05.7	18.3	00.0	02.8	25.7
Q100/86	03	47.9	00.0	10.8	00.0	22.7	20.7	00.0	08.4	20.6
S100/84	04	20.5	00.0	20.5	00.0	20.5	07.5	00.0	17.5	16.0
O100/84	04	07.0	19.5	18.0	00.0	03.0	13.0	00.0	05.5	30.0
R100/84	04	21.0	00.0	11.0	00.0	21.0	42.5	00.0	07.5	17.5
S075/84	04	00.0	00.0	02.0	04.5	44.5	06.0	00.0	07.0	31.0
O100/86	04	07.8	20.5	10.0	00.0	01.1	17.0	00.0	12.2	29.3
R100/86	04	10.7	00.0	00.0	22.8	56.5	22.6	00.0	18.2	34.2
S075/86	04	00.0	00.0	02.3	14.3	24.4	00.0	42.0	20.4	22.8
S100/86	04	03.5	00.0	00.0	10.5	24.2	14.5	17.3	21.2	43.0
Q000/84	05	19.5	00.0	07.5	09.5	05.0	11.5	00.0	13.5	25.0
M200/86	05	00.0	00.0	02.3	00.0	43.8	00.0	03.8	01.0	55.0
L200/86	05	00.0	00.0	09.5	00.0	38.7	13.0	00.0	03.2	47.1
Q000/86	05	22.1	09.5	10.8	36.1	13.5	00.0	00.0	04.2	50.2
O025/84	06	00.0	00.0	04.5	00.0	07.5	60.5	00.0	00.0	30.5
O025/86	06	00.0	00.0	03.6	00.0	07.3	21.4	00.0	13.8	55.0
S025/84	07	00.0	00.0	00.5	06.0	56.0	01.0	00.0	04.0	24.0
S000/84	07	01.0	00.0	04.0	06.0	31.5	17.0	00.0	03.5	37.5
S050/84	07	05.0	00.0	08.0	12.0	36.5	20.0	00.0	00.0	05.0
S000/86	07	00.0	00.0	00.0	29.4	34.4	07.1	00.0	00.0	59.3
L150/86	07	00.0	00.0	07.7	00.0	42.0	29.9	00.0	03.8	33.4
M000/86	07	00.0	00.0	01.7	00.0	23.7	03.6	58.4	02.4	30.1
S050/86	07	00.0	00.0	00.0	00.0	47.5	07.6	00.0	03.6	45.3
S025/86	07	00.0	00.0	01.2	00.0	43.3	07.6	00.0	11.0	41.2
M050/86	08	00.0	00.0	00.0	06.6	00.0	00.0	40.0	00.0	34.8
R025/84	13	06.0	00.0	02.0	09.0	22.5	08.5	00.0	04.0	44.5
R025/86	13	07.5	00.4	10.0	00.0	23.1	28.5	00.0	47.5	37.9
K100/86	16	25.7	00.0	00.0	00.0	31.4	00.0	36.4	01.9	34.4

overlap between the groups (Fig. 5—3), the group centroids were significantly different ($F = 2.68$; $df = 9$ and 65; $p = 0.01$). There were 4 plant species which, when taken separately, accounted for the greatest degree of generalized distances (expressed in standard deviations) between used and unused habitat groups: silverweed, 1.022 S.D.; croton, .745 S.D.; deerweed, .388 S.D.; and buckbrush, .381 S.D. Only two of these, silverweed and croton, differed significantly ($p < 0.05$, Student Newman-Keuls Multiple Range Test) between the used and unused habitat groups. The mean cover of silverweed was nearly 4 times higher at stations used by rats than at unused stations (Table 5—3). Conversely, the mean cover of croton at used stations was only half that recorded at unused stations. Although not statistically significant, the mean cover values of deerweed and buckbrush were somewhat lower at stations used by rats than at unused stations. It should be kept in mind that the previous comparisons of plots at Pecho and Bayview indicated that buckbrush, deerweed, and silverweed covered a greater proportion of the Bayview plots than the Pecho plots. Thus, even though rats tended to show a weak aversion toward buckbrush and deerweed among the stations at Bayview, the general Bayview area had greater coverage of these two species than did the unoccupied habitats at Pecho.

Table 5—3. Mean absolute cover values of 9 major habitat (cover) variables at the Bayview site from pooled data collected in 1984 and 1986. The means of species indicated with an "*" were significantly different ($p < 0.05$, Student Newman-Keuls Multiple Range Test). Unused habitat is represented by 20 sample stations where no Morro Bay kangaroo rats were caught from 1984 — 1986. Used habitat is represented by 55 sample stations where one or more Morro Bay kangaroo rats were caught from 1984 — 1986.

	MEAN COVER VALUES AT BAYVIEW	
SPECIES	UNUSED HABITAT	USED HABITAT
* *Horkelia cuneata*(silverweed)	5.40	20.65
* *Croton californicus*(croton)	11.10	5.50
Lotus scoparius(deerweed)	23.02	16.73
Ceanothus cuneatus(buckbrush)	12.36	6.31
Artemisia californica(California sagebrush)	6.45	8.74
Ericameria ericoides(mock heather)	2.67	5.63
Salvia mellifera(black sage)	9.64	6.73
Dead litter	9.47	12.05
Bare ground	29.78	31.52

The results of Geisser classification (from MDA) indicated that 76 % of the stations were predicted to have been drawn from their correct group (hits) and 24 % of the stations were predicted to have been drawn from an incorrect group (misses). Twelve stations were predicted to have been drawn from the unused microhabitat (7 were hits and 5 were misses from the used microhabitat group. Sixty-three stations were predicted to have been drawn from the used microhabitat (50 were hits and 13 were misses from the unused microhabitat group). Of the 18 incorrect classifications, 72 % were unused stations which had cover that indicated they should have been used by Morro Bay kangaroo rats. Since our designation of used and unused habitat was based upon live trapping results, it is possible that animals did use the area around these 13 stations but

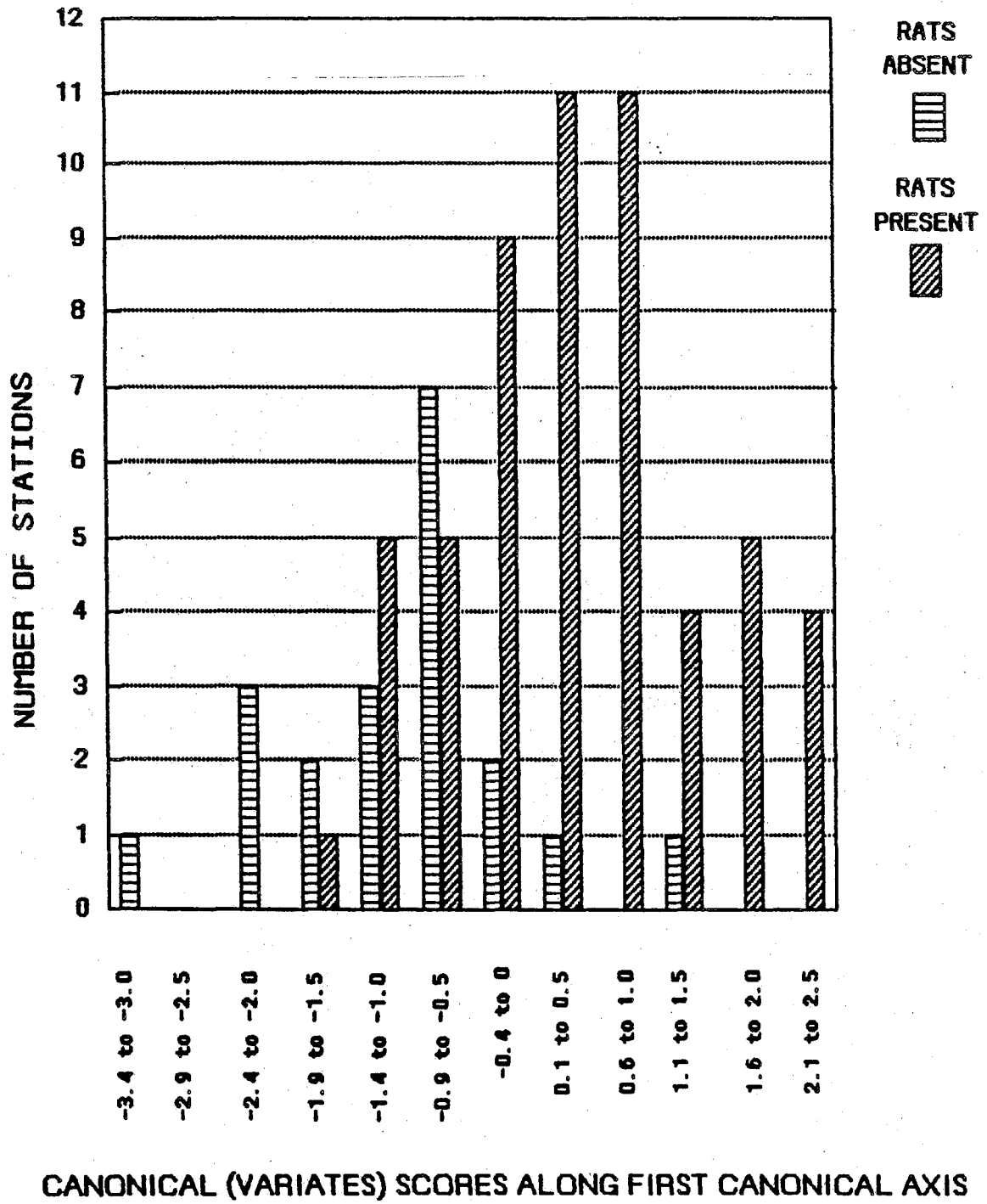


Figure 5–3. Frequency distribution of canonical scores for all individual stations along the first canonical axis. The mean scores of stations with no rats and stations with rats were −.997 and +.363, respectively.

avoided the traps. It is also possible that the reduced number of variables used in the MDA somehow resulted in a disproportionate number of misses in the unused habitat group; however we found no evidence of this when we examined the conditioning of the dispersion matrix. It seems more likely that these miss-classified unused stations at Bayview were not used because the Morro Bay kangaroo rat population was too small to occupy all of the usable habitat there. The lower incidence of incorrect classifications (28 %) from used to unused habitat tends to support the notion that the population was below carrying capacity. Had the used habitat been populated to carrying capacity, then any new animals probably would have been forced to take up temporary residence in less suitable areas which in turn would have produced more incorrect classifications from used to unused habitat than were actually observed in the analysis.

Multigroup Principal Component Analysis— Multigroup PCA of the same data set generally confirms the results from MDA and provides several additional details concerning the influence of variables within each of the 2 microhabitat types. For the 20 stations which were not used by Morro Bay kangaroo rats, the first principal component axis accounted for 29.4 % of the total variance and the first and second axes combined accounted for 53.7 % of the total variance. The percent of variance and component correlations of the major variables for the first principal component axis were:

Habitat Variable	% Variance	Comp. Corr.
deerweed	70.1 %	+ .837
croton	62.8 %	+ .793
buckbrush	45.1 %	− .671

The percent of variance and component correlations of the major variables for the second principal component axis were:

Habitat Variable	% Variance	Comp. Corr.
silverweed	76.4 %	+.874
mock heather	73.8 %	+.859

Thus the majority of the variation among stations which were not used by rats was accounted for by differences in the cover of deerweed, croton, buckbrush, silverweed, and mock heather. The high degree of variation attributed to deerweed, croton, buckbrush, and silverweed (species which were largely responsible for discrimination between the two groups in MDA) on unused stations probably explains the high incidence of miss-classification of unused stations in MDA. In other words, it appears that some of the unused stations actually had cover characteristics which were typical of used stations.

For the 55 stations which were used by Morro Bay kangaroo rats, the first principal component axis accounted for 24.9 % of the total variance and the first and second axes combined accounted for 41.9 % of the total variance. The percent of variance and component correlations of the major variables for the first principal component axis were:

Habitat Variable	% Variance	Comp. Corr.
croton	42.7 %	−.654
California sagebrush	38.3 %	−.619

The percent of variance and component correlations of the major variables for the second principal component axis were:

Habitat Variable	% Variance	Comp. Corr.
deerweed	43.2 %	−.658
bare ground	31.9 %	−.565
dead litter	29.4 %	+.542

It's interesting to note that 3 of the 5 major variables (California sagebrush, bare ground, and dead litter) involved in the first and second principal components were ones which were not particularly influential in discriminating between used and unused stations in the MDA. One might speculate than when one or more of the major habitat characteristics are optimal (e.g. silverweed, deerweed, buckbrush, or croton) then Morro Bay kangaroo rats might use microhabitats that showed considerable variation in the coverage of other habitat components such as California sagebrush, bare ground, or dead litter.

By synthesizing results from both levels of habitat analysis and assuming that the remnant population at Bayview persists there because of more favorable habitat conditions, it is possible to construct a general picture of the present habitat relations of Morro Bay kangaroo rats. The present population of Morro Bay kangaroo rats shows a definite preference for Coastal Dune Scrub communities covered with plenty of buckbrush *(Ceanothus cuneatus)*, deerweed *(Lotus scoparius)*, and silverweed *(Horkelia cuneata)* and little yarrow *(Achillea borealis)*. Stands of Coastal Dune Scrub having optimal coverage of these 4 species usually are not populated uniformly by rats because of subtle differences in microhabitats within the stand. Those microhabitats within the stand that have a higher silverweed *(Horkelia cuneata)* coverage and a lower croton *(Croton californicus)* coverage generally were preferred over other microhabitats not having this particular relationship of habitat attributes. It appears that when the population size of Morro Bay kangaroo rats was low, some of the microhabitats having suitable cover were not used. These microhabitats may have been outside the home range of the nearest individual, they may have been too small to support one animal, or they may have been slightly less suitable than other available sites.

CONCLUSIONS ON HABITAT RELATIONS

1. Multivariate analysis of overall plant cover revealed a substantial difference between the habitat occupied by Morro Bay kangaroo rats at Bayview and habitat not occupied by Morro Bay kangaroo rats at Pecho.

2. The present population of Morro Bay kangaroo rats showed a definite preference for Coastal Dune Scrub communities with fairly low plant species diversity, plenty of buckbrush, deerweed, and silverweed and little yarrow, iceplant, California aster, and Dudleya. Within stands of Coastal Sage Scrub having the above attributes, Morro Bay kangaroo rats were found in microhabitats that had significantly higher silverweed cover and significantly lower croton cover.

3. Multivariate analysis revealed that manipulated (cleared and burned) habitats at Pecho were still substantially different from habitat now occupied by Morro Bay kangaroo rats at Bayview. Plant succession on the cleared and burned habitats probably will return these manipulated habitats back to pre-manipulated conditions within a relatively short period of time.

4. Our findings suggest that potential reintroduction sites at Pecho (e.g. cleared or burned sites) having greater coverage of buckbrush, deerweed, and silverweed would be preferable to other sites where these 3 species were less abundant. Obviously, we would expect the greatest success if reintroduction attempts were made on sites that were essentially identical to the Bayview site.

VI. RECOMMENDATIONS

MANAGEMENT RECOMMENDATIONS

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

2. Serious consideration should be given to plowing a 10 to 15 acre experimental plot at the Pecho site. This is the one method of habitat manipulation (conducted by the U. S. Army in about 1955) that has been positively associated with a thriving population of Morro Bay kangaroo rats at the Pecho site (Stewart 1958 and Roest personal comm.). Complete removal of all shrubs by means of ground-breaking "rippers" would be preferable to more burning or brush clearing at this point because the latter two manipulation methods have not yet produced "ideal" results. Plowing also would provide an additional dimension to the diversity of habitats available to rats released at Pecho. Such dramatic habitat manipulation should be completed before Morro Bay kangaroo rats are allowed to range freely at Pecho. News releases, signs explaining the purpose of the project, and other media efforts would at least provide concerned citizens with an explanation of what might appear to be an extreme method of habitat management.

3. The continued spread of California ground squirrels into cleared, burned, and undisturbed habitat at Pecho represents a serious obstacle to both present and future introductions of Morro Bay kangaroo rats there. A ground squirrel control program should be instituted throughout the Critical Habitat as soon as possible. This action should be completed before Morro Bay kangaroo rats are allowed to range freely at Pecho.

4. A serious effort should be undertaken to identify parcels of "undeveloped", potentially suitable habitat which could be purchased by governmental agencies and then modified to support Morro Bay kangaroo rats. A suitable parcel would be circular or at least compact covering about 90 ha. A 90 ha parcel would probably support a population of about 350 individuals. Parcels smaller than 90 ha might be feasible if a high level of management effort could be devoted to them. Obviously, a number of 90 ha parcels would be required to support the 2,500 animals prescribed in the recovery plan. Assuming that an average density of 4 individuals / ha could be achieved over all habitat, the total amount of land required to support 2,500 individuals would be about 625 ha (= 1,500 acres = 2.4 square miles). Even if habitat could be created that would, for example, support an average density of 8 individuals / ha, the amount of land required still would be about 1.2 square miles.

5. A long range program of experimental habitat manipulation and/or restoration should be instituted for the Critical Habitat area as well as other sites (e. g. the Buckskin, Bayview, Junior High, and Santa Ysabel Essential Habitat areas) where such activities would be feasible. Habitat management should be followed by successive introductions of Morro Bay kangaroo rats when sufficient rats become available and the habitats are judged to be suitable. Assuming that Morro Bay kangaroo rats eventually become free ranging at Pecho or elsewhere, it will become increasingly more important to carefully weigh the benefits (vs) the risks to these animals of future habitat manipulation and/or restoration programs proposed for that site.

6. Experiments should be undertaken to evaluate the efficacy of supplemental feeding as means of increasing the future density of wild populations of Morro Bay kangaroo rats. "Before and after" experiments would be the designs most likely to reveal the effects of such a procedure.

7. Periodic ground reconnaissance trips should be made along the eastern boundary of public land in the Critical Habitat area. The purpose of this is to ensure early detection of erosion, invasion of weedy plants, runoff, and other adverse impacts to Critical Habitat originating from neighboring residential developments. When Morro Bay kangaroo rats become free ranging at Pecho, it may be necessary to monitor domestic pets, vehicles, livestock, and foot traffic in the area to ensure that the rats, as well as their burrows and food sources remain undisturbed.

RESEARCH RECOMMENDATIONS

1. Maintenance and expansion of the captive breeding facility are essential to ensure that animals will be available for future management projects. Assuming that the 1988 reintroduction continues to be successful, preparations should be made for future reintroductions of Morro Bay kangaroo rats at Pecho and elsewhere. It may be necessary to employ artificial insemination, hormone or dietary supplements, reversed or altered photoperiods, and other procedures in order to promote maximum reproductive output of captive animals.

2. Controlled food discrimination experiments should be conducted on captive Morro Bay kangaroo rats so that all the common plant species can be ranked according to their preference by rats. This information, when combined with field data on plant communities, would permit a more detailed evaluation of the importance of certain plants and it could suggest specific ways to restore or manipulate habitats. Results from these experiments also would provide valuable background information for a proposed supplemental feeding experiment.

3. Population estimates of the Morro Bay kangaroo rats at Bayview should be conducted every 1 — 2 years. This is particularly important because the Bayview population is the only viable wild population known to exist at the present time. Thorough ground searchs for signs of Morro Bay kangaroo rats should be conducted at the Pecho, Bayview, Buckskin, and Junior High / Santa Ysabel sites every year.

4. At the present time, the Bayview site represents the best field site for assessing the population response of Morro Bay kangaroo rats to habitat manipulation. A set of "before and after" experiments would allow direct comparisons of rat responses to several types of habitat manipulation and/or restoration procedures.

5. Every effort should be made to monitor burrow system development, foraging activities, microhabitat preference, general physical condition, signs of agonistic interactions, reproductive success, and dispersal of adult and young Morro Bay kangaroo rats that have been introduced into protective enclosures at the Pecho site. Although difficult, it will be especially important to monitor the introduced animals after they have been allowed to leave the enclosures. These animals would be the logical subjects for measurements on root-mean-squared dispersal distance per generation and net lifetime production of female offspring per adult female (measures which are used to

estimate minimum habitat requirements). This latter monitoring work would be most efficiently done using biotelemetry and night vision equipment.

6. Continued monitoring of small mammal communities on the plots at Pecho will provide population baselines which can be used to assess possible competitive interactions between Morro Bay kangaroo rats and other small mammal species there. It would be particularly useful to design a set of field experiments which would directly measure the degree of actual competitive interactions.

7. Continued vegetation sampling of the cleared and burned plots is important in order to follow the succession of these plots back to maturity (pre-manipualtion conditions). These data should be correlated with results of small mammal sampling so that changes in habitat conditions can be evaluated in terms of small mammals.

8. Continued sampling of plant communities at all future reintroduction sites will become increasingly important as free ranging populations of Morro Bay kangaroo rats becomes established at these sites. Careful assessment of plant communities that are either used or unused by rats should provide a more precise evaluation of the importance of vegetation composition and structure as well as the efficacy of habitat manipulation techniques in providing optimal habitat for Morro Bay kangaroo rats.

9. A comprehensive examination of the genetic variance present in wild and lab animals using no risk, non-invasive genetic "fingerprinting" techniques should be conducted as soon as possible.

10. The preservation of Morro Bay kangaroo rat cellular and/or genetic specimens in a long-term "gene bank" should be initiated so that future scientific study may be conducted on properly preserved material. It may be possible to combine genetic preservation with genetic "fingerprinting" (above).

11. Field research biologists from various agencies and institutions could mount a more effective and expedient recovery effort on kangaroo rats if they worked through a local "research/recovery center" on a full time basis.

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APPENDIX A.

OTHER VERTEBRATE SPECIES AT THE PECHO AND BAYVIEW SITES

Mammals— In addition to domestic dogs and cats, other mammal species known to occur on one or both of the sites include: Virginia opossum, *Didelphis virginiana;* Trowbridge's shrew, *Sorex trowbridgii;* broad-footed mole, *Scapanus latimanus;* brush rabbit, *Sylvilagus bachmani;* desert cottontail, *Sylvilagus audobonii;* black-tailed hare, *Lepus californicus;* Botta's pocket gopher, *Thomomys bottae;* California vole, *Microtus californicus;* coyote, *Canis latrans;* gray fox, *Urocyon cinereoargenteus;* raccoon, *Procyon lotor;* long-tailed weasel, *Mustela frenata;* badger, *Taxidea taxus;* striped skunk, *Mephitis mephitis;* bobcat, *Felis rufus;* and mule deer, *Odocoileus hemionus.*

Amphibians and Reptiles— Although no amphibians were found, reptile species known to occur on one or both of the sites include: western fence lizard, *Sceloporus occidentalis;* coast horned lizard, *Phrynosoma coronatum;* southern alligator lizard, *Gerrhonotus multicarinatus;* California legless lizard, *Anniella pulchra;* striped racer, *Masticophis lateralis;* gopher snake, *Pituophis melanoleucus;* common kingsnake, *Lampropeltis getulus;* and western rattlesnake, *Crotalus viridis.*

Birds— The most common predatory bird species seen near the sites were: turkey vulture, *Cathartes aura;* northern harrier, *Circus cyaneus;* Cooper's hawk, *Accipiter gentilis;* red-shouldered hawk, *Buteo lineatus;* red-tailed hawk, *Buteo jamaicensis;* American kestrel, *Falco sparverius;* barn owl, *Tyto alba;* and great horned owl, *Bubo virginianus.* Other common birds seen at one or both of the sites were: California quail, *Callipepla californica;* mourning dove, *Zenaida macroura;* Say's phoebe, *Sayornis saya;* scrub jay, *Aphelocoma coerulescens;* Bewick's wren, *Thryomanes bewickii;* northern mockingbird, *Mimus polyglottos;* California thrasher, *Toxostoma redivivum;* rufous-sided towhee, *Pipilo erythrophthalmus;* brown towhee, *Pipilo fuscus;* white-crowned sparrow, *Zonotrichia leucophrys;* and house finch, *Carpodacus mexicanus.*

Comparison of California mice to brush mice— During the course of the study, we occasionally caught *Peromyscus* mice that were difficult to identify using keys based upon external measurements and morphology. These rare individuals had some features which were characteristic of California mice *(Peromyscus californicus)* and other features which were characteristic of brush mice *(Peromyscus boylii).* Once this situation was discovered, body weight as well as tail, foot, and ear lengths were taken on these animals so that their identification could be verified later.

One of the authors (Gambs) conducted a separate study of the external differences between these two species using adult specimens from San Luis Obispo and Santa Barbara counties which were available at the Museum of Vertebrate Zoology, University of California, Berkeley and the Santa Barbara Museum of Natural History at Santa Barbara. The pertinent results of this study are summarized in the following table:

Comparison of adult body weights from 30 brush mice *(Peromyscus boylii)*, and 12 California mice *(Peromyscus californicus)* and external measurements and qualitative differences from 34 brush mice and 61 California mice specimens from the Museum of Vertebrate Zoology, U. C. Berkeley and the Santa Barbara Museum of Natural History. The associated significance level (P) is given for those student's "t" tests which revealed a significant difference between means.

MEASUREMENT OR FEATURE	*Peromyscus californicus*	*Peromyscus boylii*	P
MEAN (±SE) TOTAL LENGTH (mm)	224.7 ±1.5	186.7 ±1.7	≤.0005
MEAN (±SE) TAIL LENGTH (mm)	122.2 ±1.0	96.5 ±1.6	≤.0005
MEAN (±SE) FOOT LENGTH (mm)	24.8 ±0.2	21.6 ±0.2	≤.0005
MEAN (±SE) EAR LENGTH (mm)	21.6 ±0.4	16.7 ±0.5	≤.0005
MEAN (±SE) BODY WEIGHT (g)	33.5 ±0.8	24.2 ±1.0	≤.0005
* COLORATION OF THE TAIL	ESSENTIALLY UNICOLORED	DISTINCTLY BICOLORED	
* PRESENCE OF HAIR ON THE CENTER OF THE SOLES OF THE HIND FEET WHEN VIEWED WITH A 10X HAND LENS	NOT PRESENT	PRESENT	
* TAIL LENGTH OF MOST ADULT SPECIMENS IS:	> 110 mm	< 110 mm	
* BODY WEIGHT OF MOST ADULT SPECIMENS IS:	> 30 g	< 30 g	
EAR LENGTH OF MOST ADULT SPECIMENS IS:	> 20 mm	< 20 mm	
HIND FOOT LENGTH OF MOST ADULT SPECIMENS IS:	> 23 mm	< 23 mm	

* Indicates the 4 best field criteria for differentiating live California mice from live brush mice in the vicinity of the study area.

Re-examination of data collected from the few animals reported as *Peromyscus boylii* (Gambs 1986g) indicates that they had more features in common with *Peromyscus californicus* and, consequently, they have been re-assigned to the latter species in this report.

APPENDIX B.

PLANT SPECIES OF THE PECHO STUDY SITE

SHRUBS

R&E	Arctostaphylos morroensis	morro manzanita
	Artemisia californica	California sagebrush
	Baccharis pilularis	coyote bush
	Ceanothus cuneatus	buckbrush
	Corethrogyne filaginifolia	California-aster
	Ericameria ericoides	mock-heather
	Eriogonum parvifolium	coastal buckwheat
	Eriophyllum confertiflorum	common golden-yarrow
	Hazardia squarrosa	goldenbush
	Helianthemum scoparium	rush-rose
	Lotus scoparius	common deerweed
	Lupinus chamissonis	coastal silver lupine
	Prunus ilicifolia	holly-leaf cherry
R&E	Prunus fasciculata var. punctata	sand almond
	Quercus agrifolia var. frutescens	pygmy oak
	Rhamnus californica	coffeeberry
	Rhamnus crocea	redberry
	Salvia mellifera	black sage
	Senecio blochmaniae	Blochman's shrubby groundsel
	Solanum douglasii	black nightshade
	Solanum xanti	purple nightshade
	Toxicodendron diversilobum	poison-oak

HERBS

	Abronia umbellata	purple sand-verbena
	Achillea borealis	yarrow
	Amsinckia spectabilis var. microcarpa	fiddleneck
**	Anagallis arvensis	pimpernel
	Apiastrum angustifolium	apiastrum
	Artemisia douglasiana	mugwort
	Artemisia dracunculus	tarragon
	Astragalus pomonensis	locoweed
**	Avena barbata	slender wild oats
**	Avena fatua	wild oats
**	Bromus diandrus	ripgut brome

**	Bromus mollis	soft chess brome
**	Bromus rubens	red brome
	Camissonia chieranthifolia var. suffruticosa	dune evening-primrose
	Camissonia micrantha	evening-primrose
	Camissonia strigillosa	little evening-primrose
	Cardionema ramosissima	sand-mat
	Carex pansa	sedge
	Carpobrotus chilensis	ice plant
*	Carpobrotus edulis	ice plant
	Chenopodium californicum	California goosefoot
	Chenopodium carnulosum var. patagonicum	sand goosefoot
	Chorizanthe angustifolia var. eastwoodiae	spineflower
	Cirsium occidentale var. occidentale	cobwebby thistle
**	Cirsium vulgare	bull thistle
	Claytonia perfoliata	miner's lettuce
*	Conicosia elongata	narrow-leafed ice plant
	Croton californicus	croton
	Cryptantha clevelandii var. hispidissima	cryptantha
	Daucus pusillus	wild carrot
	Descurainia pinnata var. menziesii	tansy mustard
	Dichelostemma pulchellum	blue-dicks
	Dudleya caespitosa	common dudleya
**	Ehrharta calycina	veldt grass
	Elymus glaucus	wild rye
	Eriastrum densifolium	wolly gilia
R&E	Erigeron foliosus var. blochmaniae	Blochman's leafy daisy
	Eriophyllum multicaule	annual golden-yarrow
**	Erodium cicutarium	redstem filaree
**	Erodium botrys	filaree
R&E	Erysimum suffrutescens var. lompocense	San Luis Obispo Wallflower
**	Euphorbia crenulata	spurge
	Eschscholzia californica	California poppy
	Eucrypta chrysanthemifolia	eucrypta
**	Filago californica	filago
	Galium californicum	California bedstraw
	Gilia sp.	gilia
	Gnaphalium bicolor	bicolored everlasing
	Gnaphalium californicum	California everlasting
	Gnaphalium ramosissimum	pink everlasting
	Hemizonia increscens	tarweed
	Hesperocnide tenella	annual stinging nettle
	Heterotheca grandiflora	telegraph weed
	Horkelia cuneata	horkelia
**	Hypochoeris glabra	smooth cat's ear
	Juncus leseurii	dune rush
	Koeleria nitida	junegrass

	Layia glandulosa	white layia
	Layia hieracioides	small-headed layia
	Linaria texana	toadflax
	Lotus sp.	deervetch
	Malacothrix californica	California dandelion
	Marah fabaceus	manroot
	Marrubium vulgare	horehound
**	Matricaria matricarioides	pineapple weed
	Melica imperfecta	melic grass
R&E	Monardella undulata var. undulata	curly-leafed monardella
	Mucronea californica	spineflower
	Orthocarpus purpurascens var. pallidus	owl's clover
	Paeonia californica	peony
	Parietaria floridana	pellitory
	Phacelia distans	phacelia
	Pholisma arenarium	pholisma
	Plantago erecta	annual plantain
	Pteridium aquilinum	bracken fern
	Pterostegia drymarioides	notchleaf
	Salvia columbariae	chia
	Senecio californicus	groundsel
	Silene laciniata var. angustifolia	Indian pink
	Solanum douglasii	black nightshade
**	Stellaria media	chickweed
	Stephanomeria virgata	wire-lettuce
**	Tetragonia tetragoniodes	New Zealand spinach
	Tillaea erecta	pygmy weed
**	Vulpia myuros	rattail fescue
**	Vulpia octoflora	six-weeks fescue

* — Ornamental species escaped from cultivation.
** — Introduced more-or-less weedy species.
R&E — Plant considered to be rare and/or endangered.

APPENDIX C.

PLANT SPECIES OF BAYVIEW STUDY SITE

LARGE TREES

*	Cupressus macrocarpa	Monterey cypress
*	Eucalyptus globulus	blue gum
	Pinus muricata	bishop pine

SHRUBS

	Adenostoma fasciculatum	chamise
*	Aeonium sp.	aeonium
	Arctostaphylos crustacea	brittle-leafed manzanita
R&E	Arctostaphylos morroensis	Morro manzanita
	Artemisia californica	California sagebrush
	Baccharis pilularis	coyote bush
	Ceanothus cuneatus	buckbrush
	Corethrogyne filaginifolia	California-aster
	Eriastrum densifolium	wooly-gilia
	Ericameria ericoides	mock-heather
R&E	Eriodictyon altissimum	Indian Knob mountain balm
	Eriogonum parvifolium	coastal buckwheat
	Eriophyllum confertiflorum	common golden-yarrow
	Galium nuttallii	brush bedstraw
	Helianthemum scoparium	rush-rose
	Heteromeles arbutifolia	toyon
	Lotus scoparius	common deerweed
	Lupinus chamissonis	coastal silver lupine
	Mimulus aurantiacus	sticky monkeyflower
	Prunus ilicifolia	holly-leafed cherry
R&E	Prunus fasciculata var. punctata	sand almond
	Quercus agrifolia var. frutescens	pygmy oak
	Rhamnus californica	coffeeberry
	Rhamnus crocea	redberry
	Ribes malvaceum	chaparral currant
	Ribes speciosum	fuchsia-flowered gooseberry
	Rosa californica	wild rose
	Salvia mellifera	black sage
	Solanum douglasii	black nightshade
	Solanum xanti	purple nightshade
	Symphoricarpos mollis	dwarf snowberry
	Toxicodendron diversilobum	poison-oak

HERBS

	Abronia umbellata	purple sand-verbena
	Achillea borealis	yarrow
	Adiantum jordanii	California maidenhair fern
	Amsinckia spectabilis	fiddleneck
**	Anagallis arvensis	scarlet pimpernel
	Apiastrum angustifolium	apiastrum
	Artemisia douglasiana	mugwort
**	Avena barbata	slender wild oats
**	Avena fatua	common wild oats
**	Brachypodium distachyon	false brome
**	Brassica geniculata	perennial mustard
**	Bromus diandrus	ripgut brome
**	Bromus mollis	soft chess brome
**	Bromus rubens	red brome
	Calystegia macrostegia	morning glory
	Camissonia micrantha	little evening-primrose
	Camissonia strigillosa	little evening-primrose
	Cardionema ramosissima	sand-mat
**	Carduus pycnocephalus	Italian thistle
	Carex globosa	sedge
	Carpobrotus chilensis	ice plant
*	Carpobrotus edulis	South African ice plant
	Castilleja affinis	Indian paintbrush
	Castilleja foliolosa	Indian paintbrush
**	Centaurea solstitialis	yellow star thistle
	Centaurium davyi	centuary
**	Cerastium viscosum	mouse-ear chickweed
**	Chenopodium album	lamb's quarter
	Chenopodium californicum	California goosefoot
**	Chenopodium murale	common goosefoot
	Chorizanthe angustifolia var. eastwoodiae	spineflower
	Chorizanthe staticoides	spineflower
	Cirsium brevistylum	thistle
	Cirsium occidentale var. occidentale	cobwebby thistle
	Clarkia purpurea	winecup clarkia
*	Conicosia elongata	narrow-leafed ice plant
**	Conium maculatum	poison hemlock
**	Conyza bonariensis	South American horseweed
**	Conyza canadensis	common horseweed
**	Coronopus didymus	lesser wort cress
*	Cortaderia selloana	pampas grass
	Croton californicus	croton
	Cryptantha clevelandii var. hispidissima	cryptantha

	Cryptantha micromeres	cryptantha
*	Cynodon dactylon	Bermuda grass
	Daucus pusillus	wild carrot
	Deschampsia elongata	slender hairgrass
	Descurainia pinnata var. menziesii	tansy mustard
	Dryopteris arguta	wood fern
	Dudleya caespitosa	common dudleya
**	Ehrharta calycina	veldt grass
	Elymus condensatus	giant ryegrass
	Elymus glaucus	wild rye
**	Emex australis	emex
R&E	Erigeron foliosus var. blochmaniae	Blochman's leafy daisy
R&E	Erigeron sanctarum	Saint's daisy
	Eriophyllum multicaule	annual golden-yarrow
**	Erodium botrys	storkbill filaree
**	Erodium cicutarium	redstem filaree
**	Erodium moschatum	greenstem filaree
R&E	Erysimum suffrutescens var. lompocense	San Luis Obispo wallflower
	Eschscholzia californica	California poppy
	Euphorbia lathyrus	caper spurge
**	Euphorbia peplus	petty spurge
	Filago californica	filago
**	Filago gallica	filago
**	Foeniculum vulgare	fennel
	Galium andrewsii	prickly bedstraw
	Galium aparine	common bedstraw
	Galium californicum	California bedstraw
**	Gastridium ventricosum	nitgrass
**	Geranium dissectum	cutleafed geranium
	Gnaphalium beneolens	white-leafed everlasting
	Gnaphalium bicolor	bicolored everlasting
	Gnaphalium californicum	California everlasting
**	Gnaphalium luteoalbum	cudweed
**	Gnaphalium purpureum	cudweed
	Gnaphalium ramosissimum	pink everlasting
	Hesperocnide tenella	annual stinging nettle
	Heterotheca grandiflora	telegraph weed
**	Hordeum leporinum	foxtail
	Horkelia cuneata	horkelia
**	Hypochoeris glabra	smooth cat's ear
	Juncus bufonius	toad rush
	Juncus tenuis var. congestus	rush
	Koeleria nitida	junegrass
**	Lamarckia aurea	goldentop grass
	Lastarriaea coriacea	brittlestem spineflower
	Layia hieracioides	small-headed layia

**	Lepidium oblongum	peppercress
	Linaria texana	toadflax
*	Lobularia maritima	sweet alyssum
**	Lolium multiflorum	ryegrass
	Lotus humistratus	fuzzy deervetch
	Lotus strigosus	deervetch
	Lupinus nanus	sky lupine
	Madia capitata	tarweed
	Madia sativa	coast tarweed
**	Malva parviflora	mallow
	Marah fabaceus	manroot
**	Medicago polymorpha	bur-clover
	Melica imperfecta	melic grass
**	Melilotus alba	white sweet-clover
**	Melilotus indica	yellow sweet-clover
R&E	Monardella undulata var. undulata	curly-leafed monardella
	Mucronea californica	spineflower
	Navarretia hamata	hooked navaretia
	Orobanche californica	broomrape
	Orthocarpus purpurascens var. pallidus	owl's clover
**	Oxalis pilosa	native wood-sorrel
	Paeonia californica	peony
	Parietaria floridana	pellitory
	Pellaea andromedifolia	coffee fern
	Pellaea mucronata	bird's foot fern
	Phacelia distans	phacelia
**	Picris echioides	bristly oxtongue
	Piperia elegans var. elata	green rein orchis
	Pityrogramma triangularis	goldback fern
	Plantago erecta	annual plantain
**	Plantago lanceolata	English plantain
**	Poa annua	annual bluegrass
	Polycarpon depressum	polycarpon
**	Polycarpon tetraphyllum	polycarpon
**	Polygonum arenastrum	knotweed
	Pteridium aquilinum	bracken fern
	Pterostegia drymarioides	notchleaf
**	Raphanus sativus	wild radish
**	Rumex angiocarpus	sheep sorrel
**	Rumex crispus	curly dock
**	Salsola iberica	Russian thistle
	Salvia columbariae	chia
	Salvia spathacea	hummingbird sage
	Sanicula crassicaulis	sanicle
	Sanicula laciniata	sanicle
	Satureja douglasii	yerba buena

	Scrophularia californica	figwort
**	Silene gallica	windmill pink
	Silene laciniata var. angustifolia	Indian pink
**	Silybum marianum	milk thistle
	Sisyrinchium bellum	blue-eyed grass
	Solidago californica	California goldenrod
	Solidago spathulata	sticky goldenrod
**	Sonchus asper	prickly sow-thistle
**	Sonchus oleraceus	common sow-thistle
	Stachys bullata	hedge-nettle
**	Stellaria media	chickweed
	Stephanomeria virgata	wire-lettuce
	Stipa lepida	slender needlegrass
	Thalictrum fendleri	meadow-rue
	Tillaea erecta	pygmy weed
	Triodanis biflora	Venus looking glass
	Verbena robusta	vervain
**	Vulpia myuros	rattail fescue
**	Vulpia octoflora	six-weeks fescue

* — Ornamental species planted or escaped from cultivation.
** — Introduced more-or-less weedy species.
R&E — Plant considered to be rare and/or endangered