Recovery Research for the Endangered Pacific Pocket Mouse: An Overview of Collaborative Studies[1]

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Abstract

The critically endangered Pacific pocket mouse (*Perognathus longimembris pacificus*), feared extinct for over 20 years, was "rediscovered" in 1993 and is now documented at four sites in Orange and San Diego Counties, California. Only one of these sites is considered large enough to be potentially self-sustaining without active intervention. In 1998, I gathered a team of biologists to initiate several research tasks in support of recovery planning for the species. The PPM Studies Team quickly determined that species recovery would require active translocations or reintroductions to establish new populations, but that we knew too little about the biology of *P. l. pacificus* and the availability of translocation receiver sites to design such a program. Recovery research from 1998 to 2000 therefore focused on (1) a systematic search for potential translocation receiver sites; (2) laboratory and field studies on non-listed, surrogate subspecies (*P. l. longimembris* and *P. l. bangsi*) to gain biological insights and perfect study methods; (3) studies on the historic and extant genetic diversity of *P. l. pacificus*; and (4) experimental habitat manipulations to increase *P. l. pacificus* populations. Using existing geographic information system (GIS) data, we identified sites throughout the historic range that might have appropriate soils and vegetation to support translocated *P. l. pacificus*. Reconnaissance surveys of habitat value were completed in all large areas of potential habitat identified by the model. Those sites having the highest habitat potential are being studied with more detailed and quantitative field analyses. The surrogate studies helped us design individual marking and monitoring methods and will be used to test translocation methods before applying them to *P. l. pacificus*. Genetic results suggest that *P. l. pacificus* populations were naturally fairly isolated from one another prior to modern development, that genetic diversity will continue to erode in the small populations that remain, and that individuals from extant populations could probably be mixed if maximizing genetic diversity in any newly established populations is an important recovery goal. Local populations should be increased *in situ* before they can supply donor animals for translocations. Experimental habitat management (shrub thinning) at one occupied site yielded a short-term, positive, behavioral response of mice to thinned habitat plots. However, the overall population seems to be in decline, and long-term population responses to habitat manipulations are not yet evident. The approach of the PPM Study Team has been to proceed cautiously and scientifically to obtain critical information and to design a translocation program, but we are prepared to recommend swift action to prevent extinction despite "insufficient data." At this point, political and economic obstacles to species recovery seem larger than obstacles presented by scientific uncertainty.

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Introduction

Recovery planning for endangered species requires a pragmatic use of science that recognizes we cannot always expect significant sample sizes or fully informed decisions. In recovery research, the goal of sustaining and increasing populations must sometimes overrule clean experimental design; and decisions must often be made based on untested hypotheses, lest we observe extinction while we await more data. The overall guiding principal should be: proceed cautiously with good science, but be prepared to act swiftly and decisively to avoid extinction, using whatever imperfect information you have.

Recovery planning for the Pacific little pocket mouse (*Perognathus longimembris pacificus*; commonly referred to as PPM) offers a useful example of this approach. This paper briefly summarizes background information on the species, its history of decline, and initial studies in support of species recovery. I then review methods and preliminary results of some recent research tasks coordinated under the informal umbrella of the “PPM Studies Program.” Finally, I review current status of these studies and summarize future directions for the program.

Background

Perognathus longimembris pacificus is the smallest subspecies of the little pocket mouse (*Perognathus longimembris*), a nocturnal, burrow-dwelling, mostly granivorous, heteromyid rodent species restricted to arid southwestern North America (Hall 1981, Williams 1986, Williams and others 1993). It is unusual as the only subspecies or species of *Perognathus* found on the Pacific coast, rather than in arid inland deserts and grasslands. Historically, this subspecies occurred on fine, sandy soils within about 4 to 6 km of the Pacific coast of southern California, from near the Mexican border to El Segundo in Los Angeles County (Grinnell 1933, Meserve 1976, Patten and others 1998, von Bloeker 1931). Since the 1930’s, most historic habitat has been removed and fragmented by urban development and agriculture, with the last known population being extirpated by development in Newport Beach during the early 1970s (Patten and others 1998). After approximately 20 years, during which time the species was not detected, a small population (tentatively estimated at 25-36 individuals) was rediscovered on the Dana Point Headlands in 1993 (Brylski 1993).

The subspecies was emergency listed as endangered by the U.S. Fish and Wildlife Service (USFWS) in 1994 due to immediate threats to this tiny, remnant population (USFWS 1998). Subsequently, three additional population sites have been discovered on Marine Corps Base Camp Pendleton, San Diego County (Ogden 1995, 1997; MBA 1997). Despite extensive survey efforts throughout the range, these four sites (*Figure 1*) represent the full extent of the current known subspecies range (USFWS 1998, Spencer and others 2000a, 2000b).

Criteria for species recovery include permanent protection of ten independently viable populations (USFWS 1998). Currently, three of the four occupied sites (Dana Point, San Mateo North, and San Mateo South) are less than 12 ha each in size, and their populations are thought to number under 50 individuals each (Spencer and others 2000a, 2000b). Such small sizes predispose these populations to extirpation by stochastic events, catastrophes, inbreeding depression, or other factors (Noss and Csuti 1997). At present these three sites cannot confidently be called viable. The fourth and largest site (Oscar One/Edson Range) approaches 900 ha in total area (a mosaic of occupied, suitable patches and generally unoccupied, unsuitable matrix) and supports hundreds of individuals (Pavelka personal communication, Dodd and Montgomery 1998, Spencer and others 2000a). Although the Oscar One/Edson Range site is also vulnerable to extirpation, it is considered sufficiently large to be sustainable over at least the near term, barring catastrophe.

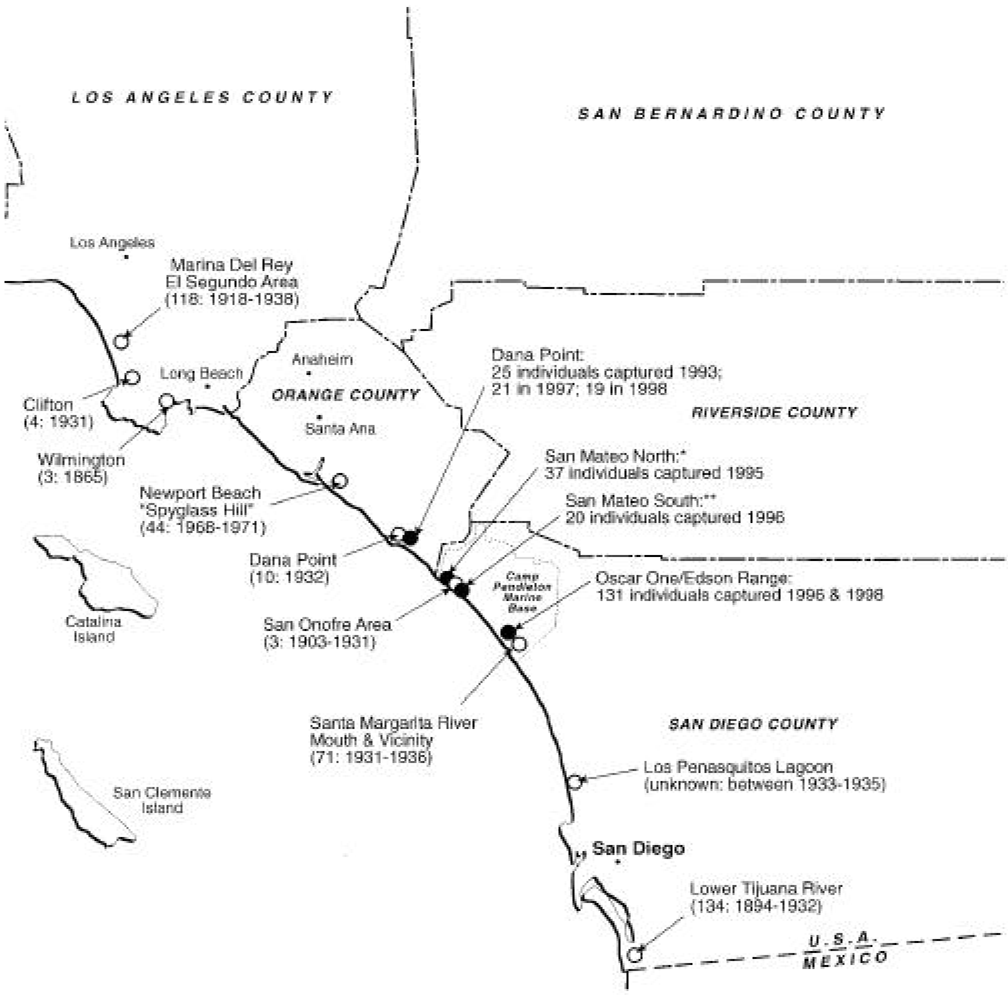

Figure 1—Historic (open circles) and extant (closed circles) locations occupied by *P. l. pacificus*. For historic locations, parentheses indicate the number of specimens in museum collections and the years of their collection. For extant populations, the numbers of individuals captured in recent years are shown. No capture-recapture estimates of population size are yet available.

Initial Studies and Founding of the PPM Studies Program

Since the listing of the species, various studies were initiated to monitor *P. l. pacificus* populations, improve field study methods, evaluate potential project impacts, and improve understanding of the species' biology. The USFWS has been studying the *P. l. pacificus* population, monitoring methods, and microhabitat selection at the Oscar One/Edson Range site since 1997; and S. Dodd and S.

Montgomery have performed yearly population monitoring at Dana Point since 1997. Dodd and Montgomery (1998) also investigated effects of trap spacing and trapping duration on monitoring effectiveness at the Oscar One site.

In 1997, the Foothill/Eastern Transportation Corridor Agencies entered into a Memorandum of Agreement (MOA) with the USFWS and California Department of Fish and Game to fund several research tasks specifically called for by the species' Recovery Plan (USFWS 1998). In response, I assembled a team of biologists (including C. Schaefer, S. Montgomery, and S. Dodd), which in July 1998 initiated four specific research tasks called for by the MOA: (1) evaluate the feasibility of translocating *P. l. pacificus* to establish new populations, (2) determine dispersal characteristics of *P. l. pacificus*, (3) evaluate effects of Argentine ants on *P. l. pacificus*, and (4) develop a *P. l. pacificus* translocation protocol. We also assembled a scientific peer review committee to review progress reports and study designs throughout the process. Participants on the committee have included Drs. James Patton, William Longland, Jay Diffendorfer, Howard Shellhammer, Nicholas Holler, Michael Wooten, and Richard Reading.

During 1998, the study team reviewed existing literature pertaining to the four initial research tasks, interviewed scientific experts, and performed very limited pilot studies. Based on this information we concluded (Spencer and others 2000a) that (1) a translocation or reintroduction program is probably necessary to achieve species recovery in the long term, but we knew too little to attempt such a program in the short term; (2) knowledge of *P. l. pacificus* dispersal characteristics would be useful, but a study specifically designed to answer dispersal questions would be prohibitively expensive, technologically impractical, and might do more harm than good to extant populations; (3) Argentine ants are unlikely to be a major limiting factor on *P. l. pacificus* due to differing habitat affinities (Argentine ants require moist ground conditions and are generally associated with irrigated landscapes in southern California [Suarez and others 1998, T. Case personal communication], whereas *P. l. pacificus* require well-drained and open vegetation communities.); and finally, (4) we felt we could not design a translocation program until critical information gaps were filled.

Table 1 summarizes information on *P. l. pacificus* available in 1998 relative to the information needed to design a translocation program, according to Nielsen (1988) and USFWS (1998). The information gaps evident in *Table 1* were used to define several research tasks deemed of highest immediate priority to further recovery: (1) a systematic review of potential translocation receiver sites based on habitat suitability and land uses, (2) a controlled laboratory study using a non-listed subspecies of P. longimembris to derive a preferred individual marking technique, (3) an intensive, multiyear study of a non-listed subspecies to test field techniques before using them on *P. l. pacificus*, to gain basic biological information on the species, and to test potential translocation methods, and (4) a population genetics study to establish baseline measures of genetic diversity within and between extant and historic P. l. pacificus populations. Once results of these studies make it possible to perform more intensive field studies on *P. l. pacificus* that would do more good than harm, we recommended (5) an intensive multiyear study of *P. l. pacificus* to obtain essential demographic and other natural history data. Finally, (6) we also recommended experimental habitat management, particularly controlled burning or shrub thinning, to improve habitat quality and *P. l. pacificus* population sizes at one or more occupied sites.

Table 1—*Translocation feasibility considerations for* P. l. pacificus *as of 1998 based on USFWS (1998) and Nielson (1988). A "yes" under "sufficient information?" indicates sufficient information exists to assess whether translocations are necessary or feasible, but does not imply that information is sufficient to design a translocation program.*

Consideration	Sufficient information?	Notes and comments
Reason for translocation	Yes	Recovery criteria probably cannot be met without a translocation/reintroduction program.
Status of wild populations	Yes	Severely in danger of extinction. Most potential habitat has been surveyed: four known occupied locations, representing three or four isolated populations. All remaining populations small.
Biology	No	Insufficient information on habitat requirements, demographics, space-use, dispersal patterns, etc. Sparse information available on related subspecies.
Size and density of wild populations	No	Rough estimates (individuals captured within a single season) available for four sites: Oscar One/Edson Range = 131[1]; San Mateo South = 20; San Mateo North = 37; Dana Point = 21 to 36. No capture/recapture population estimates.
Movements and distribution	No/Yes	Little available information on movements of *P. l. pacificus* or related subspecies. Geographic distribution fairly well established.
Male:female ratio	Yes	Dana Point: 1.1:1 to 1.4:1; San Mateo North: 0.8:1.
Annual recruitment	No	No information on *P. l. pacificus*; limited information on related subspecies.
Mortality rate and causes	No	No information on rates; some causes known or suspected from limited observations.
Health and condition of populations	No	Little information besides external observation of wild-caught specimens in hand. Most individuals appear healthy and free of external parasites.
Genetic variability and integrity	No	No information. To be determined by this study.
Status of remaining habitat	No	Although it is known that few potential habitat areas remain, systematic review needed to identify potential translocation receiver sites (this study).
Depredation rates in target areas	No	Limited information on presence or abundance of predators in potential receiver sites.
Translocation strategy	No	To be determined by this study.
Capture technique and technology	Yes	Capture methods in donor sites are relatively simple to define.
Number and location of release sites	No	Systematic review of potential receiver sites is needed to determine adequacy (this study). Recovery criteria will be used to define number and relative distribution of desirable sites.
Post-release support of translocated animals	No	To be determined by this study.

[1]Includes 111 unique captures on Oscar One (USFWS 1998) plus 20 unique individuals on Edson Range (Montgomery and Dodd 1998 unpublished data). Additional captures represent an unknown number of additional individuals because they were not marked to identify recaptures.

The remainder of this paper focuses on methods and preliminary results of those primary research tasks conducted to date, focusing on the translocation receiver site study, laboratory marking study, field marking study, population genetics study, and shrub thinning study.

Methods

Translocation Receiver Site Study

The search for sites to receive translocated populations uses a coarse-filter/fine-filter approach. We first developed a simple habitat evaluation model based on existing geographic information system (GIS) data layers to identify, at a coarse scale, large areas near the coast having appropriate combinations of soil and vegetation to possibly support translocated *P. l. pacificus*. S. J. Montgomery and S. Dodd then surveyed these areas in the field to better rank habitat conditions using a quick evaluation method developed for this purpose (coarse filter). Those sites having the highest rankings based on the field reconnaissance will be subject to more intensive, quantitative studies (fine filter). These efforts are restricted to coastal Orange and San Diego Counties, because soils maps are not available for Los Angeles County, and remaining native coastal areas there seem generally unsuitable for establishing new *P. l. pacificus* populations due to inappropriate soils, habitat degradation, abundant exotic species, and other factors (W. Spencer, personal observations; P. Behrends, S. Montgomery, and M. Pavelka, personal communications; Ogden and Dames and Moore 1999).

The GIS habitat model was used to screen out areas of Orange and San Diego Counties that are clearly unsuitable for *P. l. pacificus* reintroduction, and to identify areas deserving field evaluation. The model was therefore designed to be conservative, tending to overestimate potential habitat value for *P. l. pacificus* to minimize chances of missing a suitable site. This conservative approach recognizes that available digital information for soils and vegetation is coarse in scale relative to *P. l. pacificus* habitat selection, and may have inaccuracies.

The model ranks *P. l. pacificus* habitat potential based on three criteria: distance from the Pacific coast, soil type, and vegetation type. Nearly all historic observations of *P. l. pacificus* are within 4 km of the Pacific coast, with a few as far as 6 km, so inland limits of the study area were conservatively set at 8 km of the coast (measured from the main shoreline or the eastern shore of larger bays).

W. Spencer and M. Pavelka—in collaboration with Dr. Robert Graham, Professor of Soil Mineralogy and Pedology at U.C. Riverside—ranked all soil types mapped within this study area (USDA 1973, 1978) as having very high, high, low, or no potential to support *P. l. pacificus* based on surface horizon texture, soil depth, and other factors (e.g., presence of a hardpan, high gravel or cobble content). Care was taken to consider all physical factors likely to affect burrowing or foraging abilities of little pocket mice, as well as the potential for higher quality soils to exist as inclusions within lower-ranked soil polygons. The highest-ranking soils were classified based on results of detailed soils analyses performed by the USFWS at occupied versus unoccupied microhabitats at the Oscar One *P. l. pacificus* site (Pavelka, Winchell, and Graham, unpublished data). Those results suggest that *P. l. pacificus* are very discriminating of soil characteristics at a finer scale (measured on 20 x 20-m grids) than that of existing soils maps, and that they strongly select for deep (> 30 cm), fine-grained, loamy sands (not sandy loams) having less than about 7 percent by volume of clay and less than 4 percent by weight of gravel and rock.

Vegetation types were ranked as having high, low, or no potential to support *P. l. pacificus* using regional GIS vegetation maps (SANDAG and Ogden 1997 for San Diego County; Orange County Planning and Development Services Department 1993 for Orange County). *P. l. pacificus* have historically been associated with open coastal scrub and grassland habitats having a diversity of annual herbs, so these vegetation communities were ranked high. *P. l. pacificus* probably cannot persist in denser shrub communities, wetlands, or woodlands. However, the regional vegetation maps are coarse in scale, and some upland areas mapped as generally unsuitable natural vegetation may contain small areas of open scrub or grassland. Therefore all natural vegetation types were considered to have at least a low potential to support *P. l. pacificus*. Areas mapped as agriculture, developed, disturbed, rock, or open water were ranked as having no potential.

The soil and vegetation rankings were combined to create overall habitat rankings within 8 km of the coast (*table 2*) based on the following logic: Evidence to date suggests that soils are the primary determinant of habitat quality, at least within areas of natural vegetation near the coast. As long as the soils are highly suitable to support *P. l. pacificus*, low suitability vegetation (e.g., chaparral) may reduce *P. l. pacificus* habitat potential somewhat, but vegetation management (e.g., burning or thinning) might be used to increase habitat quality. Therefore, the presence of low quality vegetation on high quality soils only slightly reduces the overall habitat potential to support *P. l. pacificus*. However, if the soils are low quality for *P. l. pacificus*, the vegetation community type or vegetation management will probably have little effect on *P. l. pacificus* habitat potential; consequently, the overall rating reflects the soil potential (low). If either soils or vegetation are inappropriate (e.g., clay soils or agricultural fields), the site has no *P. l. pacificus* potential.

Table 2—*Habitat potential to support* P. l. pacificus *based on soils and vegetation. See text for how soils were ranked (a complete list of soil rankings is available from W. Spencer upon request). For vegetation suitability, all coastal scrub, grassland, and dune vegetation communities were ranked high; all other natural vegetation communities were ranked low; all developed, disturbed, agricultural, rock, and open water areas were ranked none.*

	Soil suitability			
Vegetation suitability	Very high	High	Low	None
High	very high	high	low	none
Low	high	moderate	low	none
None	none	none	none	none

Once maps of the overall habitat potential rankings were created, relatively large (> 20 ha) blocks of moderate to very high habitat value were outlined as field evaluation sites. S. J. Montgomery and S. Dodd then evaluated these sites in the field during 1999-2000 using a rapid evaluation data sheet to record vegetation, soil, and other site characteristics. The 5-10 sites receiving the highest scores during these coarse-level field evaluations are currently subject to more intensive, quantitative (fine-filter) study to determine their potential to support translocated *P. l. pacificus* populations.

Laboratory Marking Study

We tested four permanent, individual marking methods on a captive population of a non-listed subspecies, *P. l. longimembris*: (1) subcutaneous passive integrated transponder (PIT) tags, (2) toe clipping, (3) tiny, custom-designed ear tags, and (4) color-coded surgical sutures. *P. l. longimembris* was chosen as a logical surrogate for *P. l. pacificus* due to close phylogenetic and body size relationships and its non-sensitive status. S. Dodd captured 36 *P. l. longimembris* in Sherman live traps near Yucca Valley, San Bernardino County, California—28 during June 1999 and 8 more during May 2000. The animals were housed individually in 19 x 21 x 32-cm plastic cages supplied with natural desert soils, in a room having a skylight (for natural day/night cycles) and an air filter.

Captive animals were assigned to one of the four marking techniques or to a control group by random draw. Marking was done with the assistance and oversight of a veterinarian (Dr. Anthony Michael). Six animals were marked in one ear with custom-designed aluminum ear tags bearing 3-digit numbers etched into their surface. Six animals were marked with a 2-digit toe clip code (one digit on a front paw and one on a rear paw) using the standard mammalogical method (Baumgartner 1940, Melchior and Iwen 1965). Toes were clipped distal to the ultimate toe joint, only far enough back to remove the nail and the cells producing nail growth, using either a baby nail clipper or surgical scissors. Six animals were marked with two color-coded monofilament sutures (size 4-0 monofilament nylon surgical sutures, one black, one blue) stitched through the loose skin on the nape of the neck, tied with a triple surgeon's knot, and cut to leave 1.0 to 1.5 cm of loose thread projecting from the knot. Seven animals were tagged subcutaneously between the scapulae with PIT tags, which measure 11.5 x 2 mm. Six tags were injected using a 12-gauge hypodermic syringe, and one tag was inserted by hand via a surgical incision across the nape after shaving a patch of hair. Nine animals served as unmarked controls. They were removed from cages, weighed, and examined according to the same schedule as the marked animals.

After marking, the test and control groups were regularly weighed and examined for adverse health effects or behaviors. The examination schedule was every other day for the first two weeks, then weekly for ten more weeks, and at least monthly thereafter.

Field Marking Study

The study team initiated a field surrogate study during 1999-2000 to investigate long-term mark retention and health effects in the wild, collect basic natural history and demographic data, and to test various translocation techniques (e.g., use of enclosure fences, artificial burrow design). We established two permanent study grids near the village of Snow Creek in the Coachella Valley, Riverside County, California (San Bernardino Base and Meridian; USGS 7.5' White Water Quadrangle, Section 21 of Township 3 South, Range 3 East). Habitat on the site is relatively homogeneous creosote- (*Larrea tridentata*) dominated desert scrub on a north-sloping bajada, which is densely occupied by the non-listed subspecies, *P. l. bangsi*.

The two trapping grids (Grids A and B) were established approximately 80 m apart, with inter-trap spacing initially set at 5 m for Grid A and 7 m for Grid B based in part on the trap-spacing study for *P. l. pacificus* performed by Dodd and Montgomery (1998). Grid A consisted of 14 x 14 trap stations (196 total stations) and Grid B of 10 x 10 trap stations (100 total stations). The area trapped by each grid is thus 0.49 ha (70 x 70 m), assuming a ½-trap-space perimeter strip around each grid. Each station was set with two traps to reduce trap saturation by non-target species (especially kangaroo rats, which often enter traps early in the evening). Thus, Grid A contained 392 traps at 196 stations and Grid B contained 200 traps at 100 stations, for a total of 592 traps per night.

The grids were trapped for eight consecutive nights from 27 July to 3 August 1999 to mark residents and search for an asymptote in capture of new individuals. We also trapped the grids for two nights on 1 and 2 September 1999 to observe health and mark retention on previously marked individuals, and to see if the mice were still active above ground so late in summer (seasonal timing and influences for entering and leaving aestivation/hibernation are poorly understood in *P. longimembris*). All captured individuals were marked by a unique, 2-digit toe-clip combination. A subset of the mice were also marked by attaching a uniquely numbered ear tag to the left ear or a PIT tag inserted subcutaneously using the hypodermic needle technique. Toe clipping provided a redundant mark for animals also marked with ear or PIT tags, in case these tags were lost.

We recorded the following data for all captures: sex, weight, reproductive condition, age (young of the year or adult, by pelage appearance), location, recapture status, and notes on animal condition and condition of any previously applied marks. Reproductive condition was based on the position of the testes for males and condition of the vagina and size of mammae for females.

Trapping was continued during 2000—for five nights in April and four nights in July—with both grids trapped at the 5-m (14 x 14) trap spacing. We began marking individuals with either toe clipping or a PIT tag, but discontinued ear tagging due to high loss rates for ear tags.

Population Genetics

James Patton and Andrea Swei at UC Berkeley analyzed geographic genetic structure within and among the five subspecies of little pocket mice in southern California (*P. l. bangsi*, *brevinasus*, *internationalis*, *longimembris*, and *pacificus*) by examining haplotype variation in their mitochondrial cytochrome *b* gene (Swei and others in press). The 111 total *P. longimembris* samples they analyzed included 48 *P. l. pacificus* specimens collected in 1995-2000 (by pulling hairs or clipping toe tips from live-caught individuals) and 12 *P. l. pacificus* museum skins collected in the 1930's (from 2 x 2-mm skin snips). Full 810-base pair (bp) sequences were obtained from the live-caught specimens, and 430-bp fragments were amplified from the museum specimens. To date the following live-caught *P. l. pacificus* samples have been analyzed: Dana Point (N = 27), San Mateo South (N = 10), San Mateo North (N = 5), and Oscar One (N = 6). The historic museum specimens were collected from El Segundo (N = 1), Oceanside (N = 6), and Tijuana Estuary (N = 5). Swei and others (in press) applied a variety of analytic and statistical measures to describe phylogenetic and population genetic structure within and among the five subspecies, and to infer population genetic processes affecting *P. l. pacificus* populations historically and today (see Swei and others, in press, and citations therein for complete laboratory and analytical methods).

Shrub Thinning Experiment

A variety of theoretical and empirical evidence suggests that vegetation has become too dense at some of the occupied *P. l. pacificus* sites for optimal habitat condition, and that thinning the vegetation by fire or other means might increase habitat value and *P. l. pacificus* population sizes. Experimental habitat thinning was therefore initiated within the Dana Point *P. l. pacificus* reserve during 1999. It was not possible to obtain permission for a controlled burn at the site, so shrub cover was thinned by hand on experimental plots.

Eleven trapping grids (40 traps arranged in 4 x 10 arrays with 3-m spacing) were established and trapped during the spring and summer of 1999 (pre-thinning) and 2000 (post-thinning): three control grids and eight experimental grids. The three control grids were established in known, occupied *P. l. pacificus* habitat having relatively low shrub cover; the eight experimental grids were established in areas of dense shrub cover not known to harbor *P. l. pacificus*, but having appropriate soils. The experimental grids overlapped four roughly rectangular shrub-thinning plots of about 30 x 60 m each, such that 1/2 of each of the experimental grids was in an area to be thinned, and 1/2 in an area not to be thinned (hereafter, thinned and unthinned subgrids).

Before thinning, shrub canopies on the experimental plots covered a mean of about 83 percent (range 75-87 percent), measured at 21-60 cm above ground using point-intercept transects. During January 2000, shrub cover was thinned on the four plots to a mean of 32 percent (range 26-36 percent). Thinning was done by removing individual shrubs at ground level, using chainsaws and pruning tools to avoid soil disturbance. Concentrations of woody duff and litter were also lightly raked to uncover mineral soils.

Traplines were run for seven consecutive nights, once during spring (late April-early May) and once during summer (mid August). Captured *P. l. pacificus* were individually marked by clipping hair and using indelible colored markers (during 1999) or by toe clipping (during 2000). Use by *P. l. pacificus* of the control, thinned, and unthinned grids was compared between the pre-thinning (1999) and post-thinning (2000) periods using Chi-square. Spring and summer trapping sessions were pooled within each year, and the sample frequencies were calculated as the cumulative sum of all unique individuals captured on a grid. Thus, a recapture of an individual on the same grid was not counted as an independent observation, but a recapture on another grid was, because individuals could choose to move from one grid (e.g., a control grid) to another (e.g., a thinned grid) during the study.

Results

Translocation Receiver Site Study

Figures 2 and *3* illustrate output of the GIS habitat suitability model for the northern and southern halves of the study area, respectively. The maps also indicate general areas investigated in the field for their potential to support translocated *P. l. pacificus*. These maps surely overestimate the actual extent of high and very high quality habitat, due to the conservative model assumptions and the gross nature of the digital map information relative to the scale at which *P. l. pacificus* select habitats. Although the model correctly identified all extant *P. l. pacificus* population sites as having very high habitat quality, it missed some areas of apparently high suitability, due to inaccuracies in the soils data. Nevertheless, the maps proved useful in focusing field efforts in areas with the highest likelihood of having suitable soils and vegetation to support translocated *P. l. pacificus*. Reconnaissance surveys indicate that six or seven sites may have sufficient acreage of fine, sandy soils and appropriate vegetation to support translocated *P. l. pacificus* populations.

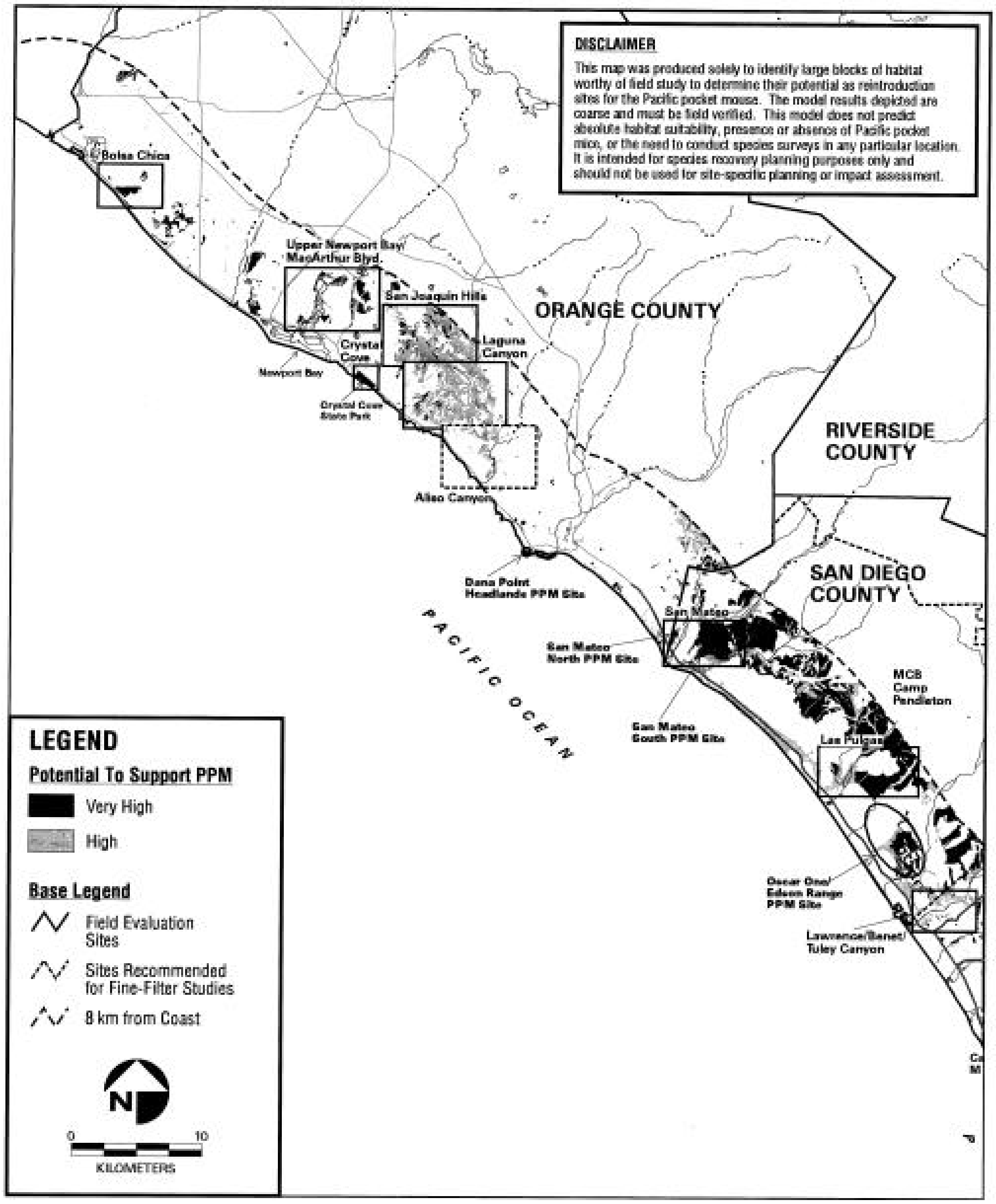

Figure 2—Areas in Orange County and Northern San Diego County having potential to support translocated *P. l. pacificus* populations, based on the GIS habitat suitability model. Boxes indicate general areas assessed in the field. Note that these maps greatly overestimate actual habitat suitability in many areas, due to conservative

model assumptions and coarse data input scales. They may also miss areas of potential due to inaccuracies in model input data.

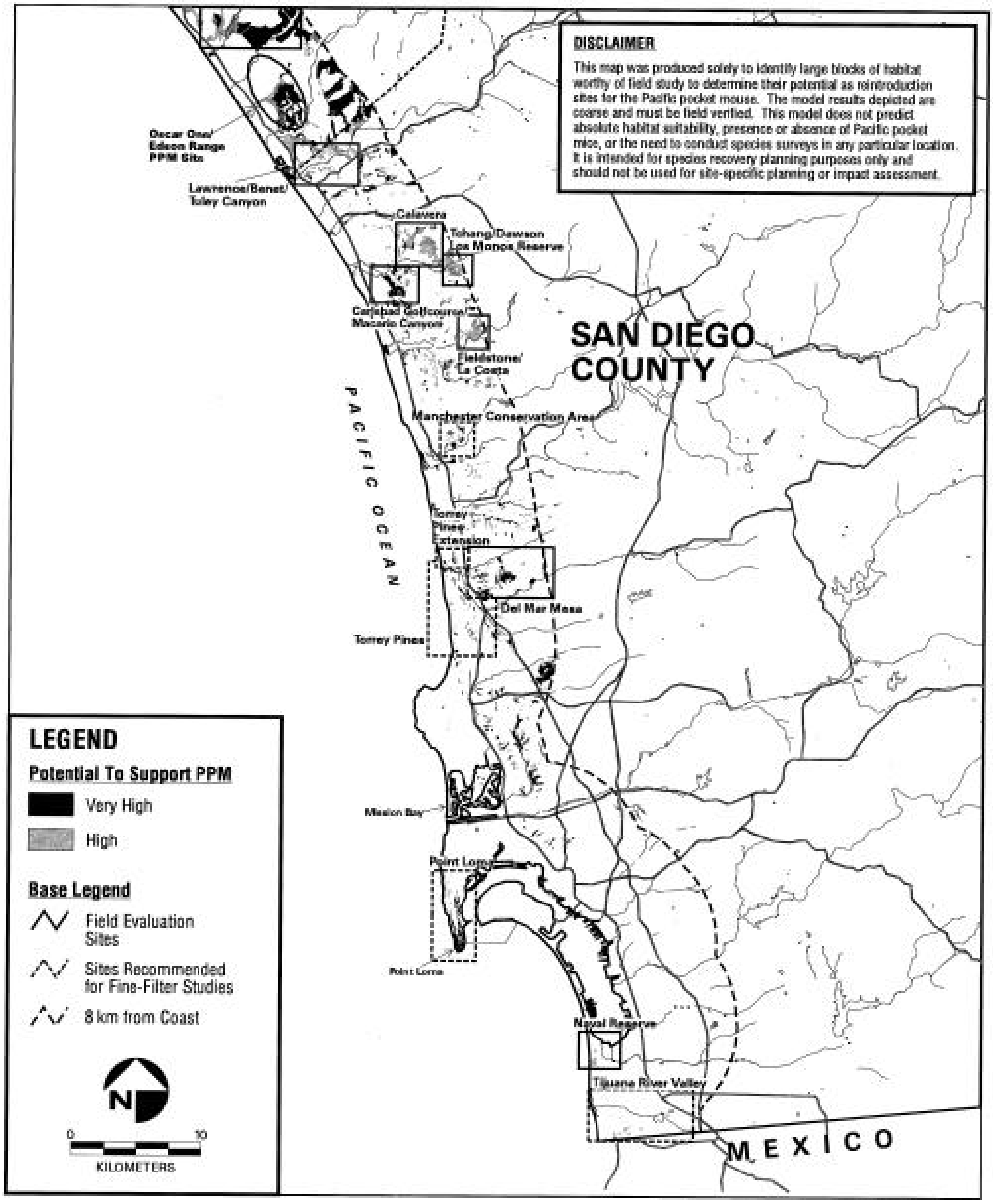

Figure 3—Areas in San Diego County south of Camp Pendleton having potential to support translocated *P. l. pacificus* populations, based on the GIS habitat suitability model. Boxes indicate general areas assessed in the field. Note that these maps greatly overestimate actual habitat suitability in many areas, due to conservative model assumptions and coarse data input scales. They may also miss areas of potential due to inaccuracies in model input data.

Laboratory Marking Study

Of the various marking techniques tested, toe clipping seemed clearly the least harmful, and possibly the most reliable for uniquely identifying animals over their life span. The suture technique and ear tags experienced high rates of tag loss (100 percent and 50 percent, respectively) and other complications, and are not recommended for further testing. PIT tags seem promising and are recommended for further testing on surrogates. However, the puncture wound for tag insertion is large for such small animals, and once inserted, PIT tags sometimes migrated under the skin or caused rumpling of the skin and hair. PIT tags would offer substantial benefits over toe clipping if they could be made smaller to reduce potential adverse health effects, but they are not recommended for use on *P. l. pacificus* in their currently available dimensions.

Field Marking Study

Table 3 summarizes captures of male and female *P. l. bangsi* on the two grids in 1999 and 2000. Sex ratios recorded on grids using 5-m trap spacing (Grid A during both years and Grid B during 2000) did not differ significantly from each other nor from 1:1 (χ^2 = 0 to 0.5; df = 1; $P > 0.25$ for all comparisons). However, during 1999, when Grid B used 7-m inter-trap spacing, few females were captured and the recorded sex ratio strongly favored males (24 males:9 females = 2.67:1). This ratio almost differed significantly from that recorded on the same grid using the 5-m spacing in 2000 (χ^2 = 3.79; df = 1; P = 0.051), and it did differ significantly from an even ratio (χ^2 = 6.82; df = 1; $P < 0.01$). These results support a hypothesis that the 7-m spacing may have under-sampled females on Grid B during 1999 (compare the low number of females captured in this treatment relative to all others in *table 3*). Although we recognize that this conclusion is weak due to a lack of grid replication, reduced female captures at greater trap spacing would be expected if females move less extensively than males, which is true in most pocket mice (review in Jones 1993).

Table 3—P. l. bangsi *captures at the Snow Creek study grids during 1999 and 2000.*

	Sex		
Trap Session	**Male**	**Female**	**Total**
Grid A			
Summer 1999	22	22	44
Spring 2000	15	20	35
Summer 2000	53	40	97 (4 not sexed)
Grid B			
Summer 1999[1]	24	9	33
Spring 2000	17	15	32
Summer 2000	37	32	71 (2 not sexed)

[1]Traps on Grid B used 7-m inter-trap spacing in summer 1999; otherwise, all traps had 5-m inter-trap spacing.

Captures on both grids more than doubled between summer 1999 and summer 2000. This reflects a large reproductive output in 2000, with 126 of 162 aged individuals (78 percent) identified as young of the year during summer 2000. In contrast, we identified all individuals captured during April 2000, and all but one individual captured during July-August 1999, as over-wintered adults. The reproductive season seemed near a peak during April 2000, with most individuals showing signs of sexual activity, including descended testes in males or perforate vagina in females. By July-August of both years, very few individuals showed signs of sexual activity and we were able to distinguish three age classes: adult, subadult, and juvenile.

Pooling both years, a total of 248 individuals were toe clipped, 34 were PIT tagged, and 50 were ear tagged. All ear tags were applied in 1999, because a very high rate of tag loss caused us to discontinue this method in 2000. By the end of the first 1999 trap session, at least a third of the ear-tagged individuals exhibited various levels of ear inflammation and redness, ripping around the tag insertion hole, or drooping ears. One individual had lost its ear tag when it was recaptured 7 days after marking. At least seven more ear tags were lost by the second trapping session (4-5 weeks after tagging).

Toe clipping was the fastest and easiest marking technique under field conditions, and seemed to have little or no adverse effects on animal health. Clipped toes exhibited no or very little bleeding (one or a few drops), which ceased within minutes; and recaptured animals rarely showed inflammation or redness of the wound. Nevertheless, toe clipping is not without problems, as evidenced by about 25 problem incidences (out of 248 toe clipped individuals) due to natural causes or human error: (1) ten cases of naturally missing, deformed, or injured toes, which would make toe clipping potentially confusing; (2) six or seven cases where field workers apparently read the wrong code on a previously toe-clipped animal; (3) three or four cases where the toe tip grew back, apparently due to not clipping far enough back; (4) and four cases where two individuals were mistakenly given the same toe clip code. In addition, the number of unique toe-clip codes is finite (depending upon the number of digits clipped), which poses problems for population monitoring in a fairly long-lived species (up to at least 6 years with about 30 percent over-winter survival; Bailey 1939, Chew and Butterworth 1964, Behrends personal communication).

The hypodermic insertion PIT-tagging procedure worked well in the field with practice. Most mice seemed to experience minor inflammation, scabbing, and sensitivity to touch at the insertion wound. Tags appeared to migrate under the skin, which exhibited bulging on some individuals. Unfortunately, recapture rates were too low (no over-winter recaptures of PIT-tagged individuals) to ascertain health effects of PIT tagging in the field.

Population Genetics

Swei and others (in press) found that all *P. l. pacificus* haplotypes analyzed to date are unique to that subspecies, and all are closely linked genealogically. *P. l. pacificus* has apparently been diverging from its geographically closest relatives (*P. l. brevinasus*, *bangsi*, *internationalis*, and *longimembris*) for some time, although none of these subspecies is reciprocally monophyletic (i.e., no subspecies has a common ancestor not shared with any other subspecies).

Pooling all extant populations of *P. l. pacificus*, the subspecies exhibits similar levels of nucleotide and haplotype diversity as other southern California subspecies of *P. longimembris*, although the sample from Dana Point has markedly low haplotype diversity in comparison to all other subspecies or populations. Of the total genetic variation among samples of *P. l. pacificus*, about 39.1 percent is variance among individuals within populations, 54.4 percent is between populations within a time period, and 6.5 percent (which is not significantly different from zero) is between modern and historic samples. Thus, the pattern of haplotype differentiation suggests that historical populations (in the 1930s) were already largely isolated from one another, and that current patterns of genetic diversity are due largely to natural isolation of these populations prior to the modern urbanization of coastal California. Indeed, the genetic signatures measured by Swei and others (in press) suggest that, although populations of *P. l. pacificus* were somewhat isolated in recent evolutionary time, they do not yet reflect a loss of genetic diversity due to habitat losses in modern times. Swei and others (in press) concluded that 40 to 70 years of habitat reduction at locations like Dana Point are insufficient to override the population's deeper genetic history, but that we can confidently predict future losses of genetic diversity unless current population declines are reversed.

Measures of gene flow between populations of *P. l. pacificus* are quite low, both in historical and current times. This stands in sharp contrast to higher levels of gene flow measured across greater geographic distances in the Mojave Desert for *P. l. longimembris*. Measures of gene flow between the Dana Point population and all other *P. longimembris* populations are especially and uniformly low. The Dana Point population also has the lowest haplotype diversity of any sample of *P. longimembris* (only 9 unique haplotypes recovered from 27 individuals). Together, these results suggest that the Dana Point population has been relatively small, as well as isolated, for some time. Slightly higher gene flow measures and haplotype diversity were recorded among the three sites on Camp Pendleton (San Mateo North and South and Oscar One).

Swei and others (in press) concluded that, given current levels of fragmentation and low population sizes, genetic diversity will continue to erode within *P. l. pacificus* populations. This suggests that mixing of individuals from different sites may be necessary to meet the recovery goal (USFWS 1998) of maintaining the full remaining genetic variability of the subspecies. Although the haplotypes of extant *P. l. pacificus* populations are largely apportioned among populations, they are all genealogically closely related, and genetic variability seems to be governed by neutral (rather than selective) genetic processes. It is possible that there are selective differences among these populations, which are more likely to be expressed in nuclear than mitochondrial genes, but this seems unlikely given the small geographic range of the subspecies and similarities in ecological conditions at occupied sites. Thus it appears that mixing individuals from different *P. l. pacificus* populations during translocations should not have any deleterious genetic effects (e.g., "outbreeding depression").

Shrub Thinning Experiment

P. l. pacificus seemed to respond quickly and positively to the shrub thinning by redistributing themselves into the newly thinned habitat areas. During 1999 (pre-thinning), 11 individual *P. l. pacificus* were captured, yielding 12 independent grid observations (i.e., one individual was captured on two different grids)—nine observations (nine individuals) were on the known occupied control grids, two were on subgrids to be thinned (including one individual that also used a control grid), and one on a subgrid not to be thinned. In contrast, during the year 2000 (post-thinning), ten individual mice were captured for a total of 18 unique observations—four on control grids, 11 on thinned subgrids, and three on unthinned subgrids. This shift in the distribution of captures is statistically significant ($P = 0.026$), largely due to the great increase in captures on the thinned subgrids. During the year 2000, six of 10 individuals were captured only on thinned subgrids (five were captured on only one subgrid, but one male was captured using three different thinned subgrids). Three of the four individuals captured on control grids were also captured on thinned subgrids. No individuals were captured only on unthinned subgrids—all three individuals captured on unthinned subgrids were also captured using the adjacent thinned subgrid. In fact, all captures on unthinned subgrids were less than 6 m (two trap distances) from the thinned area that these individuals also used. Moreover, all capture locations on unthinned subgrids were connected to the thinned plots via natural inter-shrub openings.

Thus, the pattern of captures before and after the thinning suggests a strong shift in distribution to the newly thinned habitat areas or their edges. This reinforces observations that *P. l. pacificus*, like other species of *Perognathus*, are most abundant in fairly open habitats, although they may prefer to forage in microhabitats in or near shrubs (Brown and Lieberman 1973, Harris 1984, Meserve 1976, Price 1978, Reichman and Price 1993). Although *P. l. pacificus* may forage under shrubs near openings, they do not seem to frequent interior portions of closed-canopy shrub cover, especially when other options are available.

Unfortunately, intensive trapping of the Dana Point site during May-June 2001 captured only four *P. l. pacificus* (2 female, 2 male; USFWS unpublished data). This sample is too small to reveal any patterns relative to the shrub-thinning experiment. Moreover, these results reinforce a general pattern of population decline at Dana Point since the population's discovery in 1993. Whether or not shrub thinning may positively influence population size at this or any other site is therefore not yet determined.

Discussion

The informal collaborative process followed by the PPM Studies Team—with frequent re-evaluation of priorities, methods, and results—has thus far proved effective in addressing the most urgent questions bearing on species recovery. We benefited greatly from an active peer input and review process, which helped to keep the program focused and scientifically valid, while allowing for flexible, pragmatic responses to new information. We have proceeded with a realization that statistical certainty, while desirable, isn't always possible or necessary when prudent actions must be taken to recover rare species.

During 1998, the study team concluded that *P. l. pacificus* translocations were necessary to achieve species recovery, but that existing information was insufficient to design a translocation program. We therefore refocused our research to answer those questions considered most critical to designing a *P. l. pacificus* translocation program. We now feel we have gained sufficient information to begin designing the program as one essential recovery tool. Please note that our goal is translocations to establish new *P. l. pacificus* populations, and thereby to help recover the species from the brink of extinction. No one should interpret our intent as translocation to mitigate proposed take of *P. l. pacificus* or their habitat by development projects.

In the future, we hope to comprehensively update our evaluation of translocation feasibility, design a framework translocation program based on the updated information, and design experiments to test translocation methods (e.g., use of release enclosures and artificial burrows) prior to implementing the program. At this point in the process, I am confidant that continued research and common sense could sufficiently answer the most pressing biological questions bearing on species recovery. Less certain, however, are methods of overcoming political and economic obstacles. For example, subsequent to the drafting of this document, the U.S. Marine Corps denied requests from the PPM Studies Team to continue *P. l. pacificus* studies on Camp Pendleton, due apparently to concerns that the results might constrain military training and readiness. This has postponed indefinitely our ability to answer remaining questions and further species recovery. Such non-scientific obstacles must now take center stage if we are truly to recover populations of this charismatic little mouse.

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References Cited

Bailey, V. 1939. **The solitary lives of two little pocket mice.** Journal of Mammalogy 20:325-328.

Baumgartner, L.L. 1940. **Trapping, handling and marking fox squirrels.** Journal of Wildlife Management 4:444-450.

Brown, J.H.; Lieberman, G. 1973. **Resource utilization and coexistence of seed-eating desert rodents in sand dune habitats.** Ecology 54:788-797.

Brylski, P.V. 1993. **A focused survey for the Pacific pocket mouse (*Perognathus longimembris pacificus*) on the Dana Point Headlands, Orange County, California.** Unpublished report prepared for EDAW, Inc.

Chew, R.M.; Butterworth, B.B. 1964. **Ecology of rodents in Indian Cove (Mojave Desert), Joshua Tree National Monument, California.** Journal of Mammalogy 45:203-225.

Dodd, S.C.; Montgomery, S.J. 1998. **Draft report: results of an investigation of trap spacing and duration of trapping period for monitoring studies of the Pacific pocket mouse (*Perognathus longimembris pacificus*).** Unpublished report prepared for California Department of Fish and Game. 27 March.

Grinnell, J. 1933. **Review of the recent mammal fauna of California.** University of California Publications in Zoology 40:71-234.

Hall, E.R. 1981. **The mammals of North America.** 2nd Ed. John Wiley and Sons, New York.

Harris, J. 1984. **Experimental analysis of desert rodent foraging ecology.** Ecology 65:1578-1584.

MBA (Michael Brandman Associates). 1997. **Results of focused surveys for the Pacific pocket mouse, Foothill Transportation Corridor – South.** Unpublished report prepared for Foothill/Eastern Transportation Corridor Agency.

Melchior, H.R.; Iwen, F.A. 1965. **Trapping, restraining, and marking arctic ground squirrels for behavioral observations.** Journal of Wildlife Management 29:671-678.

Meserve, P.L. 1976. **Habitat and resource utilization by rodents of a California coastal sage scrub community.** Journal of Animal Ecology 45:647-666.

Nielsen, L. 1988. **Definitions, considerations, and guidelines for translocation of wild animals.** In: Nielsen, L.; Brown, R.D., eds. Translocation of wild animals. Wisconsin Humane Society, Milwaukee, Wisconsin, and Caesar Kleberg Wildlife Research Institute, Kingsville, Texas; 12-51.

Noss, R.F.; Csuti, B. 1997. **Habitat fragmentation.** In: Meffe, G.K.; Carroll, R.C., eds. Principles of conservation biology. 2nd edition. Sunderland, MA: Sinauer Associates; 269-304.

Ogden Environmental and Energy Services (Ogden). 1995. **Biological resources survey report for FY MCON P-577 water distribution plan, MCB Camp Pendleton.** Unpublished report prepared for KEA Environmental. September.

Ogden. 1997. **Pacific pocket mouse survey, Phase III, Marine Corps Base, Camp Pendleton.** Unpublished report prepared for Assistant Chief of Staff, Environmental Security, Marine Corps Base, Camp Pendleton. November; 46 p.

Ogden and Dames and Moore. 1999. **Rancho Palos Verdes NCCP Subarea Plan, Phase I Summary Report.** Unpublished report prepared for City of Rancho Palos Verdes. January 1999.

Orange County Planning and Development Services Department. 1993. **Vegetation database for Orange County.**

Patten, M.A.; Myers, S.J.; McGaugh, C.; Easton, J.R.; Erickson, R.A. 1998. ***Perognathus longimembris***. In: Hafner D.J.; Yensen E.; Kirkland, G.L, Jr., compilers and eds. North American rodents: Status survey and conservation action plan. IUCN/SSC Rodent Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK; 83-85.

Price, M.W. 1978. **The role of microhabitat in structuring desert rodent communities. Ecology** 59:910-921.

Reichman, O.J.; Price, M.V. 1993. **Ecological aspects of heteromyid foraging.** In: Genoways, H.H; Brown, J.H., eds. Biology of the heteromyidae. American Society of Mammalogists, Special Publication No. 10; 539-574.

San Diego Association of Governments (SANDAG) and Ogden. 1997. **Vegetation database for western San Diego County**. Revised 1997.

Spencer, W.D.; Schaefer, C.; Dodd, S.; Montgomery, S.J. 2000a. **Pacific pocket mouse studies program Phase I report: Task 1, translocation feasibility, and Task 3, dispersal characteristics.** Unpublished report prepared for Foothill/Eastern Transportation Corridor Agencies and U.S. Fish and Wildlife Service. January 2000.

Spencer, W.D.; Schaefer, C.; Dodd, S.; Montgomery, S.J.; Holland, H. 2000b. **Pacific pocket mouse studies program Phase II report. Task 5, translocation receiver site study, Task 6, laboratory surrogate study, and Task 7, field surrogate study.** Unpublished report prepared for Foothill/Eastern Transportation Corridor Agencies and U.S. Fish and Wildlife Service. May 2000.

Suarez, A.V.; Bolger, D.T.; Case, T.J. 1998. **Effects of fragmentation and invasion on native ant communities in coastal Southern California.** Ecology 79:2041-2056.

Swei, A.; Brylski, P.V.; Spencer, W.D.; Dodd, S.C.; Patton, J.L. In Press. **Hierarchical genetic structure in fragmented populations of the little pocket mouse (*Perognathus longimembris*).** Conservation Genetics.

U.S. Department of Agriculture. 1973. **Soil Survey of San Diego County, California.**

U.S. Department of Agriculture. 1978. **Soil survey of Orange County and western part of Riverside County, California.**

U.S. Fish and Wildlife Service. 1998. **Pacific pocket mouse (*Perognathus longimembris pacificus*) recovery plan.** Portland OR. 112 p.

von Bloeker, J.C., Jr. 1931. ***Perognathus pacificus* from the type locality.** Journal of Mammalogy 12:369-372.

Williams, D.F. 1986. **Mammalian species of special concern in California.** California Dept. Fish and Game Report 86-1; 112 p.

Williams, D.F.; Genoways, H.H.; and Braun, J.K. 1993. **Taxonomy**. In: Genoways, H.H.; Brown, J.H., eds. Biology of the heteromyidae. American Society of Mammalogists, Special Publication No. 10; 38-196.