



## **SPECIES STATUS ASSESSMENT FOR THE PACIFIC POCKET MOUSE**

*(Perognathus longimembris pacificus)*



Credit: Joanna Gilkeson/USFWS

**U.S. Fish and Wildlife Service  
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## **VERSION UPDATES**

### **Version 1.0**

This version of the Species Status Assessment (SSA) Report was initiated in 2024 and completed in 2026. The SSA Report underwent peer and technical review. Development of this report was funded through the Marine Corps Base Camp Pendleton to help understand and project future impacts to the Pacific pocket mouse from ongoing threats.

## EXECUTIVE SUMMARY

The Pacific pocket mouse (*Perognathus longimembris pacificus*, hereafter PPM) is one of the smallest of 15 or 16 subspecies of the little pocket mouse (*P. longimembris*), associated with fine grain, sandy substrates in coastal strand, coastal dunes, river alluvium, and coastal sage scrub habitats within approximately 4 km (2.5 mi) of the ocean in southern California. The subspecies' habitat requirements include moderate to high forb cover and moderate to high open ground. Factors negatively associated with PPM occupancy include dense thatch, high shrub cover, and nonnative grasses. The PPM diet primarily consists of seeds from a wide variety of forbs, perennial herbs, shrubs and native bunch grasses. PPM dig and use burrows and cache seeds within their burrow systems to provide sustenance throughout the year. PPM reach maturity early and can breed in their natal year under favorable conditions or delay or forego breeding altogether during years of poor food availability. As a result, population sizes naturally fluctuate greatly both within and among years.

Historically documented along the coast from central Los Angeles County south to the U.S.-Mexico border in San Diego County, the subspecies is now only found in three isolated populations: Dana Point, a 12 ha (29.4 ac) property in Orange County, owned and managed by the Center for Natural Lands Management, and two populations on Marine Corps Base Camp Pendleton, managed by the U.S. Department of Defense, referred to as South San Mateo and Santa Margarita. The subspecies was recently extirpated from a third site also on Camp Pendleton, North San Mateo, where mice were last documented in 2003. Studies of genetic variation using various methods have found effective population sizes within all extant populations are low and cause for concern, and there is evidence that inbreeding depression is causing decreased fitness in the Dana Point and South San Mateo populations. To help recover the subspecies, animals from the extant populations have been brought into captivity and are being bred by the San Diego Zoo Wildlife Alliance to provide a source of animals for creating additional populations to expand the current distribution and improve species redundancy. Starting in 2016, animals from the breeding facility have been released at one site in Orange County to create an additional wild population, although this population is not yet self-sustaining. A second population creation effort was also just initiated in 2024 at Camp Pendleton, so it is also premature to judge its success.

Habitat is the main limiting factor for the subspecies. Urbanization and land conversion have led to habitat loss and have fragmented the historical range of PPM, isolating the extant populations from one another. The limited amount of suitable habitat surrounding each population has led to small populations that are susceptible to inbreeding and loss of genetic variation. Loss of fitness from inbreeding or inability to adapt to changing environmental conditions can accelerate population loss by making it harder for populations to rebound following declines. Small populations can also be extirpated by random demographic factors like unbalanced age and sex ratios, and random naturally occurring events such as floods, droughts or disease.

Ecological processes such as natural fire regimes and predator-prey relationships are also often altered due to surrounding urbanization, which leads to fire suppression, facilitated invasion of nonnative plant species, and introduction and subsidized abundance of predatory house cats, potential competitors (e.g. rats and house mice), and other nonnative animal species. The Dana Point population is intersected by a popular public access trail where high recreation

use could be causing altered spatio-temporal habitat use by mice, decreased survival and reproduction, and/or extirpation of animals from otherwise suitable habitat. The invasive, nonnative Argentine ant (*Linepithema humile*), is also present at each of the extant PPM populations where it may be contributing to habitat degradation and mortality of PPM. Other factors contributing to habitat degradation from surrounding urbanization include light and noise pollution.

Threats to the viability of the PPM populations include habitat loss, and degradation from urban edge effects, military training, and other human activities. Disturbance from human activities (recreation, research, military training) can cause direct harm to mice in their burrows from soil disturbance and compaction, and can facilitate the invasion of nonnative vegetation, predators and competitors. Where implemented, such as surrounding the Dana Point and South San Mateo populations, fire suppression may be contributing to degradation of habitat for PPM by removing a source of disturbance that likely is necessary for periodically opening the canopy of coastal sage scrub vegetation and triggering the germination of native annual forbs used as a food source. Where fire frequencies are high, such as within the Santa Margarita population on Camp Pendleton, nonnative grasses are prevalent and able to quickly invade and take over areas following disturbance, making habitat unsuitable for PPM. Thus, invasion of nonnative vegetation, particularly including nonnative annual grasses at Santa Margarita, is a major threat to PPM due to the ability of these species to quickly overtake, alter the vegetation community structure, and become entrenched in areas following disturbance. Climate change is a potential threat to PPM, as it will likely cause increased variability in precipitation among years, resulting in particularly wet and dry years that have been associated with low survivorship and low reproduction/population recruitment. At Dana Point, sea level rise could contribute to habitat loss by causing bluff erosion. Habitat management activities and the conservation breeding program have potential to positively influence future viability.

To determine the current condition of the PPM, we used population size, measured as average area of occupied habitat, and genetic diversity, measured as effective population size, to assess the resiliency of the three populations (Table A). This assessment also takes into consideration the amount of surrounding available habitat for each population, its current threats and stressors, and the amount of habitat management that is being performed. Though not yet successfully established, we take into consideration the current status of population creation efforts. All PPM populations are small and isolated, putting them at risk of extirpation from stochastic events. Analysis of the above metrics shows a gradient among the populations, with Dana Point ranking as the least resilient, and Santa Margarita ranking as the most resilient of the populations. Based on area of habitat occupied and effective population size, the Dana Point and South San Mateo populations currently have Very Low resiliency (Table A), with a high risk of extirpation over the near term from stochastic events due to limited availability of habitat, isolation, and risk of developing inbreeding depression. The Santa Margarita is scored as having moderate resiliency based on its occupancy of more than twice the area of habitat than the other two populations combined, and having an effective population size that suggests it is not currently at risk from inbreeding depression. However, due to the co-occurrence of military training activities within this population it is assessed as having a moderate to high risk of extirpation. Overall the subspecies currently has low redundancy and representation, suggesting one or more catastrophic impacts (e.g., due to a series of wet winters, a particularly strong storm event, or disease) could lead to the loss of one or more populations.

**Table A.** Average area occupied in hectares (ha) and the effective population size ( $N_e$ ) requirements for each resiliency level.

| <b>Resiliency</b> | <b>Avg. Area Occupied (ha)</b> |     | <b>Eff. Pop. Size (<math>N_e</math>)</b> |
|-------------------|--------------------------------|-----|------------------------------------------|
| Very Low          | -                              | -   | <50                                      |
| Low               | <100                           | or  | <100                                     |
| Moderate          | 100 to 200                     | and | ≥100                                     |
| High              | >200                           | and | ≥500                                     |

For High and Moderate resiliency, metrics for both area occupied, and effective population size must be met. However, only one metric must be met for Low resiliency, where a population is Low if either the area of habitat occupied (ha) or effective population size ( $N_e$ ) are below 100. Populations with effective population size ( $N_e$ ) below 50 are ranked as having Very Low resiliency, regardless of how much habitat is occupied.

While the PPM currently exists as three extant populations, the future condition of this subspecies depends on both the future of the extant populations and the success of efforts to establish additional populations on the landscape. The future condition of each PPM population depends on its current resiliency, how habitat conditions change in the future, both in terms of controllable (management) and uncontrollable (weather events, etc.) elements, and whether genetic diversity can be maintained or increased through genetic rescue. To forecast the future resiliency of the populations, we consider the same metrics assessed for the current condition (average area of occupied habitat and effective population size), and project how these metrics are likely to vary across two time intervals (10-20 years, and 30-50 years in the future) in response to a range of plausible management scenarios.

Because the variables that contribute to future resiliency (occupied habitat and genetic diversity) will be determined by the amount of habitat and genetic management that is implemented, we define the management scenarios based on a range of projected capacity and resources for management. Types of management considered in these scenarios include habitat management (prescribed fire, mechanical or chemical vegetation treatments, seeding/planting), threat management (access limitations, training limitations, etc.), and genetic management (translocations, genetic rescue, conservation breeding, etc.). The four scenarios include: No Change in Management, Moderate Management Increase, Large Management Increase, and Management Decrease.

Given the opportunities and constraints on each population in terms of the ability to expand habitat use and increase genetic diversity, we assess the resiliency of each of the populations under each of the four scenarios based on projections of the average habitat area occupied and effective population sizes (Figure A).

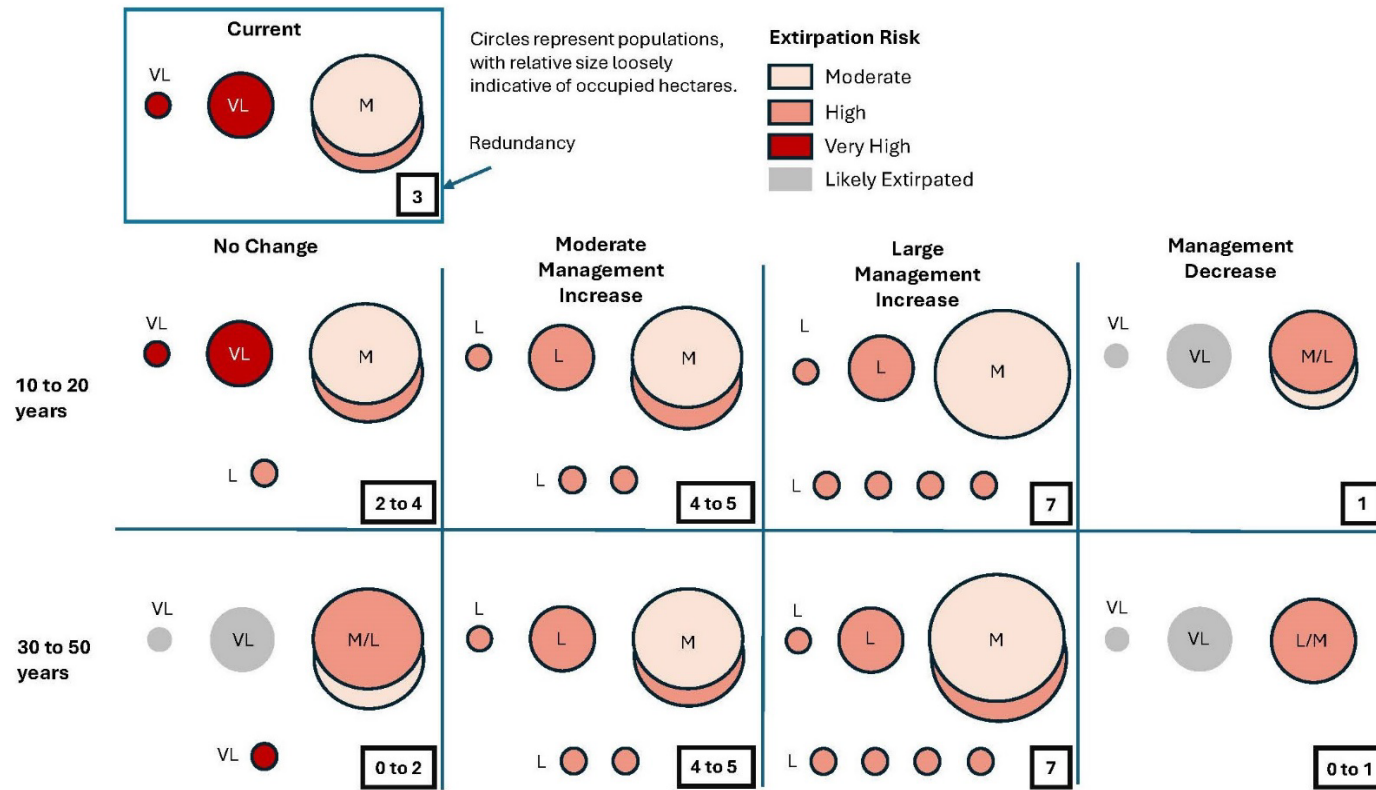


**Figure A.** Depiction of the future condition of the Pacific pocket mouse at two timesteps (10 to 20 years and 30 to 50 years in the future) under four potential management scenarios, indicating number of populations, relative population size, resiliency, redundancy, and extirpation risk. Populations are depicted within each scenario from left to right: Dana Point, South San Mateo, and Santa Margarita. Newly established populations are depicted along the bottom of each scenario. Resiliency is indicated by letter (VL = Very Low, L = Low, M = Moderate). Extirpation risk is based on resiliency and the added impacts of potential genetic degradation, threats and stressors, and climate change over time.

Overall, given the constraints on each population in terms of the ability to increase habitat, reduce threats and stressors, increase genetic diversity, and increase population size, our results indicate that current resiliency can only be increased for the three extant populations under scenarios where genetic diversity is increased through genetic rescue (Figure A). Added habitat alone, given the amount we propose is practicable, is not sufficient to appreciably increase the resiliency of any of the extant populations under any scenario.

Under a No Change or Management Decrease scenario, resiliency of each population is projected to decrease slightly but remain constant under the resiliency category for current conditions with two populations remaining at Very Low resiliency and the third at Moderate resiliency. While the resiliency scores do not change, we do however project that the risk of extirpation will slightly increase in the future and two populations could be extirpated by the second timestep under both scenarios; Dana Point and South San Mateo could be possibly extirpated by the first timestep under a Management Decrease scenario. The additional introduced population in the No Change scenario would start with a high likelihood of extirpation and increase to very high by the second timestep.

If genetic rescue is conducted for all three populations, as under the Moderate and Large Management Increase scenarios, we project that resiliency could be increased to Low for the Dana Point and South San Mateo populations and would remain Low for these populations in the future. Any new populations would also retain a Low resiliency. Because it is uncertain whether genetic management can increase the effective population size of the Santa Margarita above 500, we project with this population will maintain Moderate resiliency over both time steps under both the Moderate and Large Management Increase scenarios. Without the ability to reduce the threats to this population from military training activities it is also likely to continue to face a moderate to high risk of extirpation.

While redundancy could potentially be raised with the creation of additional PPM populations, this requires both the successful establishment of new populations and the preservation of the currently extant populations. Under the moderate and large management increased scenarios, a total of 5 to 7 populations could be achieved. Given a No Change scenario, redundancy could reach 4 populations in 10 to 20 years, but with potential extirpations of the very low resiliency populations, redundancy could be substantially reduced in 30 to 50 years (Figure 22). Under both a No Change and Management Decrease scenario, redundancy is projected to decrease with just one or two populations supporting the subspecies over the next 50 years.

Representation is currently low for this subspecies but could be improved with the creation of additional populations (Moderate and Large Management Increase scenarios) as well as with genetic rescue, both of which would increase the prevalence of rare alleles, increase heterozygosity within and among populations, and prevent or decrease the rate of genetic erosion. Even under optimal conditions, though, the subspecies overall is likely to have limited adaptive capacity to respond to changing conditions due to the fragmented nature of its habitat, need for long term genetic management, and the resulting inability of the populations to shift distribution in space.

In conclusion, the future of the PPM depends on management of each of the populations such that habitat is always available and accessible, and the populations are genetically diverse and large enough to withstand years when weather patterns or other factors cause population declines. Conservation of the extant populations, creation of new ones, and genetic management are needed to provide enough redundancy and representation to maintain subspecies viability.

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## SECTION 1 – INTRODUCTION AND ANALYTICAL FRAMEWORK

### 1.1 Species Overview

The Pacific pocket mouse (*Perognathus longimembris pacificus*; hereafter PPM) was considered extinct for 20 years until a small population was rediscovered in 1993 at the Dana Point Headlands in Orange County, and three additional populations were discovered in 1995 on Marine Corps Base Camp Pendleton (MCBCP), San Diego County, California (MBA and LSA 1995, pp. 8–9; Ogden 1995, p. 2; Spencer 2005, p. 7; USFWS 2010, p. 14). The PPM was federally listed as endangered under the Endangered Species Act (ESA) on September 29, 1994 (FR 59:49752-49764) following an emergency listing on February 3, 1994 (FR 59:5306-5310). The PPM is one of the smallest of the 15 to 16 subspecies of the little pocket mouse (*Perognathus longimembris*; hereafter PELO) (Patton 2005, pp. 844–858; Williams et al. 1993 pp. 177–184; Hafner 2016, pp. 202–209). The body pelage of the PPM is silky and predominately brown, pinkish buff or ochraceous buff above and light brown, pale tawny, buff, or whitish below (Hall 1981, p. 537; USFWS 2010, p. 5).

This Species Status Assessment (SSA) Report provides a review of the available information pertaining to the subspecies' biology and current condition, assesses the resources needed to maintain viability, and evaluates the potential for long-term viability under four future scenarios. The intent is for the SSA to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from consultations to recovery.

### 1.2 SSA Framework

The U.S. Fish and Wildlife Service (USFWS) uses the SSA framework (USFWS 2016, entire) to provide an integrated analytical approach to assess a species' or subspecies' current biological condition and its projected capability of sustaining populations in the wild into the future (Smith et al. 2018, entire). The purpose of the SSA Report is to provide a risk assessment of a species or subspecies and assist in informing decisions and activities under the ESA. Building on the best of our current analytical processes and the latest scientific information in conservation biology, this framework integrates analyses that are common to all functions under the Act, eliminates duplicative and costly processes, and allows the Service to strategically focus on our core mission of preventing extinction and achieving recovery.

Using the SSA framework (Figure 1), we consider what a species or subspecies needs to maintain its viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (3 Rs) (Shaffer and Stein 2000, pp. 308–311). For this assessment, we define viability as the ability of the PPM to sustain healthy populations in natural ecosystems within a biologically meaningful timeframe, in this case, 10 to 20 years into the future. We chose 10 to 20 years because the available data allow us to reasonably predict the potential effects of management activities on the current stressors within the range of the PPM through this timeframe. We further provide an analysis 30 to 50 years into the future to represent a period of time that captures a range of variation in environmental conditions which the species will need to withstand in order to sustain populations into the future. The 3 Rs are defined as follows:

- **Resiliency** describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health, such as birth versus death rates and population size. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.
- **Representation** describes the ability of a subspecies to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a subspecies is capable of adapting to environmental changes. The more representation, or diversity, a subspecies has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range of the subspecies.
- **Redundancy** describes the ability of a subspecies to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the subspecies has a margin of safety to withstand or can rebound from catastrophic events (such as a rare destructive natural event or episode involving many populations).

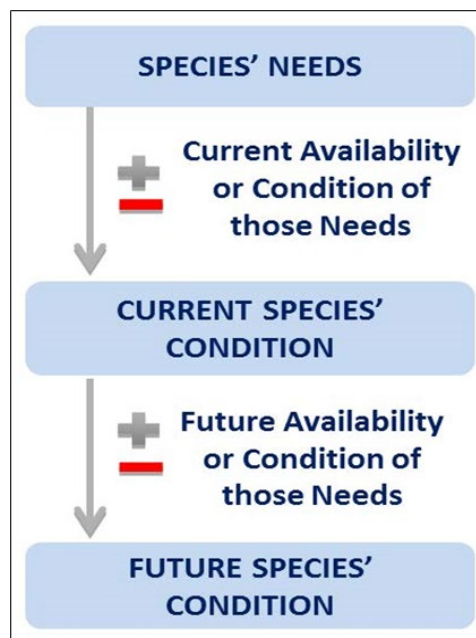


**Figure 1.** Species Status Assessment Framework.

Thus, resiliency is defined at the population level, whereas Representation and Redundancy are defined at the species' (or subspecies') level.

## SECTION 2 – SUBSPECIES BIOLOGY

In this section, we provide biological information about the PPM, including its taxonomic history, morphological description, historical and current distribution and range, known life history, and current population estimate.

### 2.1 Taxonomy

The PPM is one of the smallest of 15 or 16 subspecies of the PELO (Patton 2005, pp. 844–858; Williams et al. 1993, pp. 177–184; Hafner 2016, pp. 202–209). It was first described as a species by Edgar Alexander Mearns in 1898 from animals collected at the U.S./Mexico border (i.e., the type locality) (Mearns 1898, p. 299). Subsequently, Von Bloeker Jr. (1932, pp. 127–129) described *Perognathus longimembris cantwelli* from specimens collected at Hyperion and elsewhere along the coast in Los Angeles County, and reduced *P. pacificus* to a subspecies of *P. longimembris*. In 1939, Huey (1939, pp. 52–54) synonymized *P. l. pacificus* with *P. l. cantwelli*, assigning the name of the earlier described subspecies. PPM was considered extinct for 20 years until a small population was rediscovered in 1993 at the Dana Point Headlands in Orange County, and three additional populations were discovered in 1995 on MCBCP, San Diego County, California (MBA and LSA 1995, pp. 8–9; Ogden 1995, p. 2; Spencer 2005, p. 7; USFWS 2010, p. 14). Based on an analysis of morphological characters, Patton and Fisher (2023, entire) recently concluded that animals from the type locality at the U.S./Mexico border are morphologically distinct from the extant populations and have suggested the extant populations all belong to the previously described *P. l. cantwelli*. Because all existing populations are still considered a single subspecies, this proposed name change does not impact the results of this assessment. As the USFWS has not yet formally recognized the proposed name change in the Federal Register, for the purpose of this Species Status Assessment, this subspecies will continue to be referred to here as the PPM (*Perognathus longimembris pacificus*). When subspecies-specific (PPM) information is unavailable, we report information for the little pocket mouse (PELO) in the sections below.

### 2.2 Subspecies Description

The body pelage of the PPM is silky and predominately brown, pinkish buff or ochraceous buff above and light brown, pale tawny, buff, or whitish below (Hall 1981, p. 537; USFWS 2010, p. 5). There are generally two small but conspicuous patches of lighter hairs at the base of the ear (Ingles 1965, p. 219). The tail can be either distinctly or indistinctly bicolored (Hall 1981, p. 537). Body length from nose to tip of tail for PELO ranges from 110–155 mm (Hall 1981, p. 537; Ingles 1965, p. 219) with the ratio of length of tail to head and body usually ranging between 1.03 to 1.40 (Williams et al. 1993, p. 177). Body dimensions of the PPM subspecies appear to fall at the lower end of this range, with PPM considered to be one of the smallest members of the species, with body length ranging between 111 to 130 mm, and a mean body length of 118.6 mm (Huey 1939, pp. 49–54; Miller et al. 2017, pp. 86–87). Weight is reported to vary between 7–10 grams (Burt and Grossenheider 1976, p. 136; Jameson and Peeters 1988, p. 286), though adult PPM have occasionally been captured weighing as little as 5 to 6 grams. Like all members of the family Heteromyidae, PPM have external, fur-lined cheek pouches.

## 2.3 Range and Distribution

Historically, PPM were documented along the coast from central Los Angeles County through Orange and San Diego Counties extending to the Tijuana River valley at the U.S.-Mexico border. PPM are generally located within approximately 4 kilometers (km) (2.5 miles (mi)) of the ocean in southern California (Figure 2) (USFWS 2010, pp. 12–14). The subspecies is associated with coastal sage scrub habitats, much of which has been lost to urbanization and land conversion, fragmenting the historical range of PPM (Gilpin 1987, p. 136). Populations are assumed to have once been very connected, where dispersal and immigration could sustain the populations through their natural population fluctuations (see Section 2.5).

Rediscovery of a single population in 1993 at the Dana Point Headlands helped prompt additional surveys, and the PPM was found at three additional sites (North San Mateo, South San Mateo, Santa Margarita) within MCBCP (Figure 3). PPM were last observed at North San Mateo in 2003 (Brehme and Fisher 2009, pp. 3, 17; Montgomery 2005, p. 25; Natural Resources Assessment 2003, p. S–1; USFWS 2010, pp. 22, 65–66), and multiple comprehensive surveys performed at that site since then have not detected PPM (Brehme et al. 2015, pp. 14, 17; Brehme et al. 2019, p. 4), suggesting this population has become extirpated. Thus, PPM remains extant at only three, isolated locations: Dana Point Headlands, owned and managed by the Center for Natural Lands Management (CNLM), and South San Mateo and Santa Margarita, located on MCBCP. All other historical locations are thought to be extirpated (Figure 3; USFWS 2011, pp. 11–26). Recent surveys in Baja California have not detected populations of PPM south of the border (Tremor 2025, pers. comm.).

To help recover the subspecies, animals from the extant populations have been brought into captivity and are being bred by the San Diego Zoo Wildlife Alliance (SDZWA) to provide a source of animals to expand the current distribution of the subspecies through the creation of additional populations in the wild, thus providing more subspecies redundancy. Starting in 2016, animals from the conservation breeding facility have been released at one site in Orange County to create another wild population, although this population is not currently considered self-sustaining. A population creation effort was also just initiated in April 2024 near Wire Mountain housing on MCBCP. Details of the reintroduction efforts are provided in Section 4.5.

The area within each extant population that is assumed to be potential habitat is defined by CNLM for Dana Point and by U.S. Geological Survey (USGS) in Brehme et al. (2023a, pp. 3–7) for populations on MCBCP. These management units are 12 ha for Dana Point, 105 ha for South San Mateo, and 885 ha for Santa Margarita. However, the area estimated to be occupied by PPM within these management units varies and can sometimes be much smaller than the area within the delineated management unit boundaries. Areas of dense shrub cover, compacted soils and nonnative annual grasses within these management units generally require habitat management to make conditions suitable for PPM.



**Figure 2.** Estimated historical range of the Pacific pocket mouse with the locations of the three extant populations. However, per the recent findings of Patton and Fisher (2023, entire) the range of the Pacific pocket mouse may not have extended to the border.

## 2.4 Habitat

PPM have been associated with fine grain, sandy substrates in coastal strand, coastal dunes, river alluvium, and coastal sage scrub habitats within approximately 4 km (2.5 mi) of the ocean (USFWS 2010, pp. 14–37). Modeling by Brehme et al. (2019, p. 27; 2023b, p. 7) found that increased nonnative grass cover was a strong predictor of decreased colonization and increased extirpation probability. Moderate to high forb cover (between 40 and 80 percent) and moderate to high open ground (between 20 to 70 percent) were top predictors of PPM occupancy across all sites, while moderate to high (>30 percent) nonnative grass cover was negatively associated with likelihood of PPM occupancy (Figure 4; Brehme et al. 2023b, p. 7). PPM is typically not found in areas covered by dense nonnative grasses and thatch or dense closed-canopy shrub cover. In a desert environment, PELO is associated with shrub cover, possibly related to diet or as protection from predators while foraging (Kenagy 1973, p. 1204; Kotler 1984, pp. 696–700). Thus, PPM appear to benefit from some level of shrub cover (USFWS 2010, pp. 35–37) while also requiring open ground, where they forage for the diverse seeds in their diet and use open ground for sandbathing to maintain their pelage, removing oils, ectoparasites and imbuing the soil with their scent to communicate with conspecifics (Brehme et al. 2023b, p. 7; Shier 2008, pp. 33–39).

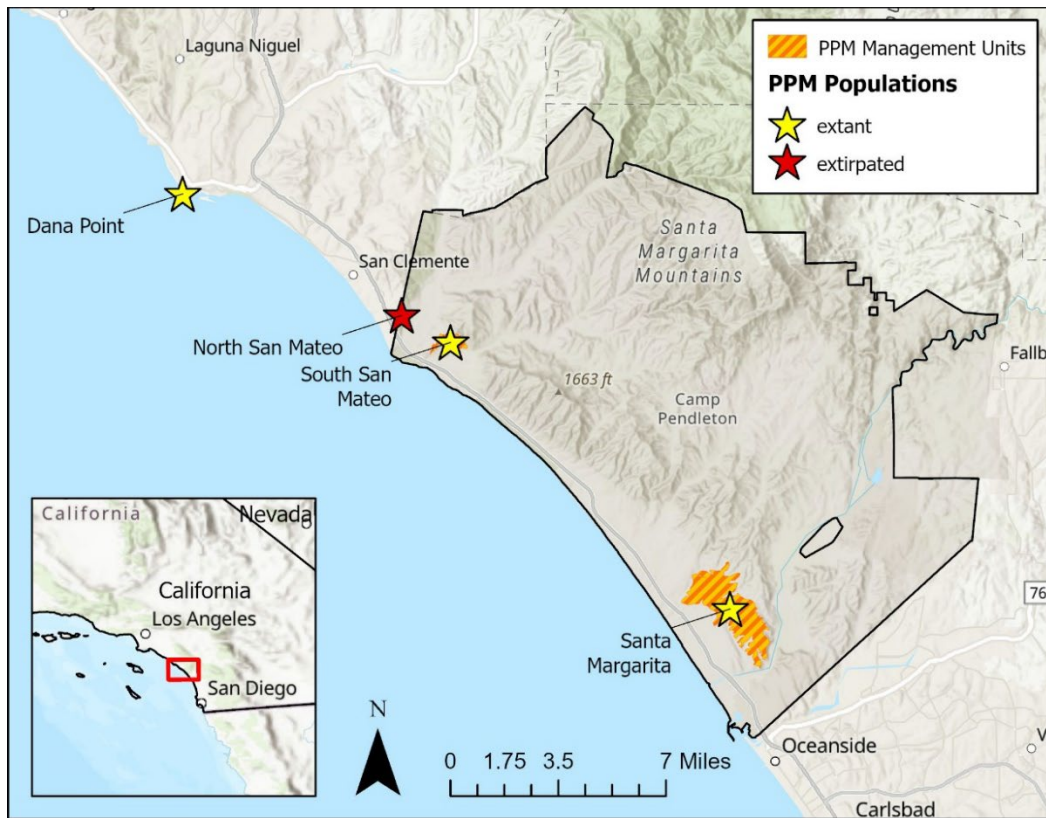


**Figure 3.** Current range of the Pacific pocket mouse (PPM). Management units are the area defined by the Center for Natural Lands Management and U.S. Geological Society as potential habitat for PPM (see Current Condition, below).

The Dana Point Headlands site is a remnant coastal bluff top habitat fragment that overlooks Dana Point Harbor and the Pacific Ocean and is otherwise surrounded by urban development. The PPM habitat at Dana Point is dominated by coastal sage scrub vegetation growing within loamy sand soils. The North San Mateo site (now presumed extirpated) is located on a south-facing slope in the northwest corner of MCBP. When PPM were captured at the North San Mateo site, the habitat was predominately mature coastal sage scrub growing within loamy coarse sands and sandy loams (MBA and LSA 1997, p. 17). The South San Mateo site is located within a military training area that is adjoined by two military housing developments and three covered water reservoirs, and is intersected by access roads, fire breaks and electrical lines within approximately 3.2 km (2 mi) of the Pacific Ocean. Habitat at this site is characterized by coastal sage scrub growing in fine sandy loam and loamy coarse sand soils (Ogden 1997, pp. 21–25).

The Santa Margarita site is the southernmost and largest habitat area that supports PPM, and overlaps two military training areas on MCBP, Oscar One and Edson Range. This site supports military training infrastructure, firing ranges, dirt and paved roads and has the greatest range of habitat conditions. Within the management unit boundaries the vegetation ranges from areas predominated by coastal sage scrub to sage scrub- grassland ecotone, mixed native and nonnative grassland and forblands, and areas of dense nonnative grasslands (USFWS 2010, pp. 26–27).

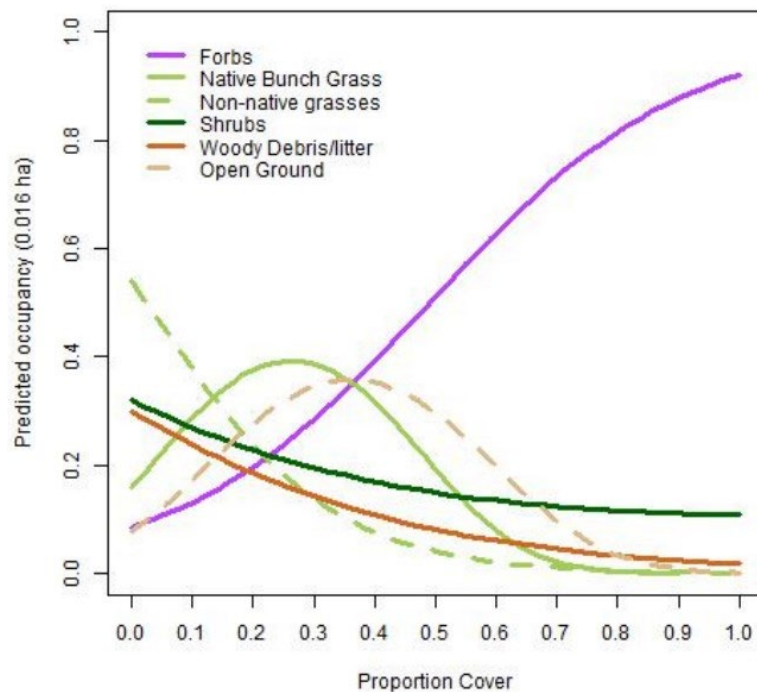


**Figure 4.** Relationships between Cover-Proportions and probability of Pacific pocket mouse presence. (Figure from USGS 2022, p. 4)

## Home Range and Spatial Distribution

PPM exhibit variability in movement distances, with individuals often appearing to remain relatively sedentary within their home ranges but occasionally dispersing longer distances of 150 m (490 ft) or more; presumably in response to high population abundance or to search for mates (USFWS 2010, pp. 12–14). Males consistently are observed to have larger home ranges than females (approximately 0.005 to 0.015 ha larger; Shier 2009, pp. 34–38). In addition to sex, home range size also varied by site and annual precipitation levels, likely a product of food availability; home range size did not vary by age (Shier 2009, pp. 34–38; USFWS 2010 pp. 11–12). During trapping studies, mean observed range length (ORL), the farthest distance between capture locations, is significantly different between male and female PPM (USFWS 2020b, p. 4). Across a 4-year monitoring period, mean ORL of PPM that were captured on more than 1 bout (10-night trapping period) was 29.3 and 17.9 m (96.1 and 58.7 ft) for males and females, respectively. Some PPM were also observed to occasionally go on longer distance excursions and relocate their primary area of activity to different areas within the monitoring grids (USFWS 2020b, p. 4).

## 2.5 Life History

### Reproduction

PELO become sexually mature at approximately 41 days of age and can breed in their natal year during favorable conditions (Hayden et al. 1966, p. 416; Miller and Pavelka 2008, pp. 28–29; USFWS (2020, p. 4). Female PPM may begin estrus as early as 35 days of age, and males may become scrotal or partially scrotal at 42 days of age (Shier et al. 2016, p. 14; Shier et al., in review). Estrus lasts 1 to 180 minutes in captivity and can happen at any time of the day or night. Most unsuccessful copulation attempts in captivity end with female to male aggression (King et al. 2023, p. 21). PPM gestation typically lasts 23.3 days, and young are weaned after 30 days (Shier et al. 2016, pp. 18, 31). Breeding typically begins in early spring and lasts through late September (Shier et al. 2024, p. 5; USFWS 1998, p. 11). In the wild, USFWS (2008a, pp. 28–29) documented pregnant PPM in April and as late as mid-September, with many of the later pregnancies occurring in young of the year. This pattern is supported by observed seasonality of estrous cycling in females and reproductive readiness in males (Shier 2007, entire). The conservation breeding program has documented breeding PPM February through late September (Shier et al. 2024, p. 5). Captive PPM produce 1 to 7 pups per litter with an average litter size of 3.41 (plus/minus 0.27 standard error). Survival of pups has ranged from 65 to 100 percent under care but is notably variable under laboratory conditions (King et al. 2023, p. 22). In the wild, PELO produce four to six offspring per litter under suitable conditions (Cramer and Chapman 1990, p. 364; Hayden et al. 1966, p. 417; Kenagy and Bartholomew 1985, p. 386). PPM are on the lower end of this range and have up to two litters in high resource years, with their female offspring reproducing concurrently with adults in the same season (Miller and Pavelka 2008, pp. 28–29). Conversely, in years of poor food availability (e.g., drought), PPM may delay breeding or forego breeding altogether, resulting in little to no recruitment and population decline (Beatley 1969, p. 721; Brehme et al. 2022, p. 13; French et al. 1967, p. 538; Kenagy and Bartholomew 1985, p. 390; USFWS 2008, pp. 28–29).

### Diet

PPM is a strong seed specialist, although its diet may occasionally include insects and green vegetation (Reichman and Price 1993, p. 540; Meserve 1976a, p. 312; USFWS 2010, p. 5). PPM forage on both native and nonnative vegetation species, with seasonal and site differences in PPM diet. PPM appear to prefer a wide variety of forbs, perennial herbs, and native bunch grasses over perennial shrubs and nonnative grasses (Iwanowicz et al. 2016, pp. 15–16; Vandergast et al. 2023, p. 1). Seeds found within the cheek pouches of PPM have come from the following plants: *Heterotheca grandiflora* (telegraph weed), *Hordeum murinum* (barley), *Pluchea sericea* (arrow weed), *Crysothamnus* sp. (rabbitbrush), *Croton californicus* (croton), *Centaurea melitensis* (tocalote) (Von Bloeker 1931, p. 371), *Lotus prostratus*, *Monanthochloe* sp. (shoregrass), *Franseria* sp. (ragweed, bur-sage), a rush, two species of salt bush, heliotrope, and mustard (Bailey 1939, p. 327). An intensive field study of the dietary preferences of PPM based on fecal analysis found the diet of PPM included arthropods and seeds or green vegetation from *Eriogonum fasciculatum* (California buckwheat), *Acmispon glaber* (California broom), *Rhus integrifolia* (lemonadeberry), *Salvia* sp. (sage), *Erodium* sp. (storksbill), *Cryptantha clevelandii* and grasses (Meserve 1976a, p. 312) and a more recent intensive field study of the

dietary preferences of PPM based on metabarcoding of scat found primary diet species included the genera *Erodium*, *Croton*, *Calystegia*, *Deinandra*, *Corethrogyne*, *Chorizanthe*, *Acmispon*, *Phacelia*, *Dichelostemma* (forbs, perennial herbs) and *Stipa* (grass) (Vandergast et al. 2023, p. 1). While Meserve (1976a, p. 310) found that PPM “shows strong specialization on grass and forb seeds with relatively less utilization of other foods,” PPM were also found to consume a higher proportion of forb seeds in the spring, and a higher proportion of grass seeds later in the year, which may relate to seasonal food availability (Meserve 1976b, p. 661). Vandergast et al. (2023, p. 1) found that grass seed made up a small percentage of PPM diet across two populations and two years on MCBP, with forbs being the predominant food source across all seasons. A study of dietary preferences in captive PPM found that pre-weening exposure can influence an individual’s foraging behavior (Harvey 2018, entire).

## Behavior

Like other pocket mice, PPM are solitary and nocturnal. Like other Heteromyidae, they are semifossorial and have periods of inactivity, including seasonal dormancy, when they remain in their burrows feeding on seed caches and going in and out of torpor (Brehme et al. 2019, p. 37).

### Burrowing

PPM dig and live in burrows underneath the soil surface and cache seeds either within small depots outside the burrow or within their home burrows to provide sustenance throughout the year (Randall 1993, pp. 267–268; Merrill et al. 2023, pp.42–46; Chock et al. 2019, p. 1068). Burrows have been documented to extend approximately one foot underground, although burrows and tunnels may sometimes be closer to the surface (1 to 4 in) (Bailey 1939, p. 326; Merrill et al. 2023, p. 44; SDNHM 2021, p. 51) and burrow depths of 1 to 75 cm having been documented for other PELO subspecies in the deserts (Kenagy 1973, pp. 1210–1211). Soil and substrate types and proximity to moisture vary amongst current and historical PPM populations and may also affect burrow depth and complexity. Burrow depths for PPM have not been studied in great detail in the wild and remain a key variable to establish. Based on direct observation and comparison with other subspecies, PPM burrows are vulnerable to compaction. Within the Santa Margarita population soil compaction has been found to be negatively correlated with PPM presence (SDNHM 2021, pp. 51, 55).

### Foraging and Torpor

Adaptations that likely are associated with the longevity of PELO (see “Longevity,” below) are its semifossorial habit and residence in burrows during periods of inactivity, its seed-caching behavior, and its physiological capacity to enter torpor (USFWS 2010, p. 6). PELO appear to prefer euthermy to torpor, likely to reduce chances of freezing in hibernation and the ability to escape predators, and under natural conditions probably only goes into torpor when the highest temperatures available to mice are below thermal neutrality (i.e., when environmental temperature is less than body temperature; French 1976, entire). Brehme et al. (2019, p. 37) found that PPM seasonal dormancy varies spatially and temporally, with different individuals within the same population entering and/or emerging from dormancy at different times within years. Additionally, they found that surface activity varies among years, with some individuals emerging as early as February and/or remaining active until December. Miller and Pavelka

(2008, pp. 63–64) found that prolonged surface activity can be indicative of prolonged reproduction and population growth, although Brehme et al. (2019, p. 41) found this to not always be the case. PPM at one location ceased reproductive activity by mid-June but remained active until mid-December (Brehme et al. 2019, p. 41). To understand whether PPM foraging and seed caching behavior helps to promote its co-existence with other small mammals, Chock et al. (2019, entire) found that PPM and Los Angeles pocket mice (*Perognathus longimembris brevinasus*) pilfered from larger heterospecifics more often than heterospecifics pilfered from them, but did not find strong evidence that either subspecies took advantage or experienced benefits from the seed caches of heterospecifics.

### Communication

Little is known about communication in the PPM. The San Joaquin pocket mouse (*Perognathus inornatus*) uses visual, tactile, acoustic, and chemical channels (Best 1993, entire). Auditory signals include both vocalizations (growls, squawls, and low grunts) as well as tooth-chattering and foot-drumming (Best 1993, entire). Heteromyids use sandbathing to clean their fur, and as a form of chemical communication (Eisenberg 1963, p. 21; USFWS 2020b, p. 3). Shier et al. (2016, pp. 22–23) found that female PPM in estrus spent more time investigating male-scented sand than female-scented sand, and there were no differences in responses (i.e., time spent investigating male-scented sand, and frequency and duration of sandbathing) of wild-caught versus captive-born female.

### Social Structure

PPM are solitary animals. King et al. (2018, p. 12) observed PPM, particularly female PPM, display aggression towards male conspecifics during breeding events in the conservation breeding program. Chock et al. (2018, p. 198) observed that body size differences of other native rodent species within the San Diego coastal sage scrub habitat strongly predicted dominance; three of the four rodent species, those with larger body sizes, were dominant over PPM, while one rodent (western harvest mouse; *Reithrodontomys megalotis*) with a similar body size did not differ from PPM in dominance index. PPM actively avoided all other species except the western harvest mouse. Such behavioral avoidance is consistent with the monitoring program finding that PPM detection probabilities are lower when other rodent species are present (Brehme et al. 2019, p. 26).

### Survivorship

PELO is long-lived, considering its size (Brown and Harney 1993, p. 622; Edmonds and Fertig 1972, p. 301; French et al. 1967, p. 537), living in captivity more than 7 years (Bailey 1939, p. 328; Egoscue et al. 1970, p. 623; Edmonds and Fertig 1972, p. 301) and sometimes living 3–5 years in the wild, although life expectancy in the wild is approximately just one year (French et al. 1967, p. 537). PPM have lived to nearly 10 years in captivity (GSRC and SDZWA 2023, entire). PPM surviving for more than 5 years in the wild likely represent the maximum end of the longevity curve, with mean individual survivorship likely lower (USFWS 2010, p. 7). A demographic study of PPM from 2003 through 2006, estimated distinct monthly survivorship rates during summer and winter months, that generally corresponded with periods of above ground activity and below ground inactivity, respectively (USFWS 2008, p. 74). Mean monthly summer survivorship on two population monitoring grids was estimated at  $81 \pm 5\%$  (Mean  $\pm$

Standard Error) and  $75 \pm 5 \%$ , and monthly winter survivorship was estimated at  $92 \pm 3 \%$  and  $91 \pm 2 \%$ , respectively. On one of the two grids, there was lower overwinter survivorship during the winter of 2004 to 2005 ( $66 \pm 4 \%$ ), which was likely associated with near record rainfall during that winter and spring, causing lower survivorship at that location. If each survivorship rate applies for 6 months of the year, then for the grid with better overall survivorship, this would result in a mean annual survivorship rate of around 17 percent. This is consistent with the observation of just a few individuals with ages of two or more years during prolonged monitoring studies (USFWS 2008, pp. 71–77).

## Genetics

Demographic modeling from genetic data suggests the extant populations were historically much larger and each likely supported tens of thousands of individuals (Wilder et al. 2025, pp. 835–836). This modeling further suggests these populations were historically connected by immigration/emigration, with gene flow between the Santa Margarita and South San Mateo populations being lost relatively recently, while Dana Point has been isolated from these populations for a much longer time (Wilder et al. 2025, pp. 835–836).

Of concern is the isolation and contraction in size of the extant populations that can lead to losses of genetic variation and inbreeding depression. Long-term effective population size ( $N_e$ ), which can be estimated under coalescent models of mutation-drift equilibrium, is the primary determinant of a population's level of standing genetic variation and reflects the magnitude of genetic drift (i.e., loss of variation) over thousands of generations. By contrast, contemporary effective population size reflects recent impacts of genetic drift and the amount of genetic diversity that is currently being or has recently been lost. References to effective population size throughout this document refer to contemporary effective population size.

Soule (1980, pp. 151–169) and Franklin (1980, pp. 135–149) proposed an effective population of  $N_e \geq 50$  is necessary to prevent inbreeding depression over the short term, and Franklin (1980, pp. 135–149) proposed an  $N_e \geq 500$  should be maintained over the long term to prevent the loss of genetic variation upon which natural selection can operate (i.e., evolutionary potential). Frankham et al. (2014, entire) critiqued the 50/500 rule as inadequate, and suggested a revised threshold of  $N_e \geq 100$  is more appropriate to limit inbreeding depression to  $\leq 10$  percent over five generations, and  $N_e \geq 1,000$  is a better approximation for conserving evolutionary or adaptive potential over the long term. Using either set of criteria, contemporary effective population size within all extant populations of PPM are low and cause for concern. Based on estimates using linkage disequilibrium statistical methods, contemporary effective population sizes are extremely small in Dana Point ( $N_e=12.3$ ) and South San Mateo ( $N_e=21.3$ ) and modest in the Santa Margarita population ( $N_e=254.8$ ; Fig. 1B; fig. S2–S3)(Wilder et al. 2025, p. 835).

Consistent with the prediction of continued loss of genetic variation from genetic drift, the remnant populations show signs of genetic erosion. Wilder et al. (2020, pp. 594–598) found significantly decreased mitochondrial haplotype diversity within the extant populations compared to what was reported by Swei et al. (2003, pp. 505–506). Mice analyzed from South San Mateo and Dana Point also had lower genome-wide heterozygosity and higher inbreeding coefficients than mice from the larger Santa Margarita population (Wilder et al, 2025, p. 835). In South San Mateo, heterozygosity declined 18 percent from 2012–2020, and though sample sizes were inadequate for statistically testing temporal declines at Dana Point, samples collected from

this population in 2012-2013 had 44 percent lower heterozygosity than an individual sampled from Dana Point in 1999 (Wilder et al., 2025, p. 835). Based on recent effective population size estimates, theory predicts a 2.3 percent per generation loss of heterozygosity at South San Mateo, and a 4.1 percent per generation loss at Dana Point (Wilder et al., 2025, p. 835).

To assess the potential functional impacts of genetic drift and inbreeding depression among the populations, Wilder et al. (2025, p. 835) estimated the level of genetic load within the populations from homozygous derived alleles that cause nonsynonymous changes at evolutionary conserved sites in protein-coding genes. Levels of genetic load were greater in the small populations, and the number of high-frequency deleterious alleles in the populations increased over time (Wilder et al., 2025, p. 835). Overall, these results indicate there has been a loss of genetic diversity and an increase in homozygous genetic load within the two smaller populations over the past several decades (Wilder et al. 2025, p. 835).

Based on low contemporary effective population size estimates and data that suggests the South San Mateo and Dana Point populations are already suffering from inbreeding depression (Wilder et al. 2025, p. 835), a genetic management strategy is being developed that recommends performing genetic rescue at South San Mateo and Dana Point (Shier et al. 2022, entire). However, genomic and karyotypic analysis indicate there are fixed chromosomal differences among the PPM populations, with the Santa Margarita and South San Mateo populations having a diploid ( $2n$ ) chromosome number of 56 and Dana Point having  $2n=58$  (Wilder et al. 2025, pp. 836–837). Genomic analysis indicates this has resulted from a split or fission of chromosome 2 (Shier et al. 2022, p. 26; Wilder et al. 2025, pp 836–837). Therefore, genetic rescue of the smallest and most inbred population, Dana Point, would require performing crosses with animals from Camp Pendleton that have a different number of chromosomes, which could cause outbreeding depression if the karyotypes are genetically incompatible (Wilder et al. 2025, p. 836). Improper meiotic segregation of chromosomes can result in aneuploid gametes, reduced fertility of fission-fusion heterozygotes, and even speciation, but the impact can also be small or undetectable, especially for simple centric fusions (Wilder et al. 2025, pp. 836–837).

In captivity bred Pacific pocket mice, chromosomal heterozygotes produced from crosses of Dana Point and Camp Pendleton mice are morphologically identical to chromosomal homozygotes and have produced viable offspring over four or more generations and multiple meiosis's (Wilder et al. 2025, p. 837). Thus, although fitness in the wild could differ, in the ex-situ environment, there does not seem to be strong selection against chromosomal heterozygotes (Wilder et al. 2025, p. 837). To assess the relative costs of inbreeding and outbreeding depression, Wilder et al. (2025, pp. 837–838) measured survival and reproduction over 8 years within admixed and non-admixed mice ( $n=253$ ) in the conservation breeding facility. Modeling the effects of heterozygosity, inbreeding coefficients, homozygous genetic load and karyotype predicts that a heterozygous karyotype would have fewer offspring than a homozygous fission karyotype with the same genetic background, but this is offset by the higher genome-wide heterozygosity of a typical outbred mouse, which can mask deleterious recessive alleles, and is predicted to result in the production of more offspring than a homozygous karyotype with genetic variation typical at Dana Point. Thus, results from the captive breeding program suggest that the benefit to the Dana Point population from genetic rescue should outweigh the risk from admixing different karyotypes (Wilder et al. 2025, entire).

Nevertheless, a genetic rescue strategy that is being explored is to cross and backcross Dana Point and Camp Pendleton mice in captivity to obtain outbred mice with the same number of chromosomes as mice in the Dana Point population, then using the admixed mice with the  $2n=58$  karyotype for genetic rescue at Dana Point. During 2023, four animals from Dana Point were brought into captivity for that purpose but only one of those individuals successfully bred during 2024 (Shier 2024, pers. comm.). This suggests it could take a number of years before enough outbred mice with the same karyotype as the Dana Point population are produced (Wilder et al. 2025, p. 838).

## **2.6 Population Demographics and trends**

Information on population demographics and trends is gleaned from monitoring efforts at Dana Point and at MCBCP. Population monitoring in these two locations estimate the Proportion of Area Occupied (PAO) annually within the management units delineated as having the potential to support each population. The PAO is estimated from probabilistic sampling of sample plots within the management units using track tube surveys and live trapping surveys (Brehme et al. 2023a, pp. 3–7). Using the PAO, we estimate the total number of hectares of the management unit that is occupied each year. The total area occupied at Dana Point was estimated to be 6 ha (15 ac) in 2023. This is an 18 percent decrease from the peak estimate of 7 ha (18 ac) in 2021, but a 92 percent increase from the most recent population decline in 2019 (Figure 5; Table 1). The total area occupied within defined population areas at MCBCP (Santa Margarita and South San Mateo) was estimated to be 183 ha in 2023. This is a 10 percent increase since 2022, but 46 percent below the peak estimate of 335 ha in 2016 (Figure 5; Table 1).

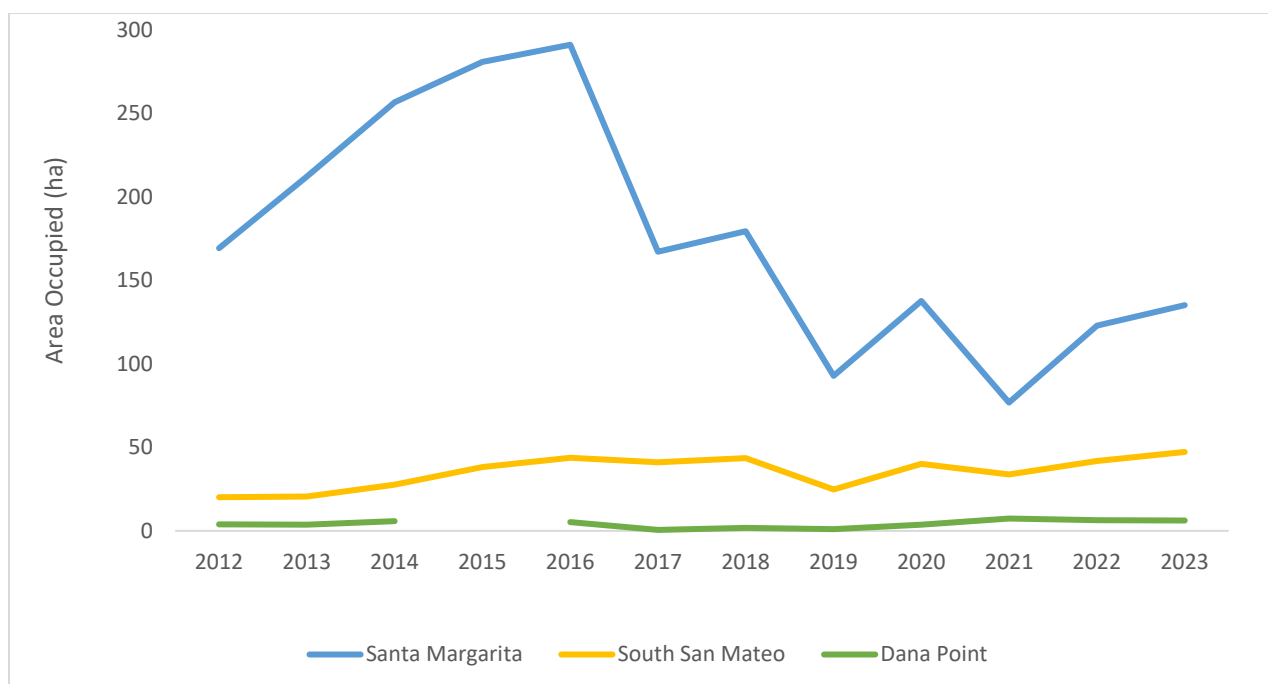


**Figure 5.** Total area in hectares (ha) estimated occupied by the Pacific pocket mouse for each population from 2012 to 2023.

**Table 1.** Estimated area occupied in hectares (ha) and proportion of area occupied (PAO) by the Pacific pocket mouse for each population from 2012 to 2023.

Santa Margarita is separated into individual sampling areas (Oscar One and Edson Range).

| Oscar One (411 ha) |               |      | Edson Range (474 ha) |      | Santa Margarita (885 ha) |      | S. San Mateo (105 ha) |      | Dana Point (12 ha) |      |
|--------------------|---------------|------|----------------------|------|--------------------------|------|-----------------------|------|--------------------|------|
| Year               | Area Occupied | PAO  | Area Occupied        | PAO  | Area Occupied            | PAO  | Area Occupied         | PAO  | Area Occupied      | PAO  |
| 2012               | 39.3          | 0.10 | 130.1                | 0.27 | 169.4                    | 0.19 | 20.2                  | 0.19 | 4.0                | 0.54 |
| 2013               | 45.0          | 0.11 | 167.4                | 0.35 | 212.4                    | 0.24 | 20.6                  | 0.20 | 3.7                | 0.51 |
| 2014               | 67.8          | 0.16 | 189.1                | 0.40 | 256.9                    | 0.29 | 27.7                  | 0.26 | 5.8                | 0.81 |
| 2015               | 28.0          | 0.07 | 253.1                | 0.53 | 281.1                    | 0.32 | 38.2                  | 0.36 |                    |      |
| 2016               | 9.7           | 0.02 | 281.6                | 0.59 | 291.3                    | 0.33 | 43.8                  | 0.42 | 5.3                | 0.71 |
| 2017               | 22.2          | 0.05 | 145.0                | 0.31 | 167.2                    | 0.19 | 41.1                  | 0.39 | 0.6                | 0.08 |
| 2018               | 37.4          | 0.09 | 142.2                | 0.30 | 179.6                    | 0.20 | 43.6                  | 0.41 | 1.8                | 0.24 |
| 2019               | 22.6          | 0.05 | 70.2                 | 0.15 | 92.8                     | 0.10 | 24.9                  | 0.24 | 1.1                | 0.14 |
| 2020               | 68.6          | 0.17 | 69.2                 | 0.15 | 137.8                    | 0.16 | 40.1                  | 0.38 | 3.7                | 0.46 |
| 2021               | 48.5          | 0.12 | 28.4                 | 0.06 | 76.9                     | 0.09 | 33.9                  | 0.32 | 7.4                | 0.95 |
| 2022               | 65.5          | 0.16 | 57.4                 | 0.12 | 122.9                    | 0.14 | 41.8                  | 0.40 | 6.4                | 0.81 |
| 2023               | 48.5          | 0.12 | 86.7                 | 0.18 | 135.2                    | 0.15 | 47.3                  | 0.45 | 6.1                | 0.78 |

## Dana Point

Dana Point Preserve is approximately 12 ha (29 ac) in the City of Dana Point, Orange County, California. It is owned and managed by the Center for Natural Lands Management (CNLM) and has the only known extant population of PPM that is located off of MCBCP. PPM were initially rediscovered in 1993 at Dana Point (Brylski 1993, entire), which was followed by inconsistent monitoring of this population during the first 15 years following its discovery. Such monitoring included deploying live traps in varying configurations to study the abundance, distribution and response of this population to experimental vegetation management treatments. In 2008, a more formal comprehensive monitoring program was initiated using track tubes deployed within a monitoring grid over the entire Preserve to estimate PAO on an annual basis. This program is complemented by live trapping that is performed on an intermittent basis (e.g., every few years) to estimate abundance (Bryski et al. 2009, entire).

Trapping results suggest that the Dana Point PPM population has undergone at least two severe population contractions, with just four individuals observed during comprehensive trapping performed in 2002 and just six animals observed during comprehensive trapping performed during 2017 (Merrill et al. 2023, p. 26; USFWS 2002, p. 5; USFWS 2007a, p. 2). Conversely, population expansions were observed in 2009 and 2020 (Carranza 2014, p. 15; Merrill et al. 2023, p. 26). At its peak, 82 PPM were detected in 2009, with estimated habitat use around 74 percent (range 60–84%) within the 8 ha (19 ac) of habitat monitored at Dana Point (Brylski et al. 2010, pp. 7, 9; USGS 2022, p. 59). In 2019, habitat use was estimated to have declined to about 1 ha (3 ac) or 14 percent (95% CI, 6.68–28.52%; Table 1) of the monitored habitat (Merrill 2020, p. 12). However the population experienced a sharp rebound to an observed 77 individuals and estimated habitat use of around 46 percent (95% CI, 39–52%; Table 1; Brehme et al. 2021, p. 25; Merrill 2024, p. 12) in 2020 that coincided with increased habitat management on site and closure of the public access trail for six months.

Dana Point Preserve has endowed funding for management and monitoring (Miller 2024, pers. comm.) and onsite habitat protections implemented by CNLM include fencing the perimeter of the Preserve and along the trail to minimize trespass, controlling and limiting the hours the hiking trail is open to the public, performing ranger patrols, and management of coastal sage scrub vegetation (Merrill and Rogers 2019, pp. 23–24). To minimize the impact of public recreation on PPM, CNLM has proposed to reduce the number of hours the public is granted access to the hiking trail.

## Marine Corps Base Camp Pendleton (MCBCP)

PPM has historically been documented at three locations on MCBCP, the North San Mateo population location (presumed extirpated), South San Mateo, and the Santa Margarita population, which spans two troop training areas, Oscar One and Edson Range.

### *North San Mateo (Extirpated)*

Since PPM rediscovery in 1995, surveys at North San Mateo focused primarily on habitat delineation rather than abundance. The highest number of PPM captured during any survey event was 33 in 1995 (USFWS 2011, pp. 13–17) and PPM captures were limited to an approximate 6 ha (14 ac) area surrounded by mature coastal scrub, chaparral and adjoining urban land uses.

Overall, the maturity of sage scrub at this site is believed to have resulted in low habitat quality for PPM. Thus, attempts were made to improve habitat via a prescribed burn in 2001 and vegetation thinning in 2010 (USFWS 2011, p. 14). However, PPM have not been confirmed at North San Mateo since 2003, despite intensive trap surveys and scent dog surveys conducted in 2008 and 2009 (USFWS 2010, pp. 20–23; USFWS 2011, pp. 14–15).

Until recently, the Department of Navy leased the area supporting North San Mateo to California State Parks, who managed the area as part of San Onofre State Beach and allowed for public access and use (Brehme et al. 2009, pp. 7–10; Montgomery 2003, p. 31). However, during renewal of the lease in 2024, this area was removed from the State Park lease area and returned to the Department of Navy who has regained primary responsibility for management of this area. North San Mateo is near a residential community and golf course which subjects it to a range of anthropogenic impacts including maintenance of a fire break along its western perimeter, frequent access from domestic cats and dogs, creation of unauthorized trails and human encampments, and dumping.

### *South San Mateo*

South San Mateo is adjoined by two residential developments, water reservoirs and the habitat area is intersected by dirt roads, fire breaks and electrical power poles and power lines. Survey efforts at South San Mateo were inconsistent from 1995 to 2012, with fluctuations in capture rates, survey efforts and locations. However, it is not known if changes in capture rates were related to survey efforts, changes in the PPM population, or a combination of factors (USFWS 2010, p. 26). Beginning in 2012, MCBCP started implementation of a comprehensive monitoring program that uses PAO statistical methods to track the status each of the extant populations on MCBCP. The estimated habitat use by PPM between 2012 and 2023 at South San Mateo has averaged 35 ha (87 ac) [range 20 to 47 ha (50 to 117 ac)], or about 34 percent of the 105 ha (259 ac) area that is monitored as potential habitat (Table 1; Brehme et al. 2024, p. 12). This population experienced an early forb die off in 2018, that coincided with extremely low reproduction and an observed PAO decline in 2019. In 2020, the population experienced increased reproduction and rapid colonization along the southeastern portion of the population boundary where about 12 ha (30 ac) of vegetation management was performed (starting in 2020) to enhance habitat for PPM (Brehme et al. 2022, p. 16). Habitat management efforts at South San Mateo to reduce shrub cover and woody debris and to increase open ground and forbs has correlated with increasing occupancy (Brehme et al. 2024, pp. 18–21). Because some of the monitoring grids fall within these managed areas and their occupancy is incorporated into global occupancy estimates, occupancy estimates for South San Mateo following inception of the habitat management efforts may no longer be truly representative of overall site conditions. Estimated occupied habitat declined slightly from 40 ha in 2020 to 33 ha in 2021, in conjunction with a wet winter, and little documented reproductive activity within core monitoring plots, suggesting little to no population recruitment (Brehme et al. 2022, pp. 19–21). Estimated occupied habitat at South San Mateo increased to 47 ha (116 ac) in 2023 (Table 1; Brehme et al. 2024, p. 12).

### *Santa Margarita*

The Santa Margarita population spans two troop training areas, Oscar One and Edson Range, where there are different training regimes, operational restrictions, soils, and types of

land management. Because of this, PPM monitoring for the Santa Margarita population is subdivided and reported separately for the two training areas, although these two areas adjoin one another, and the PPM found here demographically function as a single population.

### Oscar One

Within the 411-ha (1,016 ac) area delineated for PPM monitoring within Oscar One, estimated habitat use between 2012 and 2023 has averaged 42 ha (104 ac) [range 10–69 ha (24–170 ac)] representing about 10 percent of the monitored area (Table 1; Brehme et al. 2024, p. 12). Oscar One contains dirt roads, numerous military training obstacles, a bivouac site, a land navigation training area, sandy soils, and extensive areas where the vegetation is currently dominated by nonnative grasses and nonnative forbs.

Oscar One has had relatively high PPM numbers historically within established trapping grids, but these numbers declined following a wet winter in 2004 to 2005. That was followed by an increase in land navigation training intensity within the west central portion of Oscar One around 2006, which involved overland travel of troops through PPM habitat, potentially causing habitat disturbance and degradation (PPM SSA Expert Team 2024b; USFWS 2010, pp. 28–33; USFWS 2011, pp. 20–25). Beginning in 2012, the MCBCP started implementation of a comprehensive monitoring program that uses PAO statistical methods to track the status of each of the extant populations on MCBCP. Since these monitoring efforts began, PPM occupancy at Oscar One has remained low across the training area (Table 1). In recent years, PAO and PPM captures have increased along Powerline Road where some monitoring grids are located. This area has sandy soils that allow for good drainage, and experiences a lower concentration of military training activities, with no land navigation training. Approximately 19 acres of vegetation management has also been initiated within this area to improve PPM habitat by reducing cover of dense nonnative grasses that have been found to negatively impact PPM occupancy within Oscar One (Brehme et al. 2023a, p. 14). It has been hypothesized that native fire ants (*Solenopsis xyloni*) may also be negatively affecting habitat for PPM in Oscar One (Brehme et al. 2023a, p. 17).

### Edson Range

Within the 474-ha (1,171 ac) area delineated as potentially occupied by PPM within Edson Range, estimated habitat use between 2012 and 2023 has averaged 135 ha (334 ac) [range 28–282 ha (70–696 ac)], which represents about 28 percent of the monitored area (Table 1; Brehme et al. 2023a, p. 9). Edson Range includes dirt roads, shooting ranges, and has more compact clay loam soils. Historically, vegetation within much of Edson Range was managed with frequent prescribed fire to prevent accumulation of fuels and reduce the potential for escape of wildfires from use of the firing ranges. No prescribed fires occurred within Edson Range from 2011 to 2020, in part due to monitoring results that revealed PPM to be more broadly distributed in this area than was previously recognized.

The estimated occupancy at Edson Range experienced a relatively steady and rapid decline between 2016 and 2021; in 2016, estimated occupied habitat at Edson Range was 282 ha but as of 2021 PAO was only 28 ha (Table 1; Brehme et al. 2023a, p. 14). Since 2021, estimated occupied habitat at Edson Range has increased 78 percent to 87 ha (214 ac), although this is still well below historical estimates of occupied habitat prior to 2019 (Table 1; Brehme et al. 2024, p. 12). Within this training area, there has been a documented strong positive relationship between

PPM population expansion and colonization following fire. (Brehme et al. 2023b, p. 8). PPM rapidly colonized areas within Edson Range that were burned by wildfire in 2012 and 2014, and it is hypothesized that regular prescribed fires conducted prior to the monitoring program was initiated helped to maintain habitat suitability for PPM within Edson Range. In 2020, a prescribed burn was conducted at Edson Range in the hopes of increasing the PAO. However, existing low PPM populations on site in combination with a drought year in 2021 that limited forb growth likely resulted in lower-than-expected improvement in this subpopulation. During 2022 and 2023, PPM expanded habitat use within Edson Range, likely due to increased rainfall and vegetation growth within the burn perimeter (Brehme et al. 2024, p. 19).

### Summary

In summary, Santa Margarita is the largest PPM population, with a monitoring footprint of 885 ha (2,187 ac) and an average of 177 ha (437 ac) occupied habitat since 2012 (Table 1). The Santa Margarita population experienced a significant population increase (primarily in Edson Range) in 2012 to 2016 during a known drought period, followed by a decrease between 2017 and 2019 (Table 1; Figure 5; Brehme et al. 2023b, pp. 9–12; USFWS 2023, pp. 13–14). Dynamic occupancy modeling suggested the population increase in 2012 to 2016 was likely in response to a 2011 prescribed fire and wildfires in 2012 and 2014 that helped to remove nonnative grasses and thatch and promoted the growth of forbs within Edson Range. The decrease in habitat occupancy from 2017 to 2019 occurred after a high rainfall year which resulted in a rapid expansion of vegetation cover and little open ground (Brehme et al. 2023b, p. 8). Since 2019, with a prescribed burn conducted in 2020 and recent habitat management in Oscar One, the Santa Margarita population has shown a gradual increase in habitat occupancy (Brehme et al. 2023b, pp. 9–12; USFWS 2023, pp. 13–14).

A recent (2021) preliminary population viability assessment (PVA) for the Santa Margarita population concluded that this population has a 100 percent chance of extirpation within 100 years, running 100 iterations and starting with population sizes of both 3,101 and 1,550 (Figure 6; GSRC and SDZWA 2023, p. 57). These estimates were based on a theoretical starting population size for the Santa Margarita population and preliminary demographic parameters in the PVA that may not fully account for boom-and-bust population cycles that are characteristic for the species (GSRC and SDZWA 2023, p. 61). This PVA also does not account for more recent habitat management efforts. Thus, while this study suggests the Santa Margarita population faces a high risk of extinction over the next 100 years, this is a probabilistic model that does not appear to capture the range of annual population fluctuations that has been observed within the extant populations.

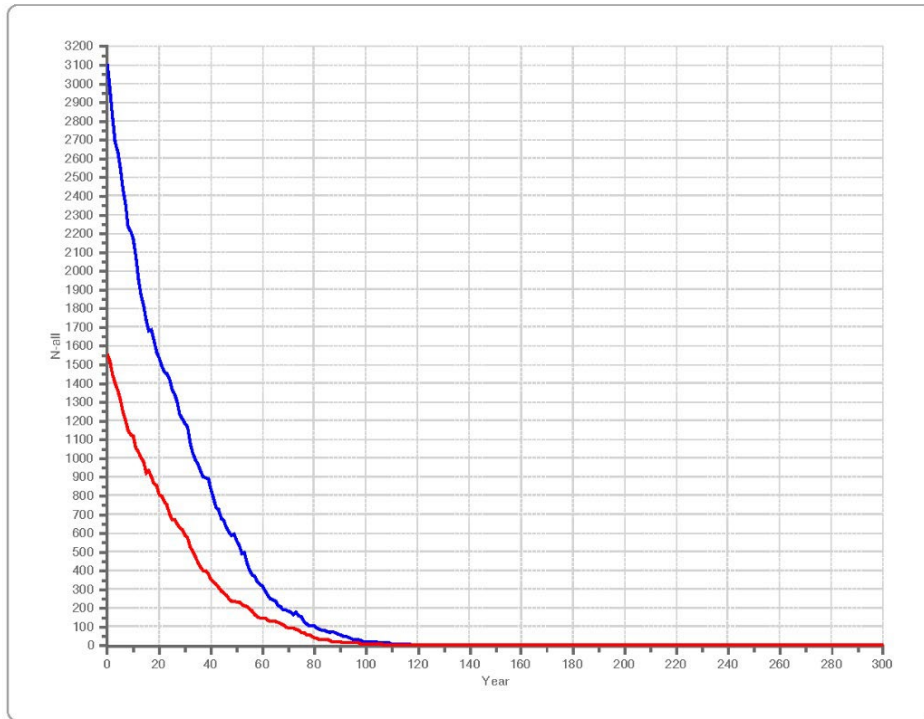


**Figure 6.** Results from preliminary Population Viability Assessment (PVA). PVA was done running 100 iterations with 2 starting population sizes of 3,101 (blue) and 1,550 (red). (Figure from GSRC and SDZWA 2023, p. 57.)

MacKenzie and Bratt (2023, entire) developed a model to predict abundance of all the MCBCP populations using 10 years of track tube survey and live-trapping data collected by the MCBCP PPM monitoring program. PPM abundance was estimated over two temporal scales including a 1-month short model, intended to provide more conservative point in time population estimates (Figure 7), and a less conservative 4-month long time interval, that ignores within-season fluctuations in population size from births and deaths and provides an indication of the number of animals that may have been alive at some point during a given year. There is a high degree of uncertainty associated with these estimates, but population trends across both time scales are comparable. Of particular interest, the Edson Range population experienced a substantial decline in both occupancy and abundance between 2016 and 2019. Both populations have remained stable to slightly increasing since 2019 (Brehme et al. 2024, p. 12; MacKenzie and Bratt 2023, entire).

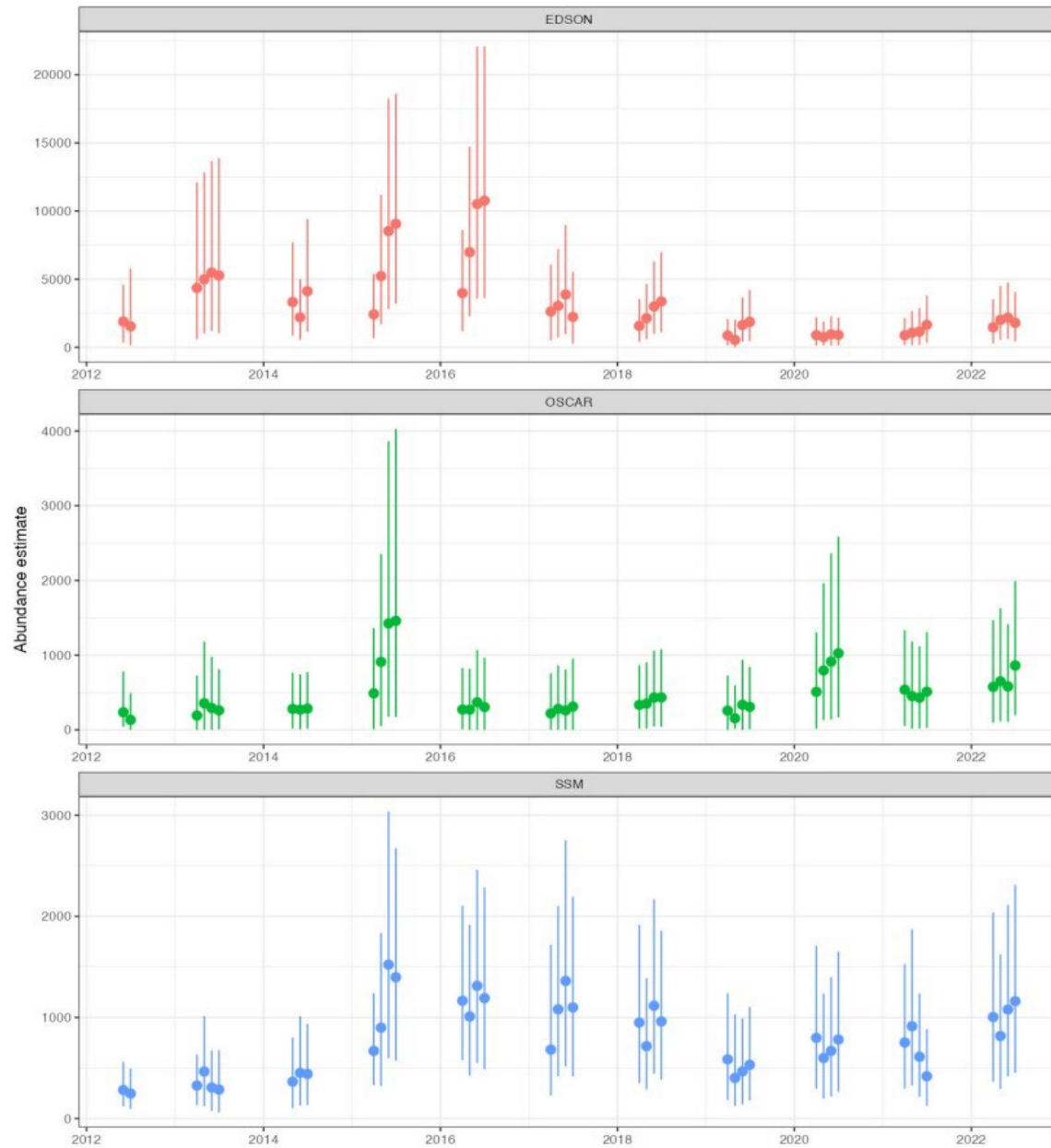


**Figure 7.** Estimated Pacific pocket mouse abundance. Estimates extrapolated from occupancy data at each site (Edson Range (red) and Oscar (green), both part of Santa Margarita, and South San Mateo (SSM; blue)), using the 1-month short model. Points indicate the posterior mean, and error bars indicate 90% credible intervals (Figure from MacKenzie and Bratt 2023, p. 17.).

## SECTION 3 – SUBSPECIES NEEDS

In this section, we synthesize the information about the range, habitat, and life history to highlight the overall needs of the PPM. We start at the individual level, then move to the population level, and then finally to the subspecies level. We consider that the effects are cumulative: survival of individuals contributes to survival of the cohort of individuals within a defined area which, in turn, contributes to the survival and persistence of the population and ultimately, the subspecies.

Theoretically, if the needs of some number of individuals in a population are being met, allowing for an adequate population size and a sufficient rate of growth, then that population will likely have resiliency. The number of resilient populations, their distribution, and their level of connectivity can be used as a measure of the subspecies' level of redundancy relative to potential catastrophes. Similarly, the breadth of genetic, phenotypic, and environmental diversity within and among populations can be used as a measure of the subspecies' level of representation. Thus, for persistence and viability, the populations need to be able to withstand stochastic events (to have resiliency), there should be enough populations to withstand catastrophic events (to have redundancy), and the populations should have adequate representation (or adaptive capacity) to adapt to changing environmental conditions.

For the purpose of this assessment, we define viability as the ability of the subspecies to sustain itself in the wild over time, and project viability over specific timeframes (see Section 6). We describe the subspecies' needs at the individual, population, and subspecies' levels in terms of resiliency, redundancy, and representation.

### 3.1 Resiliency

For the PPM to maintain viability, its populations or some portion thereof must be resilient to stochastic factors, such as annual variation in rainfall timing and amount, which influence the annual availability of dietary resources and open ground necessary to support population size and expansion. This subspecies can exhibit dramatic population fluctuations from year to year, which can reduce retention of genetic diversity over time and influence both fitness and the ability of populations to occupy all available habitat. Over a series of years with low survivorship and reproduction, a larger initial population has a higher likelihood of retaining some genetic diversity while supporting individuals capable of surviving until environmental conditions are again favorable. Thus, resiliency increases with population size, which is governed by both genetic diversity and the availability of habitat; while habitat is required for the population to expand into, genetic diversity ensures fitness and the required reproductive output to fill that habitat.

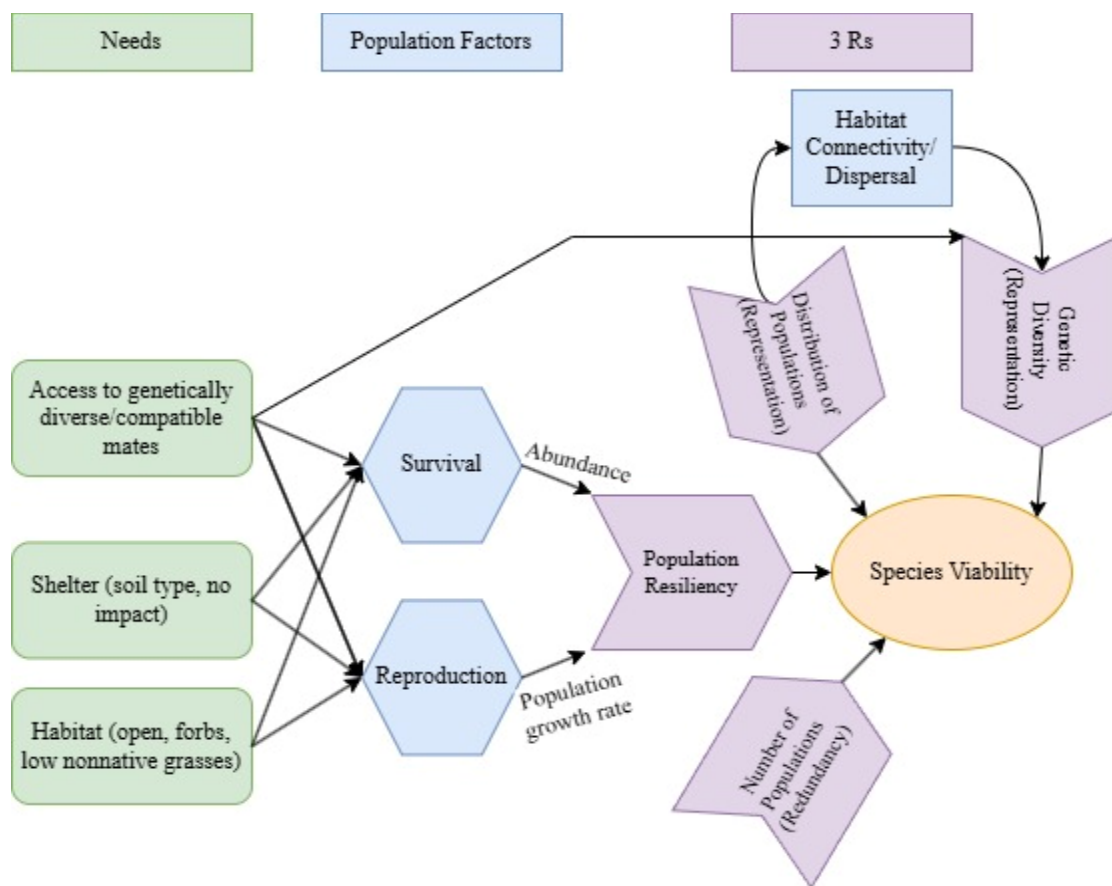


**Figure 8.** Subspecies needs and population factors that influence the viability of Pacific pocket mouse throughout its range. Habitat includes food.

## Individual Level

At the individual level, the PPM has basic needs that must be met to promote its survival and reproduction (Figure 8). The PPM needs habitat, which consists of vegetation cover from shrubs, annual and perennial forbs, and grasses, to provide cover from predators and seed for its diet, bare open areas to support movement, sandbathing and foraging, and friable sandy soils for constructing burrows. Overall, PPM appear to have a broad diet, taking advantage of almost any seed in their habitat but with apparent preferences for some forbs, perennial herbs and native bunch grasses over perennial shrubs and nonnative grasses (Vandergast et al. 2023) To meet its habitat needs, PPM also requires patches of bare ground and low coverage of invasive nonnative grasses, which threaten the availability of open space and suitability of habitat for movement and foraging. For shelter, PPM need soils that can support the construction of burrows that are sufficiently well drained to prevent flooding and the accumulation of excessive moisture that could impair the ability of PPM to effectively thermoregulate and cache seeds without loss or spoilage. Burrows must be protected from major disturbances or impacts that can cause the burrows to cave in or be invaded by predators. The subspecies also needs low amounts of noise, light, and vibration disturbances within its habitat to allow the subspecies to maintain appropriate behaviors for meeting its needs, such as time to forage, find mates, reproduce, and predator avoidance.

## Population Level

For a population to persist, enough individuals in that population must be able to successfully survive and reproduce, such that over time, the number of new individuals is equal to or higher than the number of individuals lost to mortality. For the PPM, which exists in isolated populations but can reproduce multiple times in a year and naturally undergoes large population fluctuations, persistence depends on survival and reproduction, allowing the population to recover following years during which the population contracts. Their individual needs for survival and reproduction must be met at a large enough scale to support annual population fluctuations associated with demographic and environmental stochasticity. To withstand localized population declines or changes in habitat quality, there must be enough habitat and adequate connectivity between suitable areas for shelter, foraging and mating to support the persistence of individuals through periods of low survivorship and/or reproduction (Figure 8). Further, the populations must have adequate genetic diversity and abundance to protect against inbreeding depression and loss of genetic variation, which can increase the likelihood of extirpation from the loss of overall fitness and an inability to adapt to environmental change.

### 3.2 Redundancy and Representation

#### Subspecies Level

Subspecific viability requires an adequate number of connected populations, to allow the subspecies to withstand catastrophic events (redundancy). Redundancy improves with higher numbers of resilient populations, larger population sizes, and connectivity among populations (either natural or human-facilitated) that allows the subspecies to recolonize habitat following population extirpations (e.g., resulting from a catastrophic event). Some potential catastrophic events include disease, severe drought, flooding of habitat, invasion of habitat by nonnative annual grass species, loss of ecological disturbances necessary for maintaining open space, and prolonged changes to the environment from climate change.

The populations must have adequate genetic, phenotypic, and environmental diversity to allow the subspecies to adapt to changing environmental conditions (representation). Representation improves with increased genetic, phenotypic, and/or environmental diversity within and among populations, providing increased adaptive capacity, or the ability of the subspecies to either persist in place or shift in space to cope with impacts from threats, such as disease, habitat degradation, a particularly bad drought or flood, or slower but prolonged changes to the environment, such as from climate change.

## SECTION 4 – FACTORS INFLUENCING VIABILITY

The following discussion provides a summary of the influences (including threats and other factors) that are affecting or could be affecting the current and future condition of the PPM throughout some or all of its range.

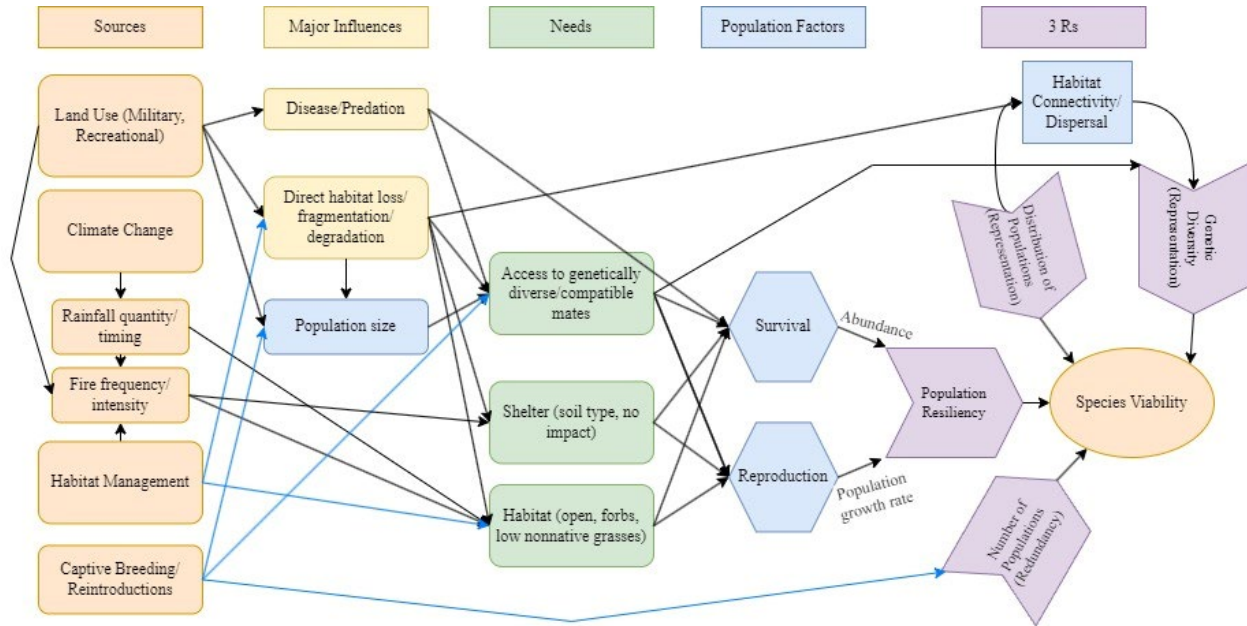


**Figure 9.** Major influences (threats and other factors) affecting the viability of the Pacific pocket mouse and the sources driving them. These factors influence the subspecies’ needs and population factors that then drive the viability of the Pacific pocket mouse throughout its range. Positive impacts are represented as blue arrows.

### 4.1 Major influences affecting viability

The major influences on the viability of the PPM can be distilled down to three main factors: 1) impacts to their habitat, including direct loss, habitat fragmentation, and degradation, potentially due to vegetation succession, disturbances or invasive or nonnative species, 2) potential impact from disease, predation, or competition, and 3) small population sizes, which is a result of several threats and other factors (Figure 9). Each is summarized below.

#### Habitat loss, fragmentation, and degradation

Land uses and habitat management practices in the range of PPM are the main influences that determine the availability of PPM habitat. Urbanization and land conversion have led to habitat loss and have fragmented the historical range, isolating the extant populations from one another (Gilpin 1987, p. 136). Fragmentation increases barriers to dispersal and can divide and isolate remaining populations into smaller areas of habitat where they are more vulnerable to catastrophes, deleterious effects of inbreeding, and environmental and demographic stochasticity (see Section 4.2). The quality of fragmented habitat may also decline because of increased vulnerability to disturbance, invasion by nonnative species, exposure to noise and artificial night-

time lighting, and impaired ecological processes. Increased exposure to artificial night-time lighting may cause problems for nocturnal rodents by increasing their vulnerability to visually aided predators, (Clarke 1983, p. 205; Dice 1945, p. 393; Prugh et al. 2014, entire), causing direct habitat avoidance (Brown et al. 1988, p. 408; Kotler 1984, p. 689; Price et al. 1984, pp. 354–355) and reduced foraging (Shier et al. 2020, entire). These edge effects also increase the likelihood of local extirpation of populations. Bolger et al. (1997, pp. 552–563) studied the effects of habitat fragmentation on rodents in southern California and found that species with lower abundance in unfragmented habitat were more frequently extirpated from small habitat fragments. This suggests that a restricted and fragmented distribution (coupled with small population sizes; see Section 4.2) continues to be a factor that threatens the viability of PPM.

### *Nonnative Vegetation*

One of the main causes of PPM habitat loss and degradation, aside from urbanization and land conversion, is the introduction of nonnative grasses. Historically, PPM habitats were largely open and dominated by native bunch grasses, forbs, and shrubs. The invasion of European annual grasses in the mid-1800s, alongside intensified agriculture and livestock grazing, led to nonnatives dominating many of these habitats (Barry et al. 2006, pp. 5-8; Brehme et al. 2023b, p. 7). Compared to native perennial bunch grasses that have deep, spaced-out root structures that allow the plants to endure the typical periods of drought experienced in this Mediterranean ecosystem (Jackson et al. 1988, p. 16), annual grasses grow in large contiguous stands with shallow roots and quickly germinate following rainfall events (Parker and Schimel 2010, pp. 40–41). This can lead to the build up of thatch and loss of open habitat conditions. Nonnatives also add nitrogen to the soil which promotes their continued perpetuation over that of native species (Brehme et al. 2023b, p. 7; Gillespie and Allen 2004, p. 650; Parker and Schimel 2010, pp. 43–46).

Nonnative grasses present in PPM habitat are primarily Brome grasses (*Bromus* spp.) and nonnative oats (*Avena* spp.) (DOD 2019, pp. 13–14). Nonnative grasses were found to make up approximately 5 to 40 percent of the total cover within PPM sites on MCBCP during surveys from 2012 to 2017 (Brehme et al. 2023, p. 7). Nonnative grass cover is a strong negative predictor of PPM occupancy and colonization and a positive predictor of localized extirpation, especially as the cover of nonnative grasses increases above 20 percent (Vandergast et al. 2023, p. 7; DOD 2019, pp. 13–14). Because nonnative grasses grow densely, they likely hinder PPM movements and reduce foraging success (Rieder et al. 2010, p. 2436). In areas of low forb cover, small amounts of nonnative grasses may be beneficial as a seed resource, but studies across MCBCP in 2016 and 2017 found that nonnative grass seed makes up only a trace amount of PPM diet (DOD 2019, pp. 13–14; Vandergast et al. 2023, p. 7). The seeds may also be less nutritious and avoided by other small mammals (Brehme et al. 2023b, p. 7; Lucero and Callaway 2018, p. 3497; Vandergast et al. 2023, pp. 10–11). Other nonnative plants (e.g., *Brassica tournefortii*, *Carpobrotus edulis*, *Centaurea melitensis*, *Oncosiphon pilulifer*, etc.) can also be problematic for PPM when they form monocultures by changing the soil composition and potentially forming thick matt or duff layers that cover the soil surface when established (Merrill 2023, pers. comm.). Germination and phenology for these species differs significantly from native vegetation in PPM habitat, leading to greater cover in early season that influences fire behavior, suppresses native germination, and can alter PPM behavior. Hurricane Hilary in

August 2023 induced germination of *Brassica tournefortii* in the Santa Margarita habitat, but native species remained dormant (Fischer 2023, pers. comm.).

Nonnative grasses and other nonnative plants represent a major threat to PPM as a main source of PPM habitat loss and degradation. They also represent a major hurdle to habitat restoration and management due to their ability to quickly colonize and overtake areas following disturbance.

### **Disturbance**

General disturbances to PPM include artificial lighting, anthropogenic noise, vibrations, and soil compaction. Disturbance from human activities (recreational, research, military training) can also increase nonnative plants and predators (ants and domestic and human-subsidized carnivores) as well as rodent competitors in the area (Chock and Shier 2021, pp. 8–9). One study found a zero percent probability of PPM occupancy near anthropogenic features such as human developments (Godfrey 2018, p. 61). Artificial lighting has been shown to impact the foraging and movement behavior of small mammals, including pocket mice, and may increase the presence of predators (Beier 2005, pp. 28–30; Kotler 1984, p. 689; Persons and Eason 2016, p. 348; Prugh et al. 2014, entire; Shier et al. 2020, entire). Soil compaction increases with foot traffic and decreases the probability of PPM presence (SDNHM 2021, pp. i–ii). Helicopter activities can also impact PPM activity, likely due to seismic and auditory signals (Shier 2008 pp. 43–46).

Disturbance resulting from land use and activities is generally regarded as a potential threat to the PPM, but disturbances can also be a positive influence on PPM habitat under the right conditions. Because the species needs open habitat, in the absence of other contributors (grazers, fire, etc.), human activities have potential to contribute to open conditions. At Dana Point, distance to the trail was a major predictor of PPM occupancy in one study, with higher probability of occupancy closest to the trail, presumably because the trail itself helps keep the vegetation sparse (Godfrey 2018, p. 62). However, more recent monitoring shows that occupancy is highest in the middle of the preserve, away from the trail (Merrill 2024, pers. comm.). Disturbances that are too frequent, too intense, or result in the compaction of soils are detrimental to the subspecies.

### **Disease, predation, and competition**

Predation by the nonnative red fox (*Vulpes vulpes*) and feral/domestic cats (*Felis catus*) was cited as a threat to PPM at the time of listing (59 FR 49762), but there are numerous potential native and nonnative predators of PPM as revealed by camera surveys at both Dana Point Headlands (USFWS 2010, p. 51, citing Carranza 2009, pers. comm.; USFWS 2020b, pp. 15–16) and within MCBCP (Wang and Shier 2017, p. 21). Domestic pet activity has been documented at North San Mateo and at South San Mateo; Montgomery (Montgomery 2003, p. 31) observed several cats entering occupied PPM habitat. At Dana Point Headlands, the predatory threat from cats has been ameliorated to some extent by management of the Dana Point Preserve. MCBCP and Liberty Military Housing have included cat restrictions in their family housing leasing agreements; if cats are documented to become an issue on MCBCP in the future, management actions (e.g., education, trapping) is proposed to be implemented (Zych 2024, pers. comm.). However, overall, predation from cats is an ongoing threat to PPM at South

San Mateo, Dana Point and North San Mateo. Increasing residential development near Dana Point Preserve could increase native and nonnative predators generally associated with human development (cats, crows, ravens, raccoons, red foxes, opossums) that could have an impact on PPM populations (Merrill et al. 2023, p. 33). Human subsidies, both intentional and unintentional, have been shown to have significant effects on predator abundance, behavior, and fecundity in southern California (Esque et al. 2010, entire; Vernadero Group Inc. 2023, entire).

The invasive, nonnative Argentine ant is an ant species that is known to prey on hatchling birds and is present at each of the extant PPM populations (Brehme et al. 2019, p. 48). Native fire ants and invasive Argentine ants may be predators of PPM that could be responsible for PPM population declines at some locations. PPM mortality due to native fire ants has been observed three times since the mid-1990s. Mortality occurred when PPM confined in Sherman live-traps (placed for population monitoring) were attacked and killed by ants (Brehme et al. 2019, p. 48). An instance of mortality due to ants was first recorded during monitoring in 1995 or 1996, and also occurred in 2004 (Miller 2023, pers. comm.) and 2014 (Brehme 2018, p. 39). Argentine ants were found during trapping events at MCBCP in traps on PPM and were also noted scavenging on two dead PPM, which were casualties associated with a live trapping event in 2020 (Merrill et al. 2023, p. 22). Prior to extirpation of the North San Mateo PPM population, State Parks would periodically spread plant mulch over a fire break adjoining this population to suppress new plant growth and reduce maintenance needs. This layer of mulch created moist soil conditions favoring the proliferation of invasive Argentine ants, that colonized the adjoining habitat and are believed to have contributed to degradation of habitat quality for PPM at this locale (Suarez et al. 1998, p. 2050; Brehme et al. 2009, p. 32).

To help determine the potential for ants to predate PPM underground, USGS performed a pilot study that involved placing dead infant (“pinkie”) mice in artificial burrows and tracking the amount of time and response of ants to mice upon discovery (Matsuda 2020, pers. comm., unpaginated). This study suggested that, of the two species discussed above, native fire ants are more likely to forage below ground and prey upon PPM when they are in their burrows (Matsuda 2020, pers. comm., unpaginated). However, the amount of mortality from ants of either species (fire or Argentine) under natural conditions when PPM are not confined in traps remains unknown (USFWS 2020b, pp. 15–16).

To date, there is no evidence that disease or parasites are affecting PPM (USFWS 2020b, p. 16; Chock and Shier, p. 20). The likelihood of introduction of an exotic pathogen may be increased in areas where there is frequent human visitation or foot traffic and introduction of nonnative rodents.

In summary, predation remains a threat to PPM across the subspecies range, but we do not have information about the amount of PPM mortality from either native or nonnative predators, including feral and domestic cats, fire ants, and Argentine ants. Therefore, the overall magnitude of this threat is unknown.

### **Small population size/genetic erosion/inbreeding**

Population size is shaped by major influences on viability, including both past and ongoing impacts. However, current habitat limitations, along with other threats and disturbances,

have resulted in all extant populations of PPM becoming relatively small, which in turn affects the subspecies' overall viability. Small isolated populations have higher probabilities of extinction than larger populations because their low abundance renders them susceptible to inbreeding, loss of genetic variation, high variability in age and sex ratios, and increased vulnerability to other random naturally occurring events. Owing to the probabilistic nature of extinction, some small populations will inevitably survive in the short term when faced with these demographic, environmental, and genetic stochastic risks, but over time are increasingly likely to become extirpated. Inbreeding depression and loss of genetic diversity increase the risk of population extirpation and extinction by reducing population growth rates and the ability of populations to evolve in response to changing environmental conditions. (Frankham 2005, entire).

Recent abundance estimates (from monitoring data) for the three extant populations are: 87 PPM (95% CI 81–99) at Dana Point in 2020 (inference for trapped areas only: 3.2 ha), 1,161 PPM (90% CI:453–2,309) at South San Mateo in 2023, and 2,652 PPM (90% CI:629–6,043) at Santa Margarita in 2023 (Brehme et al. 2020, p. 24; MacKenzie and Bratt 2023, p. 34), though populations can fluctuate dramatically from year to year and within years. Genetic data confirms these populations are isolated from one another and effective population size estimates indicate that all populations are vulnerable to continued loss of genetic variation and adaptive potential over time, and the South San Mateo and Dana Point populations are below the threshold at which reduced fitness from inbreeding (mating of closely related individuals) is expected (Frankham et al. 2014, entire; Wilder 2025 et al., entire).

Consistent with the prediction of loss of genetic variation from genetic drift, all populations have suffered a significant loss of diversity since 2000 (Wilder et al. 2000, p. 594), and mice from South San Mateo and Dana Point show signs of inbreeding depression as indicated by an increase in the estimated level of genetic load from homozygous derived alleles that cause nonsynonymous changes at evolutionary conserved sites in protein-coding genes (Wilder et al., 2025, p. 835). Based on recent effective population size estimates, theory predicts a 2.3 percent per generation loss of heterozygosity at SSM, and a 4.1 percent per generation loss at Dana Point (Wilder et al., 2025, p. 835), which will lead to an increase in the expression of high-frequency deleterious alleles in these populations over time (Wilder et al., 2025, p. 835).

## **4.2 Sources of Major Influences affecting Viability**

The influences on viability all stem from a few main sources, including land use and habitat management activities, climate change, and captive propagation and translocation efforts. While land use activities and climate change are generally projected to have negative impacts, habitat management and the captive propagation efforts are being undertaken to have positive impacts on viability.

### **Land Use Activities**

Several land uses and activities contribute to habitat availability, causing habitat loss, degradation, and fragmentation within the range of the PPM. These activities can also cause disturbance to PPM populations, which can have behavioral impacts.

The main threat to PPM resiliency and habitat availability continues to be urbanization. All of the PPM occurrences documented since the discovery of the subspecies have been impacted by the growth and density of the human population in Los Angeles, Orange and San Diego counties. Where PPM occurs in coastal southern California, terrain is gentle with sandy soils and open vegetation communities, which is highly valuable real estate for construction and expansion and there are few remaining prospective reintroduction and translocation sites with suitable habitat and compatible land uses (Chock 2024, entire; PPM SSA Expert Team 2024a, entire). Urbanization and land conversion have fragmented the historical range of PPM such that the extant populations now operate as independent units rather than parts of a stable metapopulation maintained by immigration/emigration dynamics. Isolated populations are more susceptible to long-term/permanent extirpation by accidental or natural catastrophes because the likelihood of recolonization following such events is negatively correlated with the extent of isolation (Gilpin 1987, p. 136). Incompatible land uses have ultimately isolated current populations and removed habitat corridors, leaving only the few undeveloped areas of MCBCP and Dana Point as the remaining occupied habitat. The major factors affecting viability described previously are either directly due to or are correlated with urbanization and population growth. Land use and anthropogenic activities often result in disturbances to PPM (artificial lighting, noise, etc.) and can increase nonnative plants, predators, and competitors in the area (Chock and Shier 2021, pp. 8–9).

While direct habitat loss due to land use conversion is not currently a major threat to extant PPM populations, indirect impacts from surrounding land uses (noise, light, disturbance, alteration of ecological processes, etc.) to existing populations remains a major threat, and impacts to any remaining habitat within the subspecies range could impair recovery by decreasing the availability of potential reintroduction sites (see Section 4.6).

### *Development/Project Construction*

In February of 2005, the City of Dana Point approved the Dana Point Headlands Development and Conservation Plan (HDCP), which involves residential and commercial development on about 29 ha (71 ac) of the 48 ha (121 ac) Dana Point Headlands site, and conservation of much of the remaining open space (USFWS 2010, pp. 44–45; USFWS 2020b, p. 10). An 18 ha (45 ac) area identified by Brylski (1993, p. 8) as suitable for PPM was removed by the development and the remaining conserved open space includes the 12 ha (29 ac) Dana Point Preserve, which includes the area of documented historical occupancy by PPM. A hiking trail within the Dana Point Preserve was constructed in 2007 with access to the trail during daylight hours provided to the public in December of 2009 (Merrill et al. 2023, p.4). Since listing, the quantity of habitat available to PPM at Dana Point has decreased from the residential and commercial development and construction of the public trail within the Dana Point Preserve. Impacts from edge effects have increased from the closer proximity of development (e.g. increased ambient light levels, irrigation runoff, intrusion from pets, and increased risk of nonnative plant and animal species presence) and human intrusion from passive recreation has increased with use of the trail (USFWS 2010, pp. 44–45; USFWS 2020b, p. 10). Still to be constructed on a vacant rough-graded lot created adjoining the Dana Point Preserve is a proposed 1 ha (2.5 ac) luxury hotel, which likely will exacerbate impacts from lighting, noise, and increase use of the trail (PPM SSA Expert Team 2024b; Dana Point Real Estate 2024, entire).

In 1996, the USFWS completed consultation with the MCBCP on the Crucible Challenge Course, which was built within the Oscar One training area (USFWS 1996, entire; USFWS 2010, pp. 44–45). That project involved use of existing elements of a MCBCP recruit training course already in place at the time of the consultation and construction of new course obstacles resulting in the loss of 3.2 ha (8 ac) of occupied or suitable PPM habitat within Oscar One (USFWS 2020b, p. 10). Use of the Crucible Course by recruits was proposed to include maintenance of a 6.1-m (20-ft) buffer surrounding each obstacle course element, and maintenance of the existing network of dirt roads on which it was proposed recruits would travel on foot from obstacle to obstacle (USFWS 1996 p. 4; USFWS 2010, pp. 44–45). Maintenance of the Crucible Course was anticipated to involve replacement of obstacle components due to wear or damage, mowing of vegetation within the footprint of the obstacles, and grading and gravel replacement on improved roads. In practice, there has been an accretion of habitat impacts from use of the Crucible Course due to changes to obstacle course elements, adjustments to use areas, and modification of training practices. Use of the Crucible Course was anticipated to result in the take of one PPM per company of recruits using the Crucible Course, and one PPM per year due to road maintenance activities (USFWS 1996, p. 15; USFWS 2010, pp. 44–45).

At South San Mateo, MCBCP has consulted on a variety of projects that have impacted PPM habitat including the realignment and installation of pipelines and facility upgrades associated with the Basewide Water Infrastructure (BWI) project, a reservoir repair project, which included repairing and restoring damage caused to facilities and the environment from the accidental release of water from reservoirs that fall within the bounds of the South San Mateo PPM population, and repairing impacts to habitat caused by several grading and earth disturbing incidents (USFWS 2020b, p. 10). Other construction impacts at South San Mateo have included the repair and maintenance of utility infrastructure by utility companies (discussed below). Cumulatively, just a few acres of habitat have been impacted by these projects and the impacts have generally been offset by habitat management and creation activities performed at South San Mateo (see Habitat Management, below).

In summary, development has historically resulted in extensive PPM habitat loss. More recently, development has resulted in an appreciable loss of habitat at Dana Point but other than an increase in the intensity of edge effects from the pending development of a hotel on an adjoining lot, additional habitat losses are not anticipated at this site. At MCBCP, habitat losses from project construction and development has been confined to a relatively small portion of the occupied habitat.

### *Military Training Activities*

At present, the South San Mateo area either is not used or is used only minimally by the MCBCP for training (USFWS 2010, pp. 45–46). Therefore, PPM are not currently being appreciably impacted by training activities at this site (USFWS 2020b, p. 11).

Military training at the Oscar One and Edson Range training areas that overlap the Santa Margarita PPM population primarily consists of marksmanship and recruit training that culminates in the use of the Crucible Challenge Course, with approximately 17,000 recruits completing the training annually. The course is used 36 to 40 weeks per year with 250 to 550 Marines completing the training weekly (MCBCP 2021, p. 2-1). This training includes various elements of recruit training which may include Crucible Course obstacles, land navigation, troop

movement, live firing ranges, bivouac sites, dirt roads and trails and associated facilities (USFWS 2010, pp. 45–46; MCBCP 2021, p. 2-1). Aerial photography shows increasing impacts to PPM habitat within the training areas starting around 2006. There is no evidence of increased troop numbers during this time period, suggesting these impacts were the result of altered training practices and an increase in training intensity (PPM SSA Expert Team 2024b; USFWS 2007b, entire; USFWS 2010, p. 46; USMC 2007, entire). Observed impacts within undeveloped areas include removal or reduction of vegetation, soil compaction, addition of new training elements, and increased foot and off-road vehicle traffic over a large portion of the Lower Mesa within Oscar One. One of the primary training activities is land navigation training across 134.8 ha (333 ac) of PPM habitat. This involves the movement of large numbers of troops on foot through habitat areas (MCBCP 2021, p. 2-1). This has resulted in a reduction of vegetative cover, creation of trails, and compaction of soils throughout portions of the Lower Mesa documented to be historically occupied by PPM. A study on the impact of land navigation training on PPM estimated PPM density within the land navigation course to be just 2.0 individuals ( $\pm 1.3$  SE) per hectare, but the sample size was very low, with only eight individual PPM captured within the study area (SDNHM 2021, p. ii). This study concluded that foot traffic has led to increased soil compaction within the land navigation course and use of this course has had negative effects on PPM (SDNHM 2021, p. ii).

In addition to the potential for direct impacts to PPM from crushing of burrows, these activities have degraded habitat quality for PPM by reducing vegetative cover and availability of seed resources, reducing the quality of soils for constructing burrows, and facilitating extensive proliferation of nonnative invasive plant species (see Section 4.2). Given the pre-existence of nonnative annual grasses and weeds in this area, the movement of troops throughout this area has degraded habitat quality for PPM by facilitating the continued invasion and spread of nonnative annual grasses and weeds into areas formerly densely occupied by PPM. When present in adjoining areas, nonnative grasses and forbs are often capable of rapidly expanding into areas that have experienced disturbance (D’Antonio and Vitousek 1992, pp. 63–68; Gelbard and Belnap 2003, pp. 424–425; O’Leary and Westman 1988, pp. 778–779; Stylinski and Allen 1999, p. 547; USFWS 2010, p. 46).

As a result of these observed impacts, the MCBCP modified the location of some of its training activities to locations where PPM had not been detected to minimize impacts to PPM (PPM SSA Expert Team 2024b; USFWS 2007b, entire; USFWS 2010, p. 46). Land navigation and other training practices have degraded PPM habitat in an area south of Macs Road, where PPM were once densely concentrated (Miller and Pavelka 2008, entire). Since 2012, PPM have been largely absent or detected in trace numbers within monitoring grids or live-trapping plots in this area (Brehme et al. 2020, pp. 6, 17; USFWS 2020b, p. 11; PPM SSA Expert Team 2024b, p. 1).

In 2012, about 0.6 ha (1.5 ac) of PPM-occupied habitat within Oscar One were disturbed due to the establishment of a temporary training/bivouac site (USFWS 2020b, p. 11). MCBCP moved the temporary training/bivouac site to an area suspected to be unoccupied by PPM and consulted with USFWS to address potential impacts associated with restoration of the site. Restoration of the vegetation at the bivouac site was completed in 2019 (USFWS 2020b, p. 11). In 2022, 2 ha (5 ac) of PPM-occupied habitat within Edson Range were disturbed due to the establishment of another temporary training/bivouac site (Asmus 2024, pers. comm).

In 2022, MCBCP proposed a new project for improvement and maintenance of 52 existing targets for munitions training at an established firing range (501) within Edson Range. This work involves the replacement of berms surrounding targets and, if necessary, ground disturbance to replace and repair the electrical connections providing power to the targets (not necessary to date). Following the initial target repairs, to maintain the targets these practices and associated habitat impacts are anticipated to repeated at a rate of every 1 to 3 years for targets at the front of the range and every 5 to 9 years for targets farther away (Vernadero 2023, p. 1; USFWS 2023, pp. 1–3). This range covers 25 ha (62 ac) and is used to train approximately 17,000 recruits annually. Potential impacts to PPM from range activities include direct mortality from munitions training, use of vehicles, foot traffic, and operations and maintenance of the range, all of which contribute to habitat degradation and soil compaction. During 2022, the MCBCP consulted on the impacts from maintenance and repair of the targets but did not consult on impacts from continued use of the firing range itself. The MCBCP committed to monitor PPM in this area to identify appropriate avoidance and minimization measures during its range maintenance activities (USFWS 2023, pp. 15–16, 28–29).

In summary, military training is currently a threat to the Santa Margarita PPM population within both the Edson Range and Oscar One training areas. Training activities are frequent, with 17,000 troops training annually within parts of the Edson Range and Oscar One. Current impacts are mostly concentrated in locations where PPM habitat quality has been degraded from training activities, but past changes to military recruit training intensity and practices implemented without oversight of the MCBCP Division of Environmental Security have resulted in appreciable losses of PPM and degradation of habitat for PPM within Oscar One, suggesting similar changes to training practices in this area in response to global events represents an ongoing threat to the Santa Margarita population.

### *Accidental Fire and Fire Management Practices*

Fires are periodically ignited accidentally on MCBCP from military training activities, particularly with the use of the live firing ranges within Edson Range. A review of historical fire events larger than 2 ha (5 ac) mapped by MCBCP since 1972 reveals no record of fire for North San Mateo, one large event covering South San Mateo in 1976 and a smaller event that burned a portion of this area in 1989, and a complex history of frequent fires within portions of the Edson Range and Oscar One training areas (USFWS 2005, pp. 1–3; USFWS 2010, p. 46).

Occasional wildland fire may be beneficial to PPM if fire frequency and intensity fits the ecological needs. Wildfires are a form of disturbance that can help to maintain habitat suitability for PPM by removing shrub cover and promoting germination of native forbs. However, unlike prescribed fires (see Habitat Management, below), training-induced fires have the potential for continuing overnight when PPM are active, which could increase the risk of direct harm to individuals. These fires are also often associated with reactive weather conditions, such as during Santa Ana wind events, which can cause the rapid spread of fire into PPM habitat adjoining the firing ranges. Short intervals between fires (e.g. from repeated wildfire escape) or burning of PPM habitat at the wrong time of year can result in habitat type conversion by facilitating the invasion of nonnative grasses and forbs and displacing native forbs and shrubs (D'Antonio and Vitousek 1992, pp. 63–68; Keeley et al. 2005, pp. 2114–2125; Minnich and Dezzani 1998, pp. 383–384; O'Leary and Westman 1988, p. 779), resulting in the long term loss or degradation of habitat for PPM from the accumulation of nonnative species and thatch.

The MCBCP and California State Parks have maintained fire breaks in the vicinity of South San Mateo and the historical North San Mateo population, respectively (USFWS 2010, p. 47). Fire breaks have been maintained by disking or blading down to mineral soil, which may crush PPM burrows and/or harm individuals through direct injury or displacement. Soil clods may need time to break down before surfaces become available for transit or burrowing by PPM as evidenced by similar practices implemented by the Navy and MCBCP in Stephens kangaroo rat habitat (JV 2022, p. 4-2). Maintaining mowed fuel breaks to remove wildfire fuels, as opposed to disking fire breaks, reduces the harmful effects for plants and animals that come from soil disturbance. Following the discovery of PPM at South San Mateo in 1995, the MCBCP abandoned maintenance of some of the fire break segments in the vicinity of this population to minimize and avoid impacts to PPM, although some of these fire breaks have continued to be disked and new ones created by facilities maintenance staff (USFWS 2014, pp. 1–2; USFWS 2019, pp. 5, 27; USFWS 2020a, p. 30). Since then, additional oversight of fire and fuel break maintenance is being implemented at MCBCP in association with the adoption of a formal Wildfire Prevention Plan (MCBCP 2018, entire). Several fire breaks have also recently been converted to mowed fuel breaks and MCBCP environmental staff have been given oversight to prevent disking of PPM habitat (USFWS 2020a, p. 30; Thomas 2024, pers. comm.).

In 2012, about 0.1 ha (0.3 ac) of occupied PPM habitat was impacted within a former east-west trending ridgeline fire break at South San Mateo. In 2015, the area was further disturbed by the BWI project. PPM were not recorded in these areas by 2017. MCBCP restored this habitat for PPM (USFWS 2019, pp. 26, 32), and monitoring indicates this area was recolonized by PPM in 2021 approximately 6 years after disruption by the BWI (SoCal Biological 2021 in ACS Habitat Management 2021, p. 34).

In 2014, PPM habitat was disked when a new fire break was created near MCBCP housing off Basilone Road at South San Mateo. This activity likely crushed burrows and harmed individual PPM residing within the 0.2 ha (0.4 ac) footprint of the fire break (Stewart 2014, p. 2). To monitor the response of PPM to this habitat disturbance, the MCBCP PPM monitoring program placed an “Impact” monitoring grid within the disked area that detected PPM in the cleared and adjoining area the following season (Brehme et al. 2018, pp. 5, 7, 35). Following recolonization of this area by PPM, 0.2 ha (0.5 ac) was disked again on June 21, 2017 (CLEO Incident Report 2017, pp.17–18; USFWS 2019, pp. 5, 27). However, continued monitoring of the impact grid indicates that this fire break has again been recolonized by PPM following the second disking incident (Brehme et al. 2019, p. 18).

In summary, wildfires are a form of disturbance that can help to maintain habitat suitability for PPM but high fire frequency from the escape of wildfires from the firing ranges or from other causes has the potential to degrade PPM habitat by facilitating the invasion of nonnative grasses. PPM colonization of cleared habitat following creation of fire breaks, combined with mowed fuel break maintenance practices at South San Mateo, is likely resulting in some ongoing incremental impacts to PPM habitat and direct harm to individual PPM on a periodic basis. Adoption of the MCBCP Wildfire Prevention Plan has helped to reduce the level of severity of the threat from fire and fuel break maintenance to low.

### *Road and Utility Maintenance*

Dirt roads on MCBCP are maintained either by the base, or by utility companies [San Diego Gas and Electric (SDGE), Southern California Edison (SCE)] (USFWS 2020b, p. 14). MCBCP Facilities and Range Maintenance Departments coordinate road maintenance within PPM habitat with the Environmental Security (ES) Department who provide oversight to help ensure maintenance practices avoid and minimize the potential for harm to PPM (USFWS 2010, p. 48). For routine road and utility maintenance, SDGE and SCE also follow practices to avoid and minimize the potential to injure or kill PPM, but some small scale ongoing annual take of 1–3 PPM has been authorized for each of these entities for take that cannot be avoided during maintenance of their existing infrastructure (USFWS 2017a, p. 20; USFWS 2022, pp. 16–17). SDGE and SCE also coordinate with USFWS to minimize take during routine road and electric line maintenance, and have contributed funding that is proposed to be used for population creation efforts or habitat management on MCBCP to offset impacts to PPM and its habitat (USFWS 2021, entire; USFWS 2023, p. 31). Therefore, it is likely that routine road maintenance results in few, if any, individual PPM injured or killed on an annual basis.

During 2014, the MCBCP started surfacing the dirt roads that intersect the distribution of the PPM population within the Oscar One training area with pea gravel and/or crushed stone (USFWS 2020b, p. 14). Based on alteration of the road surface from dirt to a composite rock substrate, and the observation of decreasing road permeability to movements of cactus mice (*Peromyscus eremicus*) across a change of road type from low-use dirt, low-use secondary paved, to rural 2-lane highway (Brehme et al. 2013, pp. 713, 715–716), it is possible that this road surfacing could contribute to the fragmentation of PPM habitat within the Santa Margarita population from road avoidance behavior (USFWS 2020b, p. 14).

In 2012, an emergency access road was created through PPM habitat at San Mateo South while performing repairs in response to damage to drainage ditches from the accidental release of water from the San Onofre Reservoirs (USFWS 2020b, p. 14). This resulted in the grading of an estimated 0.34 ha (0.83 ac) of PPM habitat within the South San Mateo population and likely resulted in the death or injury of at least seven PPM (Snyder 2012, p. 2). The emergency access roadbed was recolonized by PPM following this grading incident, but the road was subsequently disked in 2017 in association with the creation of an adjoining fire break (see Fire and Fire Management Practices, above; Brehme et al. 2019, p. 18; CLEO Incident Report 2017, entire). The MCBCP has consulted to place a composite surface on this road and establish it as a permanent access road for maintenance of the San Onofre reservoir facilities (USFWS 2019, p. 2; USFWS 2020b, p. 14).

## *Recreation Activities and Unauthorized Habitat Disturbances*



**Figure 10.** Map of Center for Natural Lands Management Dana Point Preserve with boundary, trail and gate features (Figure from Merrill et al. 2023, p. 5.).

Residential communities fall within close proximity to the Dana Point Headlands and South San Mateo PPM populations, and a hiking trail passes through the Dana Point Headlands population (Figure 10). Public use of these areas has potential to degrade PPM habitat through authorized trail use (i.e., the number of visitors and time of day of visitation), creation of unauthorized trails, and other habitat disturbances from human activities. Negative effects related to recreational disturbance have been documented across a wide variety of species and taxa including, mammals, birds, reptiles, amphibians, and even invertebrates (Bennett et al. 2013, pp. 1794–1795; Larson et al. 2019, pp. 5–7; Merrill et al. 2023, p. 38; Steven et al. 2011, pp. 7–9).

The Dana Point Preserve was historically fenced and closed to the public so use of this area prior to 2009 resulted from unauthorized trespass (USFWS 2010, p. 49). Because this site is one of the last remaining undeveloped coastal parcels within the city of Dana Point and occurs on a majestic coastal promontory, it experienced frequent and persistent public trespass that resulted in damage to the habitat (e.g., trails, trampling) and the surrounding fencing. While these activities were curtailed after 2005 with the acquisition and assumption of management of the site by CNLM (USFWS 2010, p. 49; USFWS 2020b, p. 14), they are continuing issues

(Merrill et al. 2023, p.13). In December of 2009, the public was granted access during daylight hours (07:00 AM to sunset, daily) to a formal trail that was constructed within the Dana Point Preserve in 2007. This led to a dramatic increase in the amount of human presence within the Dana Point Preserve during daytime due to the popularity of the trail with the public (Merrill et al. 2023, pp. 8, 78; Miller, 2010, pers. obs.). The trail was closed in 2020, at the start of the Covid-19 pandemic, and reopened later that year with limited hours, opening later and closing earlier to limit public access during low-light times of day when PPM are most likely to be active aboveground (Merrill et al. 2023, pp. 9, 45). CNLM is currently in litigation with the City of Dana Point over CNLM's proposal to curtail and more closely regulate the number of hours the public is granted access to the trail within the Dana Point Preserve, which it has proposed to minimize the impact of trail use on PPM (Greenberg 2022, entire).

The full impact of increased human presence within the Dana Point Headlands is unknown, but potential impacts to the PPM population include altered behaviors and activity patterns, which could result in decreased time spent in essential activities such as foraging or resting in torpor, degraded habitat quality due to increased disturbance adjoining the trail and possibly increased presence of nonnative species such as domestic dogs (*Canis familiaris*), house mice (*Mus musculus*), rats (*Rattus rattus*, *Rattus norvegicus*), domestic or feral cats (*Felis catus*), and Argentine ants. Between 2011 and 2017, average daily use of the trail is estimated to have increased from 344.5 (95 percent confidence interval, 324.3–364.7) to 672.5 (632.6–712.4) visitors per day, annual visitation increased from 125,740 to 245,465 visitors, and peak single day visitation was estimated to be 2,896 on December 26, 2016 (Merrill et al., 2023c, pp 17–20). Though the public is prohibited from venturing off trail, there are ongoing instances of off-trail recreation (such as hiking and mountain biking), as well as dogs off leash (Merrill and Rogers 2019, p. 23). From June 2017 to February 2023, despite numerous signs, fencing, and CNLM staff presence, 220 incidents of people going off-trail were reported. In that same period, there were 81 recorded instances of pet dogs or cats on the trail (Merrill et al. 2023, p. 13). On June 5, 2023, a dead PPM was found on the trail that appeared to have been stepped on by a pedestrian, as trauma was confirmed to be cause of death via necropsy (Merrill 2023a, p. 1; Shier 2023, pers. comm). PPM occupancy and abundance increased at Dana Point following the temporary closure of the public trail in 2020 and increased habitat management on site. While we cannot definitively attribute the increase in abundance to the trail closure alone, the rebound occurred after years of declining numbers that coincided with rising trail use. This timing suggests that closing the trail may have helped the population rebound (Merrill 2023a, p. 16).

Because South San Mateo falls entirely within a military installation, it receives the least impact from trail creation and public trespass. However, nearby Base residents occasionally use the existing road network for mountain biking, hiking, and dog walking (USFWS 2020b, p. 15).

Both trails and residential areas are within close proximity to the previously occupied North San Mateo population. Of the populations on MCBCP, North San Mateo experiences the greatest amount of habitat disturbance and recreational use from the public (USFWS 2010, pp. 49–50), which has included the creation of an increasing number of unauthorized human encampments. While it is unknown if recreational use and unauthorized habitat impacts led to the presumed extirpation of this population, it is possible that these impacts contributed to the loss of this population. Trail maintenance activities also may have altered hydrology on site, increasing erosion potential, and facilitating the invasion of the site by nonnative Argentine ants

(Brehme 2023, pers. comm.). Due to the proximity to adjoining residential development in San Clemente, recreation and human disturbance is expected to be a continuing concern at this site.

Overall, recreation activities and unauthorized habitat disturbances at the two extant northern PPM populations (Dana Point, South San Mateo) have led to a low level of continual disturbance. While each of these activities may affect only a small portion of the habitat within a site at any one time, their cumulative impact may exacerbate the risk of extirpation of these populations by degrading habitat quality and depressing the size of these already small PPM populations.

The largest impacts to PPM populations from land use activities have already occurred, surrounding and isolating the extant PPM populations from one another by urban development and other land uses. Thus, threats from nearby land use activities—which can occasionally injure or kill individuals or degrade habitat—are made more severe by limiting the ability of PPM to move between adjoining populations. This restricted movement reduces opportunities for populations to support one another during declines and limits the species' ability to recolonize suitable habitat after local extirpations. At Dana Point, the largest threats appear to be from use of the public access trail, which may degrade habitat quality and negatively alter PPM behaviors and activity patterns, and from future development of the adjoining hotel site, which is likely to increase noise and light levels, and could increase threats from invasive species and human use of the trail. At MCBP, road, utility and fuel break maintenance represent a relatively low level of on-going disturbance, although road maintenance activities may contribute to fragmentation of these populations. Within the Santa Margarita population, increased military training intensity has been shown to degrade habitat quality. Training activities now overlap areas where PPM were once more abundant but are currently found at lower densities. Although recent efforts have aimed to concentrate training in locations where PPM have not been detected or where habitat is already degraded, PPM are still likely to be affected where their distribution overlaps with training and adjustments to the location or intensity of these training activities represent an on-going threat to this population.

## **Habitat Management**

Habitat management can help to offset the negative impacts of incompatible land uses and other activities that have caused habitat loss, fragmentation, and degradation.

### ***Prescribed Fire***

The seasonality, size, intensity, and frequency of fire in coastal southern California has changed drastically over the last century in association with human settlement (Syphard et al. 2018, entire). As a result of fire suppression activities, many of coastal southern California's natural areas may be subject to less frequent fire than occurred historically (USFWS 2010, p. 46). Not allowing these habitats to burn reduces habitat quality for PPM by increasing the continuity of shrub cover and eliminating habitat openings that are thought to be an important component of PPM's preferred microhabitat (Germano 1997, p. 28; Loda et al. 1999, p. 8; Montgomery 2005, pp. 7–8; Spencer et al. 2000, pp. 12–15). While fire is generally considered to be beneficial to PPM and prescribed fire is used as a habitat management tool, the impact of fire on PPM habitat is complex, and certain fire intervals or burning at the wrong time of year can result in habitat type conversion due to the displacement of native forbs and shrubs by the invasion of nonnative grasses and forbs (D'Antonio and Vitousek 1992, pp. 63–68; Keeley et al.

2005, pp. 2114–2125; Minnich and Dezzani 1998, pp. 383–384; O'Leary and Westman 1988, p. 779). Type conversion can result in a long term loss of habitat for PPM from the accumulation of nonnative species and thatch.

Fire creates open ground, reduces nonnative grasses, and promotes the growth of forbs and native bunch grasses because it immediately clears vegetation and thatch, removes substantial quantities of nitrogen in the soil by volatilization, and, if timed appropriately, can disproportionately reduce nonnative grass seeds in the soil seed bank (Brehme et al. 2023b, p. 8; Cox and Allen 2008, pp. 40–44; Thomson et al. 2020, pp. 310–313; Valliere et al. 2020, p. 9). A fire return interval of 1 to 4 years is hypothesized as being suitable for maximizing native forb and grass cover while also reducing nonnative invasive species, helping to maintain open native grass and forb-lands in California. Burning would occur ideally in spring (or in the warm seasons) to better reduce the nonnative annual grass seed bank (Brehme et al. 2023a, p. 15; Callison et al. 1985, pp. 537–538; Carlsen et al. 2017, pp. 13–17; Gillespie and Allen 2004, pp. 649–651; Parsons and Stohlgren 1989, pp. 166–167; Stromberg et al. 2007, entire). Forbs, an important food source for PPM, have been shown to be the densest and the most diverse in the first several years after fire (Callison et al. 1985, p. 538; Conlisk et al. 2016, pp. 35–37).

PPM residing within habitat that is burned have potential to succumb to the fire from burning, asphyxiation or heat prostration, or may survive either by fleeing or by sheltering in place. Prescribed fire is typically conducted early in the day with low potential for burns lasting into the evening and avoiding PPM activity cycles. Weather prescriptions in burn plans also harness relative humidity and temperature to control intensity. Studies that have been performed to understand the potential for fire to result in direct harm to small mammals suggest many small mammals are able to shelter in place within crevices in rock outcroppings, burrows, and unburnt or protected areas within the burn perimeter that provide insulation from direct heat and fresh air (Gashwiler 1959, pp. 134–138; Howard et al. 1959, pp. 232–234; Lawrence 1966, pp. 284–287; Price et al. 1995, pp. 55–57; Quinn 1979, pp. 131–132; Tevis 1956, pp. 407–408;). Due to its burrowing habit, PPM are likely to be predisposed to be able to survive and withstand fire by sheltering in place within burrows, where there is adequate insulation from heat (USFWS 2020b, p. 11).

At Dana Point and South San Mateo, a lack of recent fire has resulted in these sites being dominated by mature large stature sage scrub shrubs that overlap with one another and provide nearly continuous canopy cover over the ground (Germano 1997, p. 28; Loda et al. 1999, p. 8; Montgomery 2005a, pp. 7–8; Spencer et al. 2000, pp. 12–15). Due to the close adjacency of residential development and overhead powerlines, prescribed fire cannot be used as a management tool to improve habitat at Dana Point or South San Mateo.

Within the Santa Margarita PPM population's Edson Range, prescribed fire has historically been used within a 225 ha (556 ac) area to prevent fires from escaping the vicinity of live firing ranges where there is a high risk of fire ignitions. Prior to 2011, this area was historically burned around every 3 years, and wildfires burned portions of this area in 2012 and 2014. Information gathered by the MCBCP PPM monitoring program within Edson Range showed PPM rapidly colonized areas burned during the 2012 and 2014 wildfires, and modeling strongly suggests PPM occupancy is negatively associated with time since fire (Brehme et al. 2023b, p. 8). A prescribed fire was implemented in Edson Range on May 30, 2020, when the PPM population in this training area was low, with the expectation that this portion of the Santa

Margarita population should start to rebound in 2021. However, 2021 was a drought year which limited the post-fire growth of forbs on which PPM depend. While there was an overall decline in the occupancy rate within Edson Range in 2021, occupancy rates increased in 2022 and 2023 (Brehme et al. 2023a, p. 14; Brehme et al. 2024, p. 12).

While additional prescribed fire is generally considered a management tool that could increase PPM habitat suitability, a 2013 report modeled vegetation and species' responses to five different prescribed fire management options. The model results were that, for 90 percent of the 500 model runs, PPM were extirpated or nearly extirpated, regardless of management option (Environmental Sciences Branch 2013, pp. 123–124).

In summary, prescribed fire is generally considered a valuable management tool for creating and maintaining PPM habitat and creating conditions conducive for PPM to disperse or expand their home range. While prescribed fire may involve direct injury to some individuals during the fire event, maintenance of suitable habitat for PPM over the long term is assumed to outweigh short-term losses of individuals (USFWS 2022, pp. 19, 25), as increases in PPM occupancy within the fire footprint have been documented after fire. Monitoring of the post-fire response of PPM is warranted to confirm the assumption that implementation of prescribed fire only results in the short-term loss of a small proportion of individuals within the Santa Margarita population and otherwise helps to maintain habitat suitability for PPM over the long term.

### *Other habitat management activities*

Other potential habitat management activities that help to reduce nonnative grasses but may be used in areas where fire cannot (areas within proximity to housing, powerlines, freeways, etc.) include mowing, grazing, herbicide application, brush thinning, dethatching (removal of down, dead and duff vegetation) and following these manipulations with native seeding. With the exception of mowing and grazing, these methods have been shown to improve forb cover and increase open ground and are currently being implemented to test their efficacy at creating and maintaining more high-quality PPM habitat (Brehme et al. 2021, p. 1).

Experimental shrub thinning at Dana Point in 1999 yielded a short-term, positive response of mice to the thinned habitat plots (Spencer 2005, p. 107). Hand removal of nonnative grasses and dead vegetation at Dana Point across 2.93 ha (7.2 ac) from 2017 to 2022 was followed by a population increase, and this form of management continues to be practiced at this site (Figure 11). Due to the proximity of adjoining development and size of this site, management at Dana Point is limited to hand treatments and does not involve large machinery. Occupancy modeling for Dana Point in 2020 showed that the location and frequency of habitat management were primary predictors of PPM occupancy, but increased habitat occupancy also coincided with a reduction in foot traffic on the trail system in association with the temporary closure of the public access trail during the first 6 months of the Covid-19 pandemic.

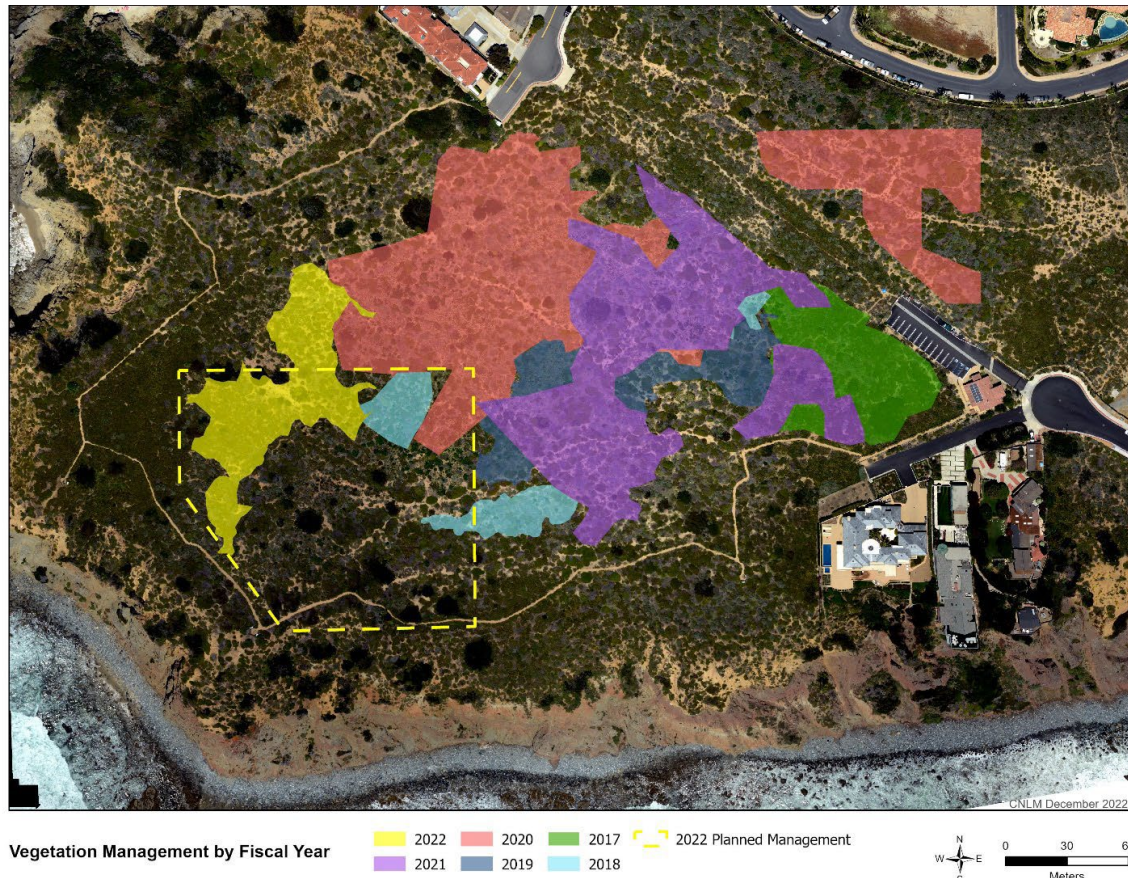


**Figure 11.** Vegetation and duff management at Dana Point from 2017 to 2022. Areas where dead and downed vegetation was removed are shaded according to the Fiscal Year management occurred. (Figure from Merrill 2023b, p. 18.)

Starting in 2020, 10 ha (25 ac) of habitat were managed at South San Mateo using a combination of vegetation thinning, dethatching and herbicide application (see Figure 12; Brehme et al. 2022, pp. 14–15). These activities intensified with additional approved herbicides and mechanical treatment methods after consultation in 2022. Following these habitat management activities, PPM activity increased in the managed areas (Brehme et al. 2023, pp. 18–21; USGS 2022, pp. 27–37). However, recent monitoring indicates PPM occupancy within the managed areas at South San Mateo has declined following conclusion of the restoration contractor’s 3-year management effort, suggesting regular vegetation management may be necessary to sustain the benefit of management efforts (Brehme 2025, pers. comm.).

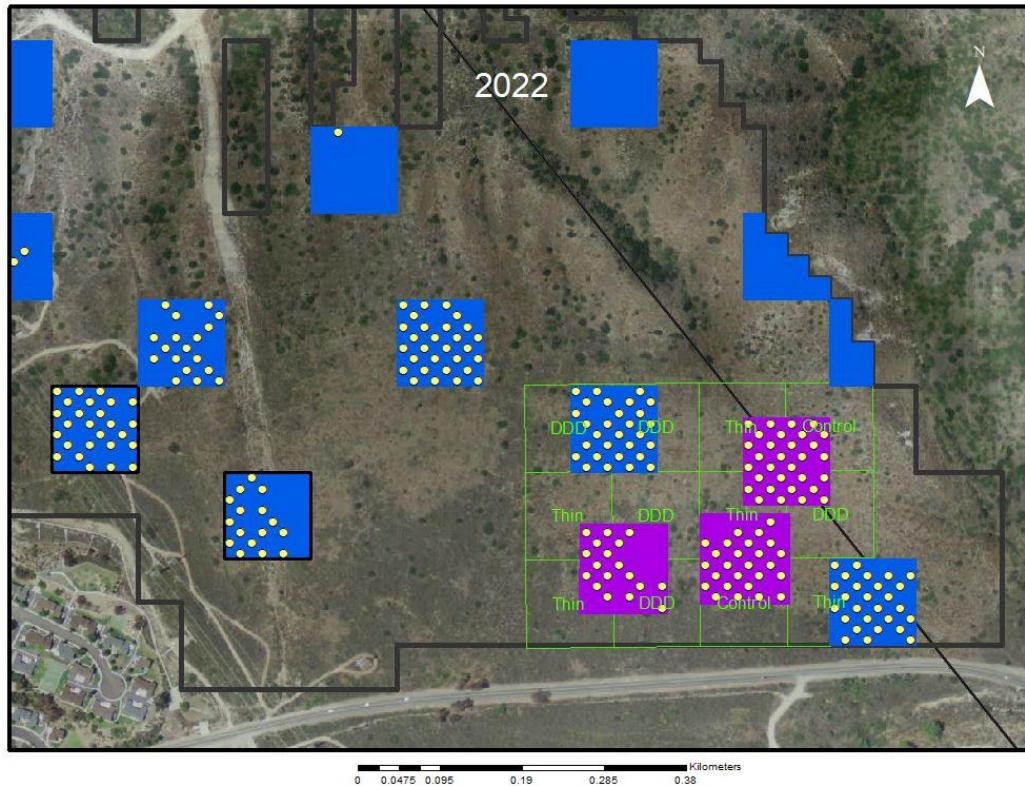


**Figure 12.** Map of South San Mateo habitat management plots in 2022. Treatments at habitat management plots (green squares) include: dead, downed duff removal (DDD), vegetation thinning (Thin), and control plots (no management). Treatment of upper left area began in 2018 and 2019, with the rest beginning in 2020. Blue squares are permanent monitoring grids where Pacific pocket mouse (PPM) were historically not detected and were newly colonized after management. Purple squares are new monitoring grids established since 2020, and yellow dots are PPM detections in 2022. (Figure from USGS 2022, p. 37.)

Similar management activities have occurred at Santa Margarita. Extensive mowing to remove vegetation in conjunction with dethatching and herbicide application in 2022 on 6 ha (15 ac) at Oscar One were followed by increased PPM presence in areas where PPM were previously undetected (Figure 13; Brehme et al. 2023, p. 19; USGS 2022, p. 11). This effort also included vegetation thinning during 2023 within an adjoining experimental 610 meter long, 2-hectare (4 ac) corridor that is intended to improve habitat connectivity between the 6-ha enhanced area in Oscar One and occupied habitat within the Edson Range training area. In 2023, native seed consisting of PPM food species was spread in islands over 2.5 ha (6 ac) of Oscar One to distribute the native species across the site while allowing for continued invasive species treatments (McNaughton 2024, pers. comm.). Within Edson Range, herbicide application to reduce cover of specific nonnative invasive plant species and anticipated native seeding on 0.6 ha (1.5 ac) is being used to support recovery from prescribed fire on more than 225 ha (556 ac) area (Figure 13; USGS 2022, p. 11).

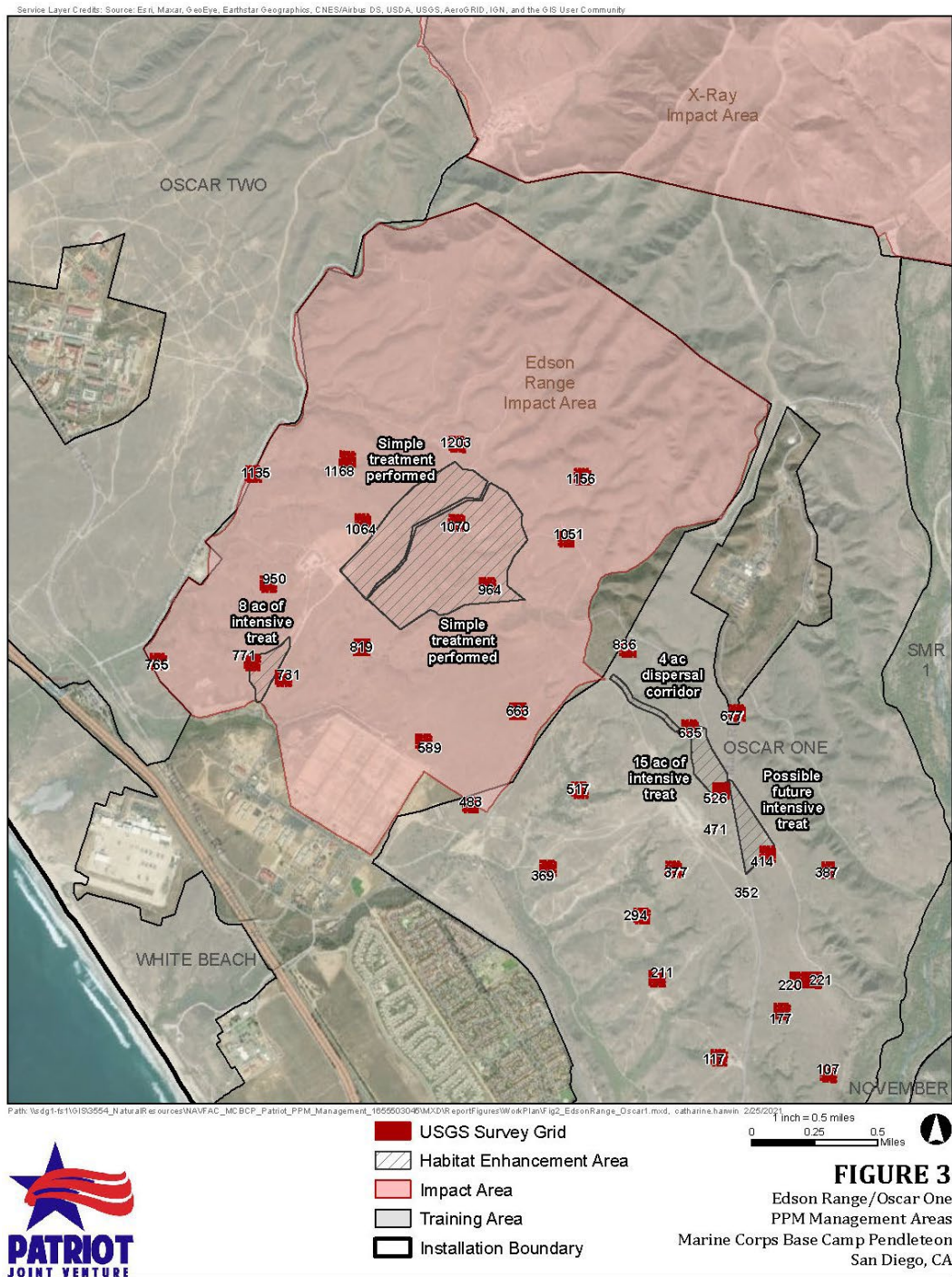


**Figure 13.** Map of the Santa Margarita habitat management areas. This includes 225 ha (556 ac) where herbicide treatment occurred and 3 ha (8 ac) that is planned to be burned in Edson Range, and a dispersal corridor (2 ha (4 ac)) that was thinned in 2023 and 6 ha (15 ac) that have been treated by dethatching and herbicide, as well as a possible additional area for treatment in Oscar One (Figure from MCBCP 2021, p. 14.)

## Climate and climate change

The range of the PPM is in a Mediterranean climatic regime with a significant maritime influence. Current models suggest that southern California will be adversely affected by global climate change through continued and worsened prolonged seasonal droughts and rainfall coming at unusual periods and in different amounts (Cayan et al. 2005, pp. 3–7, CEPA 2006, p. 33; Jennings et al. 2018, p. iii; Pierce 2004, pp. 1–33). Climate change models indicate a 4 to 9 degree Fahrenheit (2 to 4 degrees Celsius) increase in average temperature for the San Diego Area of southern California by the end of the century (Jennings et al. 2018, p. 9), with inland changes higher than along the coast (Cayan et al. 2012, p. 7). By 2070, a 10 to 37 percent decrease in annual precipitation is predicted (Jennings et al. 2018, p. iii; Kalansky et al. 2018, p. 10; PRBO 2011, p. 40), though other models predict little to no change in annual precipitation (Cayan et al. 2008, p. S26; Field et al. 1999, pp. 8–9), leaving predictions of short and long-term climatic conditions for southern coastal California uncertain. It is unknown at this time if climate change in California will result in a warmer trend with localized drying, higher precipitation events, and/or more frequent El Niño or La Niña events (Pierce 2004, p. 31). Drought has been frequent in the past 20 years (Figure 14), while other years have experienced high winter rainfall (Figure 15).

**Weekly Percentage of San Luis Rey-Escondido Watershed Experiencing Drought, 2000–2022**

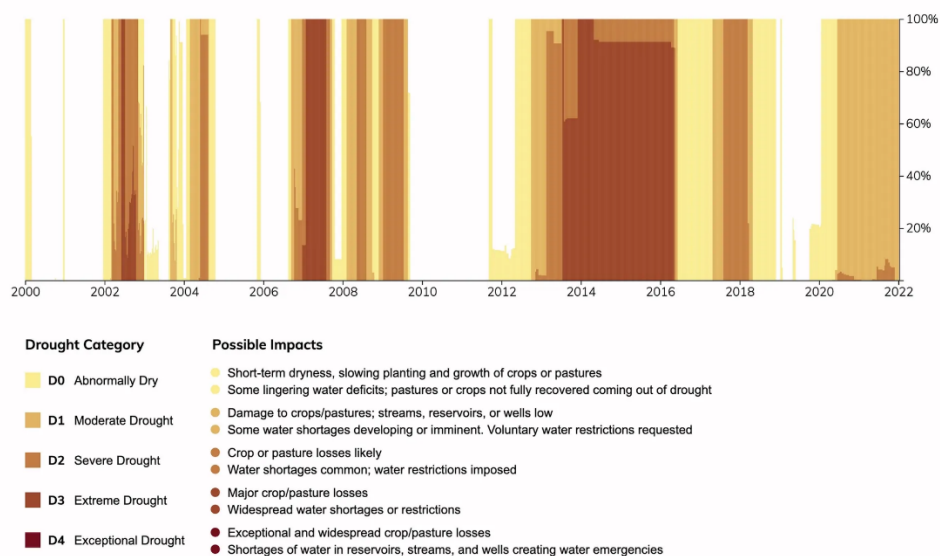


**Figure 14.** Weekly portions of the San Luis Rey-Escondido Watershed, which contains Carlsbad, CA, classified as experiencing drought by drought category.

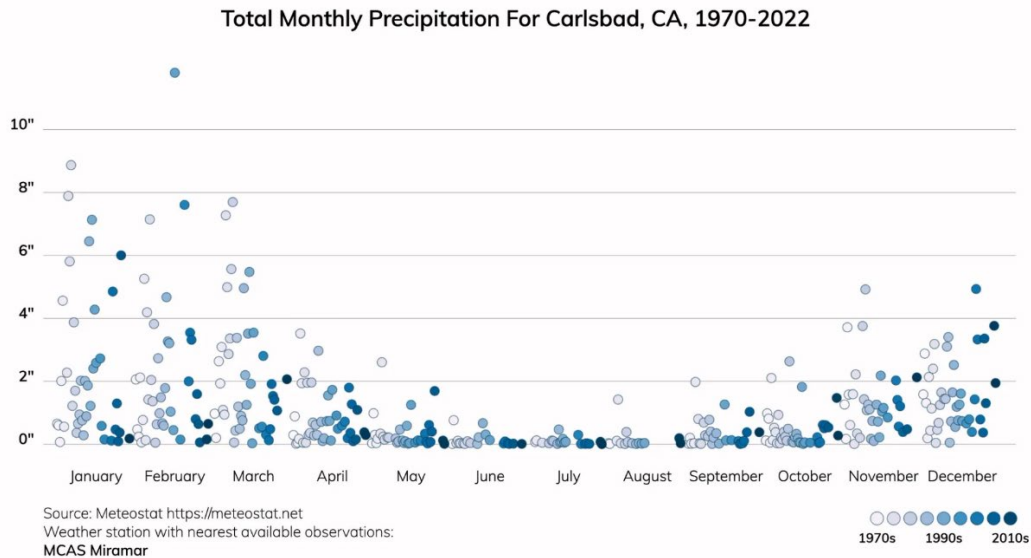


**Figure 15.** Total monthly precipitation from the 1970s through the 2010s for Carlsbad, CA.

Low-level temperature inversions are common along the California coast, and these inversions form low cloud cover (fog), otherwise known as the marine layer, which has a strong influence on coastal ecosystems. Although the area has a short rainy season, the presence of fog during the summer months helps to reduce drought stress for many plant species through shading and fog drip, and many species are restricted to this fog belt (Fischer et al. 2009, p. 783; Halvorson et al. 1988, p. 111). Thus, fog could help buffer species from extinction brought on by climatic change, as evidenced by the elevated levels of endemism along the coast of Baja California (Vanderplank 2014, p. 5). However, coastal fog has been decreasing in southern California in recent decades, possibly due to urbanization or climate change (Johnstone and Dawson 2010, p. 4537; LaDochy and Witiw 2012, p. 1157; Williams et al. 2015, p. 1527), and coastal cloud cover and fog are poorly addressed in climate change models (Qu et al. 2014, pp. 2603–2605).

Warming projections in California, particularly the possibility that the interior will experience greater warming than the coast (Cayan et al. 2012, p. 7), suggest that the fate of coastal fog is uncertain (Field et al. 1999, pp. 21–22; Lebassi-Habtezion et al. 2011, pp. 8–11). Iacobellis et al. (2010, p. 129), however, showed an increasing trend in the strength of low-level temperature inversions, which suggests that the marine layer is likely to persist and may even increase. Recent work examining projected changes in solar radiation and cloud albedo show projected increases in cloud albedo during the dry season (July to Sept) and decreases during the wet season (Nov to Dec, Mar to Apr) (Clemesha 2020, entire). The summer projections mean an increase in fog and low clouds, and the decreases in the winter likely reflect a decrease in a combination of precipitation and fog (Clemesha 2020, entire). Such a scenario would moderate the effects of climate change. Dry season low clouds and fog are particularly important to plant growth, survival and population dynamics in arid systems through both a reduction in evapotranspiration demand and potentially water deposition (Corbin et al. 2005, p. 511, Johnstone and Dawson 2010, p. 4533, Oladi et al. 2017, p. 94).

Predicting impacts to PPM due to climate change are further complicated by the timing, frequency, and amount of increased or decreased rainfall, which can impact soil moisture, vegetation cover, and seed availability for PPM (Brehme et al. 2023b, pp. 7–8). Drought may benefit PPM habitat by removing or reducing shallow-rooted nonnative grasses, increasing native forb seed banks, and reducing competition from less drought resilient small mammal competitors, such as western harvest mice (Chock et al. 2018, pp. 201–202; LaForgia et al. 2018, pp. 900–901; Prugh et al. 2018, entire). During a prolonged, 5-year drought from 2012 to 2016, the area occupied by PPM within MCBCP increased 78 percent, from 77 to 136 ha (190 to 336 ac). However, in years of poor food availability (e.g., drought) PPM may delay or forego breeding, resulting in little to no recruitment and population decline (Brehme et al. 2022, p. 13; USFWS 2008, pp. 28–29). In 2021, area occupied by PPM at Santa Margarita decreased 44 percent from 138 to 77 ha (341 to 190 ac) in conjunction with low rainfall and plant productivity in the spring (Brehme et al. 2021, pp. 11–12).

While high rainfall may result in increased seed resources, high rainfall may also negatively impact PPM by promoting grass and forb growth which reduces open ground to unsuitably low levels needed for foraging, by spoiling seed caches, or by reducing survivorship by flooding burrows and negatively affecting the ability of PPM to retain body heat when below ground and in torpor (Brehme et al. 2023b, p. 8; Valone et al. 1995, pp. 431–432). PPM numbers severely declined at Oscar One following the exceptionally wet winter of 2004–2005 (USFWS 2010, pp. 30–32). In 2017, during another above average period of winter rainfall over one-third of the PPM population was lost in a single year. Although Brehme et al. (2023b, pp. 7–8) found rainfall was not a strong direct predictor of PPM occupancy dynamics, increased rainfall was associated with a greater probability of extinction in South San Mateo. Timing, frequency, and amount of rainfall directly impact soil moisture, vegetation cover, and seed availability that can directly impact PPM.

Rainfall can impact fire, as well. Wetter conditions in the winter and early spring can lead to more plant growth early in the season which can provide more fuel for fire later. While wetter late springs and falls can prevent the fuel from drying out enough to burn (Lawson 2019, pers. comm.), wetter weather during the typical dry and dormant season in late spring and summer favors nonnative vegetation from more humid climates, including nonnative grasses and Sahara mustard (*Brassica tournefortii*). Prescribed fires have not been possible to implement within the Santa Margarita population recently due to late spring rains causing high fuel moisture levels that are too high to carry fire (Zych 2024, pers. comm.). Due to the bare ground and sandy soil requirements for PPM populations, most PPM habitats (occupied and potential) also have high erosion potential and may be more vulnerable to erosion during heavy rains than other coastal sage scrub communities.

While sea level rise has the potential to flood coastal areas, little to no inundation of coastlines is projected to occur within the range of the PPM until past the end of the century (NOAA 2023, entire). Unusually high tides, storm surges, and rainfall have eroded bluffs protecting Dana Point (Farzan 2024, entire) and may have impacted historical portions of the range. Sea level rise may have secondary consequences by inundating potential receiver sites for translocations, such as within the Tijuana River Valley, and causing human populations to retreat into remaining upland habitat areas.

Although the impacts of predicted future climate change to PPM remain unclear and predictions of climatic conditions and other physical forces in the region are uncertain, observed population fluctuations associated with periods of drought and heavy rainfall, and the potential for vegetation type conversion associated with high fire frequencies, suggest climate change is an important issue that has potential to result in significant effects to PPM and its habitat. Because PPM populations have endured periods of drought and heavy rainfall over the last 20 years and the impacts from climate change are anticipated to increase in severity over time, we cannot project the impacts to PPM from climate change over the short term (e.g., 10 to 20 years). Over the long term, projections of prolonged seasonal droughts and increased variability in the frequency, timing, and amount of rainfall suggest that climate change is likely to increase variability in PPM population dynamics and habitat conditions that will increase the risk of extirpation of the individual populations during more frequent or severe population declines.

### Conservation Breeding and Translocation

Because no new PPM populations have been discovered since 1995 (although populations have been known to expand), and attempts to locate enough animals to support a translocation were unsuccessful (e.g., 50 individuals), a PPM conservation breeding program was initiated in 2012 with the San Diego Zoo Institute for Conservation Research, now the San Diego Zoo Wildlife Alliance (SDZWA), to create additional populations of PPM as called for in the PPM Recovery Plan (USFWS 1998, p. 35; USFWS 2020b pp. 8–9). The primary objective of the conservation breeding program is to: “use non-invasive captive breeding techniques to increase numbers of PPM, prepare naïve (i.e., captive reared) animals for reintroduction to the wild, and reintroduce them to sites within their historical range from which they have been extirpated”. Long-term goals include increasing the size and viability of extant populations and establishing additional wild populations to meet recovery goals described in the Service’s “Recovery Plan for the Pacific Pocket Mouse (*Perognathus longimembris pacificus*)” (USFWS 1998, pp. 33–36; USFWS 2011, p. 2).

The initial strategy set forth in the genetic management plan for the captive population (Miller and Shier 2011, p. 2) was to collect 10 breeding individuals from each of the extant populations and interbreed them as founders for the captive population (USFWS 2020b, pp. 8–9). However, guidelines were established to collect no more than 10 percent of adult mice from a population in any one year to minimize the risk of harm to the source populations (Shier et al. 2022, pp. 2–3). A total of 39 individuals were collected between 2012 and 2019 as founders for the captive population (11, 14, and 14 individuals, respectively, from the Dana Point, South San Mateo, and Santa Margarita populations) (USFWS 2020b, pp. 8–9). Based on evidence of genetic differentiation among the populations (Swei et al. 2003, pp. 505–508), behavioral observations of cross population animal pairings were also made prior to breeding attempts to look for evidence of reproductive isolation; no within population mate preference was found (Shier et al. 2022, p. 3). As of 2023, 49 animals have been removed from the extant populations for use in the captive breeding facility (Shier 2024, pers. comm.; Miller 2024, pers. comm.). From 2013 through 2022, captive production has successfully produced 518 mice (Shier et al. 2022, p. 2). In addition to providing individuals for reintroduction, the conservation breeding program has studied PPM genetics, reproduction, behavior, and diet preference (King et al. 2018, p. 25; Shier and King 2017, pp. 9–17; USFWS 2020b, pp. 8–9).

A population viability assessment (PVA) for the captive population indicated that retention of genetic diversity within the captive population was higher when individuals were released from the captive population and reintroduced into the wild because imposition of a carrying capacity as determined by the size of the breeding facility reduced the reproductive potential of the captive population. Model results suggested that demographic stability of the captive population was likely to be more of a challenge to achieve than the retention of genetic diversity (Ivy 2014, p. 6). At the beginning of 2024, there were approximately 210 mice in the captive population, which is near capacity (SDZWA PPM Working Group presentation 2024, pp. 5, 58).

While recent genetic work indicates that Dana Point and South San Mateo would likely benefit from genetic rescue and outbreeding (see Genetics, Section 2.5), genetic rescue has not yet been attempted in either of these populations.

### *Translocations*

Translocations of PPM into unoccupied habitat were initiated in 2016 at Laguna Coast Wilderness Park (Laguna Coast) in Orange County, with the release of 50 PPM from the conservation breeding facility (Table 2) (King et al. 2018, p. 14). Following this release, there was no apparent over-winter survivorship, prompting a supplementary release of 49 mice at the same site (Water Tank 1) in 2017 (King et al. 2018, p. 18; Shier and King 2018, pp. 22, 39). These animals successfully bred following their release (39 young of the year documented), and a combination of released and wild born individuals survived overwinter. Following the detection of 37 mice at the site in April of 2018, a predator exclusion fence surrounding this site was removed and reinstalled 100 yards to the south around a second release site (Water Tank 2).

In May of 2018, a cohort of 28 captively born PPM were released at the second site. During post-release monitoring performed at both sites in August of 2018, just four individuals were confirmed to remain at Water Tank 1, and 17 PPM were found at Water Tank 2, one of which was a wild born female. Following the wet winter of 2018/2019, post-release monitoring was unable to detect any PPM remaining at Water Tank 1, and just one PPM was confirmed to survive over-winter at Water Tank 2.

In May of 2019, a supplementary release of 29 captively bred PPM was performed at Water Tank 2. By August of 2019, 10 PPM were confirmed at Water Tank 2, but there was no evidence of successful reproduction within this release cohort. In May of 2020, another 35 PPM were released and these individuals successfully reproduced. With good overwinter survivorship during 2020 and 2021, and good reproduction during the summers of 2021 and 2022, the population appeared to be beginning to self-regulate (King et al. 2022, pp. 10–11). However, during the wet winter of 2022 to 2023, the population again experienced low overwinter survivorship indicating the population is still not self-sustaining (Miller 2024, pers. comm.).

In summary, the current translocation effort at Laguna Coast has documented successful reproduction of released animals, and both captive and wild born PPM have survived overwinter. However, due to very low to no overwinter survivorship during four of the 7 years that establishment of this population has been attempted, it remains uncertain whether a self-sustaining population can be established at this location.

To improve reintroduction outcomes, stakeholders involved in PPM recovery developed a systematic and repeatable process to guide the selection of additional receiver sites for PPM translocations (Chock and Shier 2020, entire). This process uses field data and expert input to score and rank sites based on a list of variables related to their Strengths, Weaknesses, Opportunities, and Threats (SWOT) (USFWS 2020b, pp. 9–10; White et al. 2015, entire). In 2019 and 2020, seven sites including the release site at Laguna Coast were assessed and ranked as potential translocation receiver sites using the SWOT analysis (Figure 16) (Chock et al. 2022, entire). Among the major challenges identified during this process are securing landowner permissions (so far denied at two of the largest and more promising sites, El Segundo Dunes (termed “LAX”) and Tijuana Estuary) and the need to perform management to enhance habitat for PPM prior to performing translocations (Chock et al. 2022, p. 5). Laguna Coast, the current translocation site, had the highest overall score for quality, likely because it was the site with the least significant threats (Figure 16, Figure 17). Laguna Coast had a favorable threat score (meaning there were fewer threats associated with a PPM translocation than at other sites), while Tijuana Estuary, LAX, and James Dilley Greenbelt Preserve (Dilley) all scored high in the strength category (which measures the inherent biological attributes or qualities that make a site suitable for translocation), suggesting these sites had more positive inherent habitat attributes than Laguna Coast (Chock et al. 2022, p. 2) (Figure 17). Translocation efforts at the Dilley site are early in the planning stage, with plans to release captive-bred mice at this location within the next several years (PPM SSA Expert Team 2024a).

More recently, the MCBCP assessed the feasibility of translocating PPM to several sites on MCBCP that were not evaluated as part of the SWOT process. Among the sites considered are three sites evaluated as part of a formal translocation feasibility study (Wire Mountain, Cocklebur Sensitive Area, and Vernal Pool Restoration Area) (GSRC and SDZWA 2023, entire). Also being considered is the formerly occupied North San Mateo site, where PPM are now presumed extirpated. Of the three sites considered in the feasibility study, based on soil and vegetation mapping, Wire Mountain was identified as having the largest area (i.e., 24 to 32 ha (60 to 78 ac) of potentially suitable habitat where the least amount of habitat restoration would be required. The Vernal Pool Restoration Area and Cocklebur Sensitive Area, each have fewer than 4 ha (10 ac) of habitat available, and considerable restoration would be required to make these sites suitable for PPM (GSRC and SDZWA 2023, p. 50). Based on the results of the feasibility study, the MCBCP contracted with SDZWA to prepare and implement a PPM translocation at Wire Mountain (Shier et al. 2024b, entire). SDZWA released 90 captively bred mice within a roughly 0.9 ha (2.2 ac) area at the Wire Mountain site in May and June of 2024, with around 120 mice documented (released and wild born) within the receiver site in September of 2024 (Shier et al. 2025, p.2) and at least 44 mice confirmed as having survived overwinter in April of 2025 (D. Shier, pers. comm. April 14, 2025). Supplemental releases from the conservation breeding facility and habitat management are proposed to be continued at this site as necessary (Miller 2024, pers. comm.).

The MCBCP is also proposing to reintroduce PPM to North San Mateo in 2026, where the subspecies has not been confirmed since 2003. The USGS has prepared a draft reintroduction plan (Edgarian et al. 2023, entire) which it plans to implement on behalf of the MCBCP. This plan includes a proposal to perform a wild-to-wild transfer of animals from South San Mateo. The USFWS is currently reviewing the plan to make sure that the presumed cause(s) for extirpation of the North San Mateo population has been adequately addressed and is also

weighing the potential benefits of performing a wild-to-wild versus captive-to-wild transfer. A paired release of wild caught and captively bred animals is also being considered to study whether translocation success can be improved using wild-sourced founders. Particular concerns for a reintroduction at North San Mateo are the ability to adequately manage anthropogenic habitat disturbances, recreational use, Argentine ants and other threats from the nearby development (Miller 2024, pers. comm.).

**Table 2.** Summary of Pacific pocket mouse captive-bred reintroduction attempts at the Laguna Coast Wilderness Park (Laguna Coast) in Orange County and associated factors that may influence success. (Table from King et al. 2022, p. 4).

| Year of Release | Date   | Fence | Pre-reintroduction precipitation (Oct-Mar) | MNA* month before release | No. released | Age (yr) | No. offspring | MNA end of active season | Overwinter MNA (Estimated Survival %) | Fence management                              | Predicted Influence on Outcomes                                                                                                                                                                                                                                                                                            |
|-----------------|--------|-------|--------------------------------------------|---------------------------|--------------|----------|---------------|--------------------------|---------------------------------------|-----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2016            | Jun 13 | WT1   | Low (6.1 in)                               | 0                         | 50           | 1-4      | 0             | 11                       | 0                                     | Fence maintained                              | 1. Low precipitation pre-reintroduction and late reintroduction date: ↓ Reproduction<br>2. No reproduction and high precipitation post-reintroduction: ↓ Overwinter survival                                                                                                                                               |
| 2017            | May 9  | WT1   | High (29.1 in)                             | 0                         | 25           | 1-3      | 60            | 79                       | 65.5%                                 | 5 holes cut in Oct, removed in spring of 2018 | 1. High precipitation pre-reintroduction and early reintroduction date of May cohort: ↑ Reproduction<br>2. High reproduction by May cohort and low precipitation post-reintroduction: ↑ Overwinter survival<br>3. Increased heterospecific densities through holes cut in fence followed by removal: ↓ Overwinter survival |
| 2017            | Jul 5  | WT1   | High (29.1 in)                             | 22                        | 24           | YOY-3    | 0             | 79                       | 65.5%                                 | 5 holes cut in Oct, removed in spring of 2018 | 4. High precipitation pre-reintroduction and early reintroduction date of May cohort: ↑ Reproduction<br>5. High reproduction by May cohort and low precipitation post-reintroduction: ↑ Overwinter survival<br>6. Increased heterospecific densities through holes cut in fence followed by removal: ↓ Overwinter survival |
| 2018            | May 24 | WT2   | Low (4.7 in)                               | 0                         | 28           | YOY-2    | 1             | 17                       | 5.9%                                  | Fence maintained                              | 1. Low precipitation pre-reintroduction and late reintroduction date: ↓ Reproduction<br>2. Low reproduction and high precipitation post-reintroduction: ↓ Overwinter survival                                                                                                                                              |
| 2019            | May 30 | WT2   | High (31.2 in)                             | 1                         | 29           | 1-3      | 0             | 10                       | 0%                                    | Fence maintained                              | 1. Late reintroduction date: ↓ Reproduction<br>2. No reproduction and high precipitation post-reintroduction (26.3 in): ↓ Overwinter survival                                                                                                                                                                              |
| 2020            | May 7  | WT2   | High (26.3 in)                             | 0                         | 35           | 1-4**    | 64            | 71                       | 87.7%                                 | Fence maintained                              | 1. High precipitation pre-reintroduction and early reintroduction date: ↑ Reproduction<br>2. High reproduction and low precipitation post-reintroduction: ↑ Overwinter survival                                                                                                                                            |

|             |           |           |               |    |    |     |    |    |       |                                |                                                                                                                                                                                   |
|-------------|-----------|-----------|---------------|----|----|-----|----|----|-------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2021**<br>* | May<br>10 | WT2/3     | Low (4.1 in)  | 57 | 9  | 3   | 47 | 71 | 52.3% | Opened<br>barrier b/w<br>WT2/3 | 1. PPM on site: ↑ Reproduction<br>2. Low precipitation preceding emergence: ↓ Reproduction                                                                                        |
| 2022        | May<br>2  | WT2/3     | Low (6.75 in) | 34 | 27 | 1-3 | 70 | 54 | 9.3%  | Fence<br>maintained            | 1. PPM on site: ↑ Reproduction<br>2. Low precipitation preceding emergence: ↓ Reproduction<br>3. Increased heterospecific densities: ↓ Survival?                                  |
| 2023        | May<br>1  | WT 4      |               | 1  | 50 | 1-3 | 73 | 67 | TBD   | Fence<br>maintained            | 1. High precipitation pre-reintroduction and early reintroduction date: ↑ Reproduction<br>2. High reproduction and high precipitation post-reintroduction: ↓ Overwinter survival? |
| 2023        | Jun<br>27 | WT<br>2/3 |               | 5  | 20 | YOY | 39 | 33 |       | Fence<br>maintained            | 1. High precipitation pre-reintroduction and early reintroduction date: ↑ Reproduction<br>2. High reproduction and high precipitation post-reintroduction: ↓ Overwinter survival? |

\*Minimal Number Alive,

\*\*Five 4-year-old mice were included in the reintroduction cohort as a “welfare release” because their genetics were represented in the captive population,

\*\*\*With high overwinter survival in 2020/21 ( $\geq 31$ ) we limited reintroduction in 2021 to a welfare release in which nine PPM 3-year-old mice ( $\geq 33$  months of age) were reintroduced.

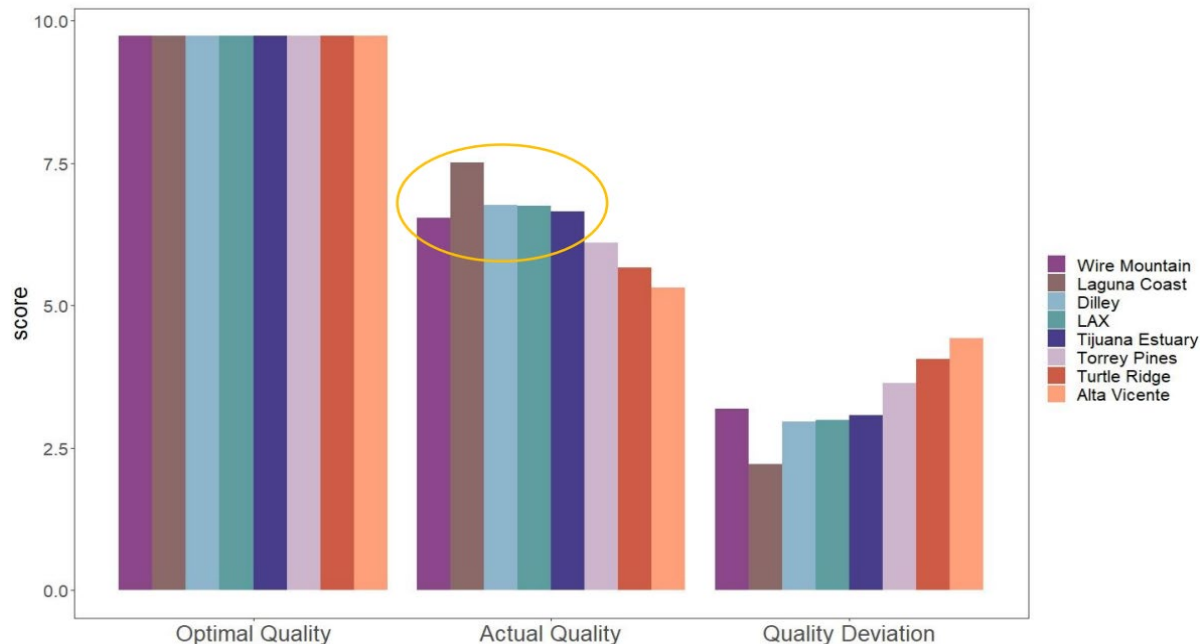


**Figure 16.** The overall quality of all 7 sites from the SWOT analysis, plus a later SWOT analysis for Wire Mountain. The Optimal Quality of all sites was the same as they were scored on the same rubric. The overall Actual Quality and Quality Deviation are shown for each site (Figure from Chock 2024, p. 8.)

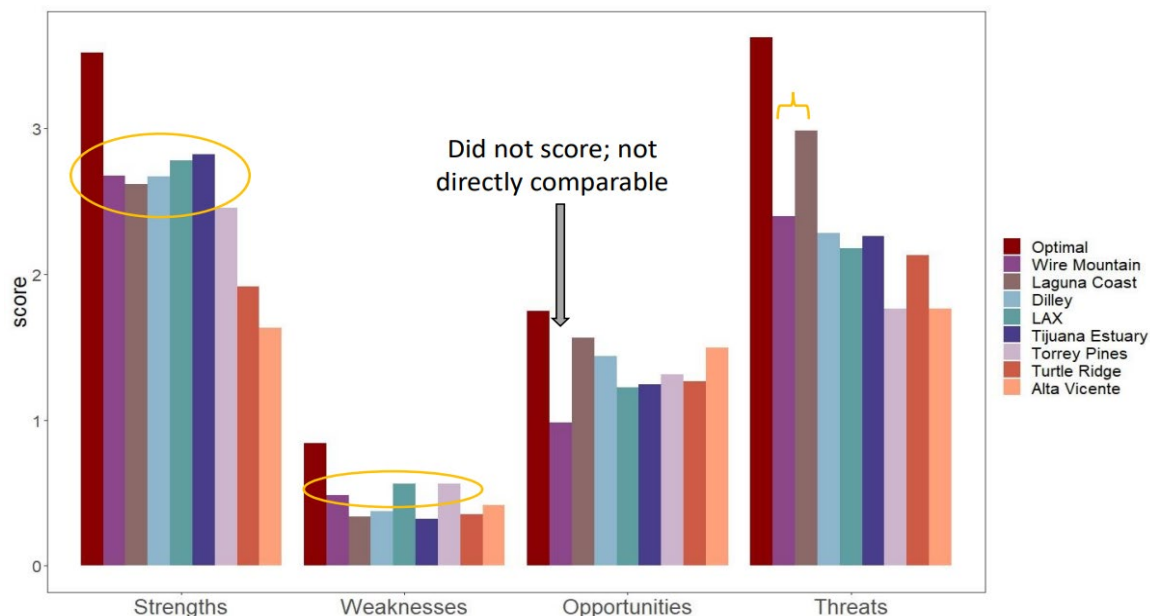


**Figure 17.** Overall SWOT rank scores for all 8 sites. Optimal score indicates the highest possible score in each category. Higher scores are better in each category (more strengths, fewer weaknesses, fewer threats, etc.). Strengths are the inherent positive attributes or qualities of a given site, weaknesses are the risks of losing those attributes due to intrinsic factors, opportunities encompass human dimensions and the potential for sustainability and optimization of attributes, and threats are the potential decline or loss of attributes to extrinsic or anthropogenic factors (Figure from Chock 2024, p. 9).

In summary, the conservation breeding program has been successful at producing mice, and funding has been secured for this program until at least July of 2027. Starting in 2016, animals produced by the conservation breeding program have been released on an annual basis at Laguna Coast, with the goal of creating a fourth wild PPM population. While the released animals have exhibited good short-term survivorship and reproduction following their release, this population is not yet self-sustaining due to poor overwinter survivorship, particularly during years of high rainfall. Three additional translocation efforts, one initiated in 2024 at Wire Mountain, one planned for 2026 at North San Mateo, and one in the early planning stages at the James Dilley Preserve, should help to inform whether the lack of success at Laguna Coast is related to poor habitat quality or other factors. At present, it is not possible to predict whether future translocation efforts are likely to be successful.

#### **4.6 Summary of Factors Influencing Viability**

The PPM is being impacted from factors stemming almost exclusively from land use activities that have reduced census and effective population sizes to dangerously low levels, eliminated historical connectivity among populations, and made the remaining populations highly vulnerable to stochastic environmental and demographic threats as well as inbreeding depression. Current land use activities that could have population level impacts include recreation and military training. The threat of invasion of PPM habitat by nonnative plants, particularly nonnative grasses, stems from historical and ongoing land use practices and represents one of the largest threats to the subspecies. Inbreeding depression is currently a threat to the Dana Point and South San Mateo populations, and the magnitude of this threat appears to currently be most significant at Dana Point. Climate change is likely to cause more variation in the timing and intensity of precipitation, potentially causing an increase in the severity of flooding, wet winters, and drought, which have been associated with PPM population fluctuations, although the timeframe for an appreciable change in the magnitude of this variation relative to what PPM has already endured is uncertain and we anticipate will be most appreciable in the latter half of the coming century (e.g., 50-100 years). While disease, predation, and competition have the potential to impact populations, the magnitude of these threats is currently believed to be relatively low.

There has been a dramatic loss of PPM habitat in association with urbanization and development, which has reduced the size of the extant populations and caused a loss of connectivity among them, resulting in the persistence of just three isolated, small, and genetically depauperate populations. Loss of connectivity among the populations prevents opportunities for demographic and genetic interchange, leaving them at risk of developing inbreeding depression, continued loss of genetic variation, and increased risk of impacts from random stochastic and unforeseen catastrophic events. Historically, more expansive habitat and connectivity among the populations would have allowed them to better withstand normal fluctuations in abundance and allow harder hit populations to recover via immigration from neighboring populations.

Within the extant populations, the amount and quality of available habitat fluctuates annually in association with density of shrub cover, forb cover, and presence of nonnative grasses. At Dana Point, there is little nonnative grass cover, and habitat suitability appears to be mostly influenced by habitat senescence that leads to dense shrub cover and low cover of forbs. On MCBP, nonnative grasses are most prevalent within the habitat of the Santa Margarita

population, where the presence of clay loam soils over significant portions of the management unit (e.g. Edson Range) in combination with disturbance from fire and military training has facilitated nonnative grass invasion (Miller 2024, pers. comm.). Here availability of suitable habitat is largely influenced by the presence and amount of nonnative grass cover, which is largely determined by the timing and amount of rainfall in a given year, and time since the last fire (Figure 18) or other management treatments. South San Mateo, like Dana Point, has well drained sandy soils and appears to be less prone to nonnative grass invasion, though nonnative grasses are prevalent across portions of this site. Thus, at South San Mateo availability of suitable habitat varies in association with both habitat senescence and the germination and density of nonnative grasses.

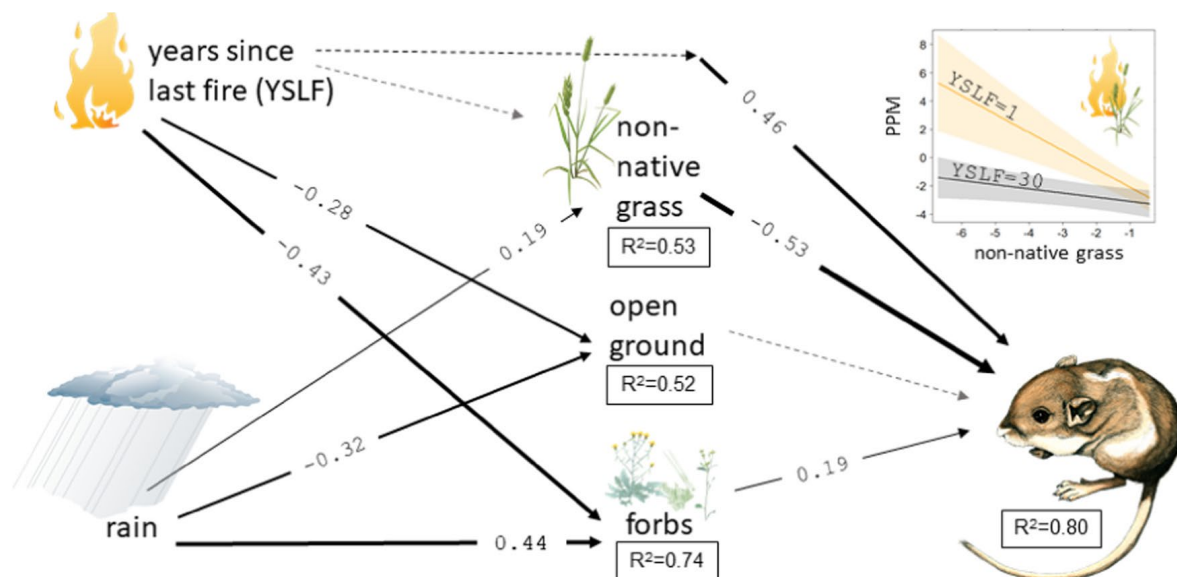


**Figure 18.** Path model showing relationships between rainfall and the years since the last fire (YSLF) on three habitat variables that predict Pacific pocket mouse (PPM) occupancy at Camp Pendleton. Arrow size is scaled to the magnitude of standardized coefficients and dashed arrows represent pathways that were non-significant. Coefficients for fire are negative, meaning that the cover of open ground and forbs decreases as the years since the last fire increases. The conditional pseudo  $R^2$  for each is displayed in the boxes, which is the level of variance explained by both fixed and random effects. Inset figure depicts the interaction between years since the last fire (YSLF) and the log transformed nonnative grass cover on the logit transformed proportion of PPM in track tube grids, which is higher at low nonnative grass cover when YSLF was more recent. (Figure from Brehme et al. 2023b, p. 6.)

Habitat management, both through prescribed fire and through mechanical means, such as thinning and removal of downed and dead wood, has been shown to be effective in both increasing PPM occupancy as well as colonization of previously unoccupied portions of the managed sites (Adsit-Morris 2024, entire). However, large-scale, targeted habitat management has only begun in the last few years, so the ability of these efforts to maintain and sustain adequate habitat and ability to fund these efforts over time are unknown. Continued habitat management on a regular or intermittent basis is likely necessary to maintain quality habitat over the long term at each of the extant populations. Habitat management projects at all three native sites may have helped to offset population losses that were anticipated following heavy rainfall events in the winter of 2022 to 2023 (PPM SSA Expert Team 2024b).

While the conservation breeding program has been successful at producing mice and serves as an insurance population in the case of catastrophic impacts to each population, this program currently only has assured funding until July of 2027. Some additional funding to support translocation efforts has been secured as mitigation for utility line maintenance projects on Camp Pendleton, but continued funding for captive breeding is uncertain. Funding availability will likely depend on the success of current and planned translocation efforts and if the captive population is needed to support genetic management efforts. Results from the current population creation efforts have led to important refinements of translocation methods but due to the recency of implementation and mixed results from these efforts it remains to be determined whether current and future translocations and reintroductions will become self-sustaining over time.

## SECTION 5 – CURRENT CONDITION

In this section, we consider the PPM's current distribution and abundance as a measure of the availability of resources and other subspecies' needs as described in the previous sections. We characterize the current condition of PPM in terms of its current resiliency, representation, and redundancy.

### 5.1 Populations

To assess the current condition of the PPM, we used the best scientific and commercial data available to analyze and describe past and ongoing changes in the species' habitat, demographic parameters, and distribution at the population scale. The PPM currently exists in three recognized extant populations at Dana Point, South San Mateo, and Santa Margarita that are isolated from one another. Each population is assumed to support genetic connectivity within each population but no immigration or emigration is apparent to support genetic or demographic interchange among populations. A conservation breeding program was also initiated in 2012 to serve as a source of animals for population creation efforts. While long term funding of this program has not been assured, it continues to act as a reservoir of animals that can be used to create new populations and/or to support genetic rescue. Mice from the conservation breeding program have also been introduced to two sites—Laguna Coast and Wire Mountain—where attempts are being made to establish additional populations in support of subspecies recovery.

### 5.2 Methods

To determine the current condition of the PPM, we first summarize the existing conditions at each of the extant populations and determine the resiliency of each. We assess the condition of each extant population using both quantitative and qualitative metrics, with resulting resiliency characterizations being comparative among populations. Though it is premature to regard the introduced populations as self-sustaining, we provide a brief summary of the current status of each of these efforts and how they are contributing to the current resiliency, representation, and redundancy of the subspecies.

For the extant populations, the main indicators of population resiliency are population size and genetic health. Larger populations are more resilient than small populations, and genetic diversity is needed to maintain reproductive fitness, and therefore resiliency, over time. Inbreeding depression and loss of genetic diversity are well known to increase the risk of population extirpation (Frankham 2005, entire).

Population monitoring at all three populations (performed annually in 60 monitoring grids distributed across the MCBCP populations and a monitoring grid that overlays all of the suitable habitat at Dana Point) provides an annual estimate of area occupied by the subspecies, which can be used as a proxy for demographic information, specifically population size. At MCBCP, we use the estimated area occupied instead of abundance estimates from Mackenzie and Bratt (2023, entire); while the two generally align, area occupied is the metric that is routinely monitored, and populations of this subspecies can fluctuate greatly within and among years. Area occupied is also the parameter that is routinely monitored at Dana Point.

To assess the genetic health of each population, we use the contemporary effective population size from Wilder et al., (2025, entire), which uses multiple samples to estimate a contemporary effective population size, rather than the effective population size estimates from Shier et al. (2022, entire), which are best suited for single sample analyses. Both studies found contemporary effective population sizes within all extant populations are low and cause for concern. We use criteria from Soule (1980, pp. 151–169), Franklin (1980, pp. 135–149), and Frankham et al. (2014, entire) to define thresholds of extirpation risk based on effective population size (see below).

Additionally, we consider existing threats and stressors to each population, amount of potential area available for population expansion, population trends, and habitat management activities and how those different metrics relate to and impact average occupied habitat and effective population sizes.

We characterize the following metrics and assumptions to assess the current condition of each population. We consider average area of occupied habitat and contemporary effective population size to be the primary drivers of current population resiliency. We use the remaining metrics (available habitat, range of occupied habitat, population trends, threats/stressors, habitat and habitat management) as additional factors with potential to affect population resiliency and help explain extirpation risk.

#### **Primary drivers of population resiliency:**

- **Average occupied habitat:** The average area occupied by the subspecies over the last 5 years (2019 to 2023; see Table 1). We assume that area occupied is a proxy for population size. Although the subspecies can fluctuate in population size annually, average habitat area occupied over the past 5 years provides a reasonable indicator of the current demographic population size. We also include a longer-term average since 2012 (see Table 1). To assess population resiliency, we group area occupied into four bins: <50 ha, 50 to 100 ha, 100 to 200 ha, and >200 ha.
- **Genetic health (effective population size):** from Wilder et al. (2025, p. 835). Contemporary estimates of effective population size reflect the ongoing impacts of genetic drift. We assume this indicates the genetic stability of each population and potential for further loss of heterozygosity (e.g., a low effective population size indicates a higher chance of inbreeding depression, which can reduce overall survivorship and the ability of a population to respond to changing environmental conditions). As general guidance, Frankham et al. (2014, entire) suggest  $N_e \geq 100$  is sufficient for minimizing inbreeding depression in the short term (i.e., over 5 generations) and  $N_e \geq 1,000$  is needed to maintain evolutionary potential into the future. Others (Hoban et al. 2020, entire) suggest applying the less conservative 50/500 rule (Soule 1980, pp.151–169 : Franklin 1980, pp. 135–149) for identifying risks from inbreeding depression and genetic erosion. For assessing population resiliency, we use  $N_e$  values of  $N_e \leq 50$ ,  $N_e$  between 50 and 100, and  $N_e \geq 100$  to indicate decreasing levels of extirpation risk and an increasing likelihood of population persistence. For our assessment of representation and the ability of individual populations to retain long-term adaptive capacity, we use  $N_e \geq 500$  as a threshold but note the more conservative  $N_e \geq 1,000$  threshold may be more appropriate for assessing long term adaptive capacity of the subspecies, assuming

gene flow can be restored among populations (e.g., via genetic rescue). Note also that contemporary metrics of effective population size are not indicative of overall standing genetic diversity, but increasing effective population size reduces the likelihood of developing inbreeding depression and continued loss of genetic diversity. Finally, we consider if there is evidence of genetic degradation within each population based on the literature (see Section 2.5).

#### **Additional supporting metrics:**

- **Available habitat/Management unit (i.e., total habitat quantity):** The area assumed to be potential habitat at MCBCP, defined by USGS in Brehme et al. (2023a, pp. 3–7), and the remaining area at Dana Point that has been conserved as natural open space. While Brehme et al. (2023a, pp. 3–7) recognize the entire management units for each population as having potential habitat for PPM, portions of these areas are likely to require management to be made suitable for PPM. The area managed for PPM and the area that is currently habitat for PPM within this broader area also varies. Therefore, we assume that populations with more habitat available (both occupied and available to expand into) are more resilient than populations with less available habitat due to the ability of larger areas to support a larger population expansions and shifts in distribution over time. Because this subspecies can experience large population fluctuations within and among years, this metric represents the maximum area that the population could foreseeably occupy in a good year provided habitat is available.
- **Range of occupied habitat:** The minimum and maximum area estimated to be occupied by the subspecies since 2012 (see Table 1), which we assume provides an indication of the range of habitat that is likely to be occupied during “good” versus “bad” years.
- **Population trends:** Descriptions of any fluctuations in area occupied that seem to be anomalies (those outside what might be expected given no major impacts) since 2012 (see Table 1) and assumed reasons for these fluctuations. This is provided as background information that could indicate potential population trajectories or threats.
- **Current threats/stressors:** Descriptions of existing threats or stressors to the populations, including human caused disturbances and habitat factors.
- **Habitat management:** Information on management practices that reduce nonnative vegetation cover, create open space, etc. for PPM. Habitat management has the potential to improve habitat quality and quantity.

We assume that these additional supporting metrics influence resiliency and extirpation risk, however, their primary effects should already be reflected in the two primary drivers of resiliency. For current condition, we consider persistence “over time” to be over the next 10 to 20 years, up to the first timestep used in the future analysis (see Section 6). Criteria for assessing resiliency are described below and summarized in Table 3.

- **Very low population resiliency** means the estimated  $N_e < 50$ . The population has little ability to withstand stochastic events due to genetic erosion and a very high potential for inbreeding depression, with a very low probability of persistence over time.
- **Low population resiliency** means that average occupied habitat is less than 100 ha, and/or the estimated  $N_e < 100$ . The population has limited ability to withstand stochastic events due to a small physical occupied area and/or a high potential for inbreeding depression, with a low probability of persistence over time.
- **Moderate population resiliency** means that average occupied habitat is between 100 and 200 ha and the estimated effective population size is  $\geq 100$ . While occupancy may fluctuate in some areas, the population can withstand some stochastic events, has a low risk of developing inbreeding depression over the near term, and has a moderate probability of persistence over time.
- **High population resiliency** means that occupancy is largely maintained with an average area above 200 ha and genetic diversity is maintained with an estimated  $N_e \geq 500$ . While occupancy may periodically fluctuate in some areas, the population can withstand stochastic events, has a low risk of developing inbreeding depression and retains evolutionary potential to adapt to changing environmental conditions, providing it with a high probability of persistence over time.

**Table 3.** Average area occupied in hectares (ha) and the effective population size ( $N_e$ ) requirements for each resiliency level.

| Resiliency | Avg. Area Occupied (ha) |     | Eff. Pop. Size ( $N_e$ ) |
|------------|-------------------------|-----|--------------------------|
| Very Low   | -                       | -   | <50                      |
| Low        | <100                    | or  | <100                     |
| Moderate   | 100 to 200              | and | $\geq 100$               |
| High       | >200                    | and | $\geq 500$               |

For High and Moderate resiliency, metrics for both area occupied and effective population size must be met. However, only one metric must be met for Low resiliency, where a population is Low if either the area occupied (ha) or effective population size ( $N_e$ ) is below 100. Populations with effective population size ( $N_e$ ) below 50 have Very Low resiliency, regardless of how much area is occupied.

## 5.3 Results

### Population summaries

#### *Dana Point*

Dana Point has the lowest population size and most limited habitat area of the PPM populations. The Dana Point population is also the most isolated and vulnerable to edge effects due to surrounding development. While Dana Point Preserve is 12 ha (29 ac) in size, a portion of this area is made up of steep coastal bluffs and only about 8 ha (19 ac) provides suitable habitat for PPM (USGS 2022, p. 59). Some population expansion is possible onto adjacent portions of the Dana Point Headlands Conservation Area managed by the City of Dana Point, but expansion into this area may be limited by clay loam soils and is otherwise precluded by surrounding urban development and the Pacific Ocean. An average of 5 ha (12 ac) has been estimated to be occupied annually since 2019, ranging from 0.6 to 7 ha (1 to 18 ac) since 2012 (see Table 1; Merrill et al. 2024, p. 12). The maturity of coastal sage scrub vegetation and lack of natural disturbances have reduced the availability of open ground and forb cover, suggesting that ongoing habitat management is likely needed to retain habitat suitability for PPM. Fortunately, nonnative grasses are not presently a dominant component of the vegetation at Dana Point, so periodic management of shrub and litter cover may be adequate for maintaining habitat suitability over much of this site (Brehme 2024, pers. comm.). This population has the lowest effective population size ( $N_e = 12.3$ , 95% confidence interval 12.1–12.6), experiences a high level of disturbance from recreational trail use and surrounding urban development, and has suffered a severe loss of genetic variation since its discovery (Wilder et al. 2020, entire; Wilder et al. in 2025, entire).

The use of the public trail system is a threat to this population, due to the high intensity of recreational use (e.g., average of 700 visitors per day in 2023), unauthorized accompaniment of humans by their pets, and occasional unauthorized off-trail use. Another threat to habitat quality within the Preserve is the presence of Argentine ants which are distributed throughout much of the Preserve. While there is endowed funding for habitat management, the inability to use prescribed fire restricts vegetation management methods for manual removal of duff, woody debris, and shrub cover to create bare ground and promote germination of forbs, and possibly broadcast seeding or planting (see Figure 11). The Dana Point population is currently threatened by continued genetic erosion and inbreeding depression (Wilder et al. 2025, entire), and has undergone at least two severe population bottlenecks since its rediscovery (Merrill 2020, p. 12; Miller 2017, p. 3). Urbanization and severe bluff erosion continue to put encroachment pressure on the outer edges of the available habitat (Partlow 2024, unpaginated). Due to the small amount of occupied and available habitat, and small effective population size, the Dana Point population has very low resiliency.

#### *South San Mateo*

The South San Mateo population is larger than Dana Point but smaller than the Santa Margarita population. While the area considered to be available and that has been delineated for monitoring of this population is 105 ha (260 ac), an average of 38 ha (93 ac) has been occupied in the last 5 years, ranging from 20 to 47 ha (50 to 117 ac) since 2012 (Table 1). This population generally has a low level of ongoing anthropogenic disturbance that is primarily associated with

maintenance of powerlines, water and drainage infrastructure, access roads, and fire breaks/fuel management zones that intersect the occupied habitat. The current level of use of this area for military training appears to be low and is likely restricted to vehicle travel on the roads and possible occasional dispersed foot travel through habitat. Free-roaming domestic cats are occasionally observed in the habitat and residents of the adjoining base housing use the roads for dog walking, hiking and biking.

While this site is adjoined by two MCBCP housing developments, the risk of further encroachment from urban development is currently low. To date, intensive habitat management has been limited to around 10 ha (25 ac) of shrub and vegetation thinning, dethatching and application of herbicides to control nonnative grasses and weeds. This population has generally occupied more habitat since 2015 than was recorded between 2012 to 2014 (see Figure 5, Table 1). However, its effective population size is also very low ( $N_e = 21.3$ , 95% CI 21.1-21.4), it has suffered a loss of genetic variation over the last 20 years, and has a high genetic load that indicates it is also likely to be suffering from inbreeding depression (Wilder et al. in 2025, entire). Thus, the South San Mateo population has a very low resiliency.

### *Santa Margarita*

The Santa Margarita population is the largest extant population of PPM, both in the amount of available habitat and average area occupied. This population has the largest effective population size ( $N_e = 254.8$ , 95% CI 250.1-259.4) (Wilder et al., 2025, pp. 835–836), suggesting it is unlikely to currently be suffering from inbreeding depression but there is evidence that this population has recently experienced a significant loss of genetic diversity (Wilder et al. 2020, p. 594; Wilder et al. 2025, pp. 835–836). The area that has been delineated as potentially available for use by PPM is 885 ha (2,187 ac) provides room for the population to expand and shift its distribution over time in response to environmental change. However, this area is fragmented by roads, buildings, infrastructure, and active military training areas that include training obstacles and firing ranges. On average, 113 ha (279 ac) have been occupied in the last 5 years, with an average occupied area of 177 ha (447 ac) since 2012, and a range of 93 to 291 ha (229 to 720 ac) of habitat occupancy since the monitoring program was initiated (Table 1). Notably, the area occupied by PPM at Santa Margarita declined about 43 percent in 2017 and has yet to rebound, remaining at less than 50 percent of peak occupancy documented in 2016 (see Table 1, Figure 5).

While threats from recreation, and urban encroachment are not significant within the Santa Margarita population, there is some uncertainty about the on-going direct impact of military training on this population. PPM habitat occupancy rates are currently low within portions of Oscar One where the highest intensity of recruit training occurs, which includes the Crucible Challenge Course obstacles and land navigation training course. Land navigation involves dispersed foot travel through habitat areas. Foot traffic within the land navigation course has been positively correlated with soil compaction and nonnative grass cover, and negatively correlated with PPM habitat use. A 2006 increase in the intensity of land navigation training within a 1.4 ha (3.4-ac) PPM monitoring grid—that was densely occupied by PPM during 2003 and 2004 (Miller and Pavelka 2008, pp. 29–49)—resulted in the compaction of soils, type conversion and replacement of the vegetation community with nonnative forbs (i.e., Sahara mustard, *Brassica tournefortii*), and scant detections of PPM in that vicinity ever since (see MCBCP PPM Monitoring Program Reports 2013 – 2024). This suggests that in addition to the potential for training activities to cause direct impacts to PPM within their burrows (e.g., via

crushing of burrow systems) on-going disturbance and habitat degradation from training may limit the ability of PPM to recolonize areas that were formerly suitable and densely occupied by PPM. Fragmentation of the habitat by roads, infrastructure and military training activities, may also degrade connectivity among patches of suitable habitat into which PPM could otherwise expand.

Much of Edson Range is used for live-fire training which largely restricts recruit activities within this training area to the firing ranges. Use of the firing ranges has also been a historical source of wildland and prescribed fire. Although much of Edson Range has clay loam soils that are generally not thought to be preferred by PPM, habitat occupancy rates have been estimated to average about 28 percent or 135 ha (334 ac) since 2012 within this 474 ha (1,171 ac) training area (Table 1). Because clay loam soils are often invaded by nonnative annual grasses on MCBCP, the historical use of prescribed fire has helped limit grass cover and maintain habitat suitability for PPM within Edson Range. Between 2011 and 2020 there was a hiatus in the application of prescribed fire in Edson Range that is thought to be associated with a decline in habitat quality and occupancy of PPM within this training area. Following a 2020 prescribed fire in Edson Range, herbicide was applied to prevent colonization of nonnative forbs within the burned habitat to safeguard and maximize the potential benefit to PPM habitat from the prescribed fire. However, the use of herbicide to maintain and help enhance habitat for PPM following prescribed fires in Edson Range was only recently initiated. During 2022, the MCBCP initiated manual habitat enhancement (removal of nonnative annual grasses and shrub thinning) of 6 ha (17 ac) in Oscar One that included vegetation management along a 610- meter “corridor” to enhance habitat connectivity between Oscar One and Edson Range. PPM have been documented moving into this area but the full effects of this management have not yet been realized. The Santa Margarita population is considerably larger than the other populations. Based on having an average of over 100 ha (247 ac) of occupied habitat over the past 5 years and an effective population size greater than 100, this population is ranked as having moderate population resiliency.

### *Conservation Breeding Program*

The PPM conservation breeding program at SDZWA was established in 2012 from founders collected from the Dana Point, South San Mateo, and Santa Margarita populations, and the ex-situ population has been grown and maintained by crossbreeding mice and their offspring from the different source populations. Goals of the conservation breeding program are to maintain a genetically diverse, demographically stable population from which animals can be removed to augment or create additional populations. To maintain genetic diversity within the captive colony while minimizing inbreeding, information from pedigrees is used to select breeding pairs that minimize mean kinship within the population, and individuals with underrepresented genes are prioritized for breeding. Additional founders from the extant populations have also been collected on an occasional basis and added to the captive colony to help preserve remaining genetic diversity within the subspecies and maintain equal genetic representation from the extant populations (Miller and Shier 2011, entire). Compared with the extant populations, the admixed captive colony has had the highest heterozygosity, lowest inbreeding coefficients and lowest frequency of homozygous deleterious alleles (Wilder et al., 2025, p. 837).

Since the inception of the conservation breeding program, reproductive output of the captive colony has increased, demonstrating an improved understanding of PPM reproductive physiology and behavior. Over the last few years, high reproductive output within the conservation breeding facility has supported releases of 30 or more animals each year, with opportunities to mate reproductively mature individuals now being surrendered due to constraints imposed by the capacity of the breeding facility. Table 4 provides the status of the ex-situ population as of September 30, 2024.

**Table 4.** The sex and origin of the ex-situ population of PPM at the San Diego Zoo Wildlife Alliance Conservation Breeding Facility as of September 30, 2024

| Age           | Founders | Captive born | Total |
|---------------|----------|--------------|-------|
| Adult Males   | 6        | 35           | 41    |
| Adult Females | 8        | 66           | 74    |
| Young of Year | -        | 78           | 78    |
| Total         | 14       | 179          | 193   |

### *Laguna Coast Wilderness Park*

Mice produced at the SDZWA conservation breeding facility have been released into habitat at Laguna Coast Wilderness Park (LCWP) in Orange County on an on-going basis since 2016. The selected receiver site, named “Water Tank”, falls within an approximate 2,833 ha (7,000 ac.) wilderness park that is included within a larger 6,961 ha (17,201 ac) coastal habitat reserve established by the Orange County Central and Coastal Subregions Natural Community Conservation Plan/Habitat Conservation Plan (NCCP/HCP). The coastal habitat reserve conserves much of the remaining undeveloped habitat in the San Joaquin Hills where an occurrence of PPM was lost to residential development in 1972 (Service 1998, p. 19).

The NCCP/HCP is a subregional multi-species conservation plan adopted by the County of Orange (owner of LCWP) and other participating landowners and jurisdictions to satisfy the requirements of the federal and state endangered species acts and the California Natural Community Conservation Planning Act, while allowing for the continued economic development of the central and coastal subregions. The NCCP/HCP provides for the conservation of 10 listed and 29 unlisted species, including PPM, and applies adaptive management within the habitat reserve system as part of its conservation strategy. The effort to introduce PPM to Water Tank is being pursued and has been accommodated under the NCCP/HCP adaptive management program.

To prepare the Water Tank site for the PPM introduction, a 5- foot predator exclusion fence was installed surrounding an approximate 0.55 ha (1.36 ac) area of habitat, and 50 animals were released in June of 2016 within artificial burrows constructed within the enclosure. Due to changes in the composition and cover of vegetation within the enclosure following the wet winter of 2016-2017, and no overwinter survivorship, during 2017 efforts were initiated to manage vegetation within the enclosure and 49 additional animals were released at the site. With good reproduction during the summer of 2017 and following high overwinter survivorship, the predator exclusion fence was removed in 2018 to allow for population expansion. However,

subsequent monitoring suggested removal of the fence was premature, as the population declined and gradually disappeared.

Attempts to establish a self-sustaining population of PPM at Water Tank have continued and have included installation of new fencing, augmentation releases of animals from the captive breeding facility every year but 2024, and annual management of vegetation within the fenced enclosure. Monitoring indicates released animals at this locale generally have relatively high short-term survivorship; successfully reproduce following release, particularly when releases are performed early in the spring; and there is good overwinter survivorship of released animals and their offspring during years with average or below average rainfall, and poor to no overwinter survivorship during years with above average rainfall. Currently, 0.83 ha (2.04 ac) of managed habitat are within the fenced enclosure where a minimum of 16 animals were estimated to remain as of June of 2024 (Thatcher et al. 2024, pp. 2–3).

Although this site falls within a habitat reserve system that conserves thousands of hectares of surrounding habitat, should this population become established, available habitat for population expansion is constrained by dense shrub cover in the area immediately adjoining the enclosure and steep topography to the northwest.

### *Wire Mountain*

Starting in 2024, mice produced at the SDZWA Conservation Breeding facility have also been released at the Wire Mountain population creation site on MCBCP. The Wire Mountain site is surrounded by roads, housing and a school site on the southern side of the Santa Margarita River about 1.6 km (1 mi) south of the Santa Margarita PPM population. Within the 32-ha (79 ac) area identified as having suitable soils for PPM at this locale (GSRC and SDZWA 2023, p. 50), MCBCP have identified a 13.52 ha (33.4 ac) PPM Translocation Management Area where the population creation effort is to be focused. In anticipation of the introduction effort, MCBCP began performing vegetation management within 2 ha (5 ac) of this area in 2023 to improve its suitability for PPM, and in 2024 installed 5-foot predator exclusion fencing around a 0.53 ha (1.3 ac) portion of this area where 90 captive bred mice were released. Around 120 mice (released and wild born combined) were documented within the receiver site in September of 2024 (Shier et al. 2025, p. 2) and at least 44 mice were confirmed as having survived overwinter in April of 2025 (D. Shier, pers. comm. April 14, 2025). In 2025, the vegetation management efforts continued, and fencing was extended around another 0.36 ha (0.9 ac) of habitat. Another 40 animals were released into the Wire Mountain site in May and June of 2024, primarily within the area of the expanded enclosure

### **Current Population Resiliency**

All PPM populations are small and isolated, making them vulnerable to extirpation from stochastic events, though the degree of risk varies. Dana Point and South San Mateo have very low resiliency (Table 5) and face the highest extirpation risk due to limited habitat, extremely small effective population sizes, long-term loss of genetic diversity, and vulnerability to environmental variation and catastrophic events. Dana Point's habitat is tightly constrained by surrounding development and the ocean, leaving little room for expansion despite past management gains. South San Mateo benefits from reduced disturbance and some colonization of formerly unoccupied habitat, but its small occupied area, management constraints, and documented genetic deterioration indicate a persistently high risk of decline. In contrast, the

Santa Margarita population has moderate resiliency (Table 5), supported by a larger effective population size and greater available habitat, yet recent declines in genetic diversity and occupied area—combined with ongoing pressures from military training and the need for active habitat management—suggest it still faces a moderate to high risk of extirpation

### **Current Subspecies Representation and Redundancy**

Both representation and redundancy are greatly decreased relative to historical levels, supported both by genetic evidence as well as past and more recent instances of extirpation due to habitat loss. Prior to the development and urbanization of the coastal lowlands in southern California during the 20<sup>th</sup> Century, PPM had a much more extensive distribution, documented from around nine general locations and 30 sites within 4 km (2.5 mi) of the Pacific Ocean extending from Marina Del Rey in Los Angeles County south to the vicinity of the U.S.-Mexico border (USFWS 1998, pp. 3–4). At present, only two landowners manage the land supporting the current populations, so budgets, management decisions, and lawsuits or other legal constraints can have major impacts on the persistence of these populations.

Redundancy is low, as there are only three extant populations and two population creation efforts that are not yet self-sustaining. Due to the small population sizes and their isolation from each other, all populations are at risk of extirpation due to a catastrophic impact, such as flooding, a series of wet winters, prolonged drought, or other major disturbance. Due to its particularly small footprint, very low effective population size and documented loss of genetic diversity, Dana Point faces the greatest risk of extirpation, followed by South San Mateo, then Santa Margarita. Due to the small number of extant populations, a single population extirpation would appreciably reduce population redundancy (discussed further in future conditions (Section 6)).

Representation is discussed in terms of adaptive capacity. Based on demographic history estimated from the genomes of wild mice, all three populations appear to have gone through bottlenecks and a loss of genetic variation for adapting to changing conditions within the past 25 to 50 generations (Wilder et al., p. 836). Low contemporary effective population sizes for each of the extant populations indicates an ongoing high risk of continued loss of genetic variation through drift (Wilder et al. 2025, pp. 835–836). An effective population size of  $N_e > 1,000$  is required to retain evolutionary potential over time, and all three populations have  $N_e < 1,000$ . Two of these populations are estimated to have an  $N_e < 50$  and have experienced an increase in the frequency of deleterious recessive alleles, suggesting they are already experiencing a loss of fitness from inbreeding (Wilder et al., 2025, entire). Low genetic variation and loss of fitness limits the ability of populations to adapt to site specific environmental changes that may be necessary to persist in place, and existing habitat fragmentation and isolation limit the ability of PPM to move in space in response to environmental change. With only a few, isolated populations, maintaining subspecies redundancy and representation will require sustaining or maximizing the size of each of the extant populations, creating additional populations as insurance against future possible extirpations, and performing genetic management to conserve remaining genetic variation.

**Table 5.** Summary of metrics impacting current resiliency for each of the three extant Pacific pocket mouse populations. Gray shading signifies metrics primarily used to assess resiliency, with other metrics informing the accuracy of these scores. Population estimates from Mackenzie and Bratt 2023, p. 34.

| Population      | Avg. Area Occ. (ha)    | Range Area Occ. (ha) | Genetic Health                                                       | Est. Pop. Avg. | Range Est. Pop | Potential management area (ha) | Population Trends (2012 to 2023)                                                                   | Stressors/Disturbances                                                                                                                                                                                                                                                                         | Habitat and Habitat Management                                                                                                                                                      | Resiliency |
|-----------------|------------------------|----------------------|----------------------------------------------------------------------|----------------|----------------|--------------------------------|----------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Dana Point      | 4.9 (4.2 since 2012)   | 0.6 to 7.4           | Ne = 12.3; evidence of inbreeding depression and genetic degradation | N/A            | N/A            | 7.8                            | Significant annual fluctuation, with very low abundance 2017 and relatively high abundance in 2020 | Edge effects from adjoining development, high use of public access trail, some non-compliance with public access rules (e.g., dogs, off-trail trespass) (Merrill et al. 2023).                                                                                                                 | Shrubs and woody debris limit open ground. Targeted, habitat management includes manual removal of shrubs, woody debris and nonnative vegetation. Use of prescribed fire precluded. | Very low   |
| South San Mateo | 37.6 (35.3 since 2012) | 20.2 to 47.3         | Ne = 21.3; evidence of inbreeding depression and genetic degradation | 774            | 492-938        | 105                            | 2012 to 2014 occupancy estimates lowest; higher estimates since                                    | Low level disturbance from operations and , maintenance of utilities and roads (USFWS 2020); infrequent use for military training (e.g., on-road vehicles, off-road foot travel) (USFWS 2010, USFWS 2020); Recreational use (dog-walking, hiking, biking) by adjoining residents (USFWS 2020). | Nonnative grasses present. Habitat improvement (vegetation thinning; dethatching) of 10 ha began in 2018. Use of prescribed fire precluded.                                         | Very Low   |

|                        |                        |               |                                           |       |           |     |                                     |                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                        |                 |
|------------------------|------------------------|---------------|-------------------------------------------|-------|-----------|-----|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| <b>Santa Margarita</b> | 113.1 (177 since 2012) | 76.9 to 291.3 | Ne = 255: evidence of genetic degradation | 2,202 | 568-5,096 | 885 | Large population decline after 2016 | Military training, fire, and fragmentation of occupied habitat by roads and training activities. Low PPM density in training areas; ongoing impacts to PPM from training not quantified (USFWS 1996, USFWS 2010). | Extensive areas dominated by nonnative grasses. Frequent prescribed fire to prevent spread of fire from Edson Range helps maintain habitat suitability in Edson Range. Herbicides used to help control nonnative plants in Edson Range. Management (mowing, herbicides, shrub thinning) of 7-ha of degraded habitat initiated in 2021. | <b>Moderate</b> |
|------------------------|------------------------|---------------|-------------------------------------------|-------|-----------|-----|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|

## SECTION 6 – FUTURE CONDITIONS AND VIABILITY

We have considered what the PPM needs for viability and the factors that are driving the viability of the subspecies (Sections 2, 3, and 4) and have assessed, to the extent possible, the current condition of the subspecies (Section 5). We now consider the plausible future conditions for the subspecies. We apply our future forecasts to the concepts of resiliency, representation, and redundancy to describe the future viability of the PPM.

### 6.1 Introduction

While the PPM currently exists as three extant populations, the future condition of this subspecies is likely to be determined both by the maintenance (and potential growth where possible) of the extant populations as well as the success of current and proposed population creation efforts. The future condition and likelihood of persistence of each extant PPM population will depend on their current levels of resiliency as well as how habitat conditions change in the future, both in terms of controllable (management) and uncontrollable (weather events, etc.) elements, and how genetic health of the populations change over time.

There is evidence that a primary limitation to PPM population resiliency is the quantity and quality of available habitat. Habitat occupancy is positively associated with high forb cover and bare ground and negatively associated with high nonnative grass cover and thatch; thus, maintenance of habitat appears to rely on periodic ecological disturbances (e.g. fire, drought) to reduce shrub cover and/or cover of nonnative invasive grasses and promote the growth of annual forbs. In the absence of natural disturbance, habitat management has been shown to have the potential to expand the distribution of PPM into new areas and increase population density within managed areas. This suggests that when there is surrounding unoccupied habitat or areas of unoccupied habitat within existing population boundaries, habitat restoration and management has potential to increase the size (and therefore, resiliency) of the extant populations by improving the amount of occupied habitat. However, habitat management is expensive, time consuming, and is likely to require ongoing sustained effort across years to maintain habitat suitability. Habitat quantity also fluctuates and can decline from a lack of natural disturbances, inconsistent management, or human activities that degrade or destroy habitat quality (e.g. from development, military training activities, recreation).

The genetics of each population also influences short- and long-term population resiliency and subspecies viability, as subspecies' representation is dependent on the genetic health of the individual populations. Currently, two of the populations have a very low contemporary effective population size and one population has a moderate contemporary effective population size. This indicates that all populations are at risk from loss of genetic variation due to genetic drift. In small populations, the loss of genetic variability from drift is greater than the gain from mutation (Franklin 1980, entire), which leads to genetic erosion. Fluctuations in population size can cause a sudden and severe loss of genetic variation (i.e., genetic bottlenecks), such as has been observed at Dana Point. Finally, small populations have a high risk of developing inbreeding depression (reductions in fitness) from the mating of closely

related individuals, as exhibited in the low fitness of individuals from Dana Point in the captive breeding program and low heterozygosity, high inbreeding coefficients, and high homozygous genetic load observed in the Dana Point and South San Mateo populations (Wilder et al. 2025, entire). Genetic diversity (e.g., allelic richness) of the PPM populations cannot be increased without the introduction of new alleles. Due to the isolation and differentiation of the extant PPM populations, a possible source for increasing genetic variation within the populations is through managed migration, or the translocation of individuals among populations. However, the feasibility and success of any genetic augmentation attempt to improve the fitness or genetic variation within the extant populations requires that 1) introduced individuals survive and successfully integrate into the population, 2) breeding occurs, and 3) the fitness of the resulting progeny is increased. While interbreeding among individuals from the different founder populations in the captive conservation breeding facility suggest this is possible, there is some uncertainty about the consequences of introducing animals from the other populations to Dana Point due to fixed chromosomal differences among the Dana Point and MCBCP populations. Nevertheless, increasing genetic diversity within the populations is not possible without genetic rescue (i.e., genetic augmentation through translocations among populations or introduction of captive bred individuals into extant populations).

A change in threats and stressors can also impact population viability. For example, disturbances from military training, recreation, nonnative plant and animal species invasions and other forms of disturbance (e.g., noise, light, vibrations, smells) could alter PPM behaviors with resulting effects to survival, reproduction, and area of habitat occupancy. To determine the success of various management scenarios, we assess how changes in these threats are expected to effect population size and resiliency over time, measured using average area occupied as a proxy in our analyses.

The potential to increase subspecies redundancy through the creation of additional PPM populations relies on the successful conservation, enhancement and/or creation of habitat within new sites, the permissions for which must first be successfully obtained. Establishment of self-sustaining populations at those sites also relies on the ability to successfully translocate captive-bred or wild caught individuals to those sites, and the survival and reproduction of the introduced mice over time. Once new populations are established, their resiliency will be affected by the same factors that affect the extant populations.

Finally, the continued existence of all populations, those that are currently extant and any that are successfully established, will depend on their ability to withstand catastrophic impacts. PPM rely on some form of disturbance to maintain their habitat, but population declines have also been documented following periods of drought and intense rainfall, and at least one population has become extirpated in recent history. Increasing frequency, intensity, and severity of droughts, precipitation, and wildfires could impact PPM resiliency.

## **6.2 Conceptual Framework**

Due to the species short generation time, the potential immediate effects of changes in habitat management and human land uses, the potential for establishment of new populations, and the risk of catastrophic events on the species, we project the first time point for future scenarios to range from 10 and 20 years. If translocation efforts are successful, any resulting populations would be considered extant populations at this timestep, then face the same risks to

population persistence (e.g., from loss and degradation of habitat and genetic erosion) as the extant populations. We also provide projections for a second point in time, 30 to 50 years into the future, which considers further changes to population persistence and resiliency based on management inputs, and how the likelihood of population persistence affects future redundancy and representation. Thus, we are assessing how a range of potential management scenarios could affect the resiliency, redundancy and representation of PPM within the next 10 to 20 years and 30 to 50 years in the future.

Under future conditions, we consider the same two primary metrics that were assessed for resiliency under current conditions: genetic health and population size (average occupied hectares) (see Table 3). The following metrics indicate what may change moving into the future, and they are defined as:

- **Genetic health (contemporary effective population size):** the genetic health of the population for reproductive success and fitness. Effective population size, as used in current condition, represents the level of risk of loss of genetic diversity. While other proxies for genetic health could include measurements of diversity of alleles, reproductive fitness (litter size, survival, etc.), presence of physical deformities, etc., we use the contemporary effective population size goals from Soule (1980, pp. 151–169), Franklin (1980, pp. 135-149) and Frankham et al. (2014, entire) to define resiliency categories (see Table 3). Given that two of the three populations are currently below an effective population size considered adequate for avoiding inbreeding depression, we assess future change to genetic diversity in terms of whether genetic rescue is attempted and successful (results in breeding/increased fitness).
- **Average occupied habitat (Population Size):** the average estimated occupied hectares. For this analysis, we define population size in terms of estimated average area occupied, based on a 10-year average.
- **Habitat management (available habitat):** how available habitat will change in the future, through changes in habitat management, as a measure of the overall quality and quantity of habitat available to the population. Habitat must be contiguous to other occupied habitat in the footprint of the population or separated by a distance and habitat conditions that PPM could be expected to easily traverse. Removal or degradation of habitat would constitute a decrease or decline in habitat quantity and quality, while adding new habitat or improving existing habitat would constitute an increase. For this analysis, we define habitat changes in terms of additional or less management, including area (ha) of increased or decreased management, if available.
- **Threats/Stressors:** the relative level of threats and stressors present within a population. While this would ideally be measured as the average impact per individual in the population, such a measure being quantifiable is unlikely. Threats and stressors include disturbances such as noise, light, vibrations, or direct impacts to individuals (such as from recreational activities, developments, military training, or road and utility maintenance), as well as predators, competitors, or invasive species. For this analysis, we define changes in threats in terms of the known or likely threats to the population.

On the ground, activities resulting in increased resiliency (increased quality/quantity of habitat, increased genetic diversity, fewer threats/stressors, larger population sizes) could include

new and/or ongoing habitat management, habitat protection or activity restrictions, introduction of new individuals with unique genetic variation from captive or other wild populations (genetic rescue), or other activities that reduce specific stressors. Because availability of habitat is assumed to be the biggest limiting factor for extant populations of PPM, we assume that a meaningful population increase will require the creation of additional habitat or the improvement of existing habitat. While unoccupied habitat likely does exist within each population, the amount available in a given year is assumed to be relatively low, and we assume that all available habitat would be occupied in good years, when the population is able to expand. Habitat creation and management is being performed to respond to the presence of nonnative grasses and forbs and senescence of sage scrub, and management activities depend on environmental factors (e.g., annual rainfall) as well as financial and logistical constraints (ability to access habitat in military training areas). Cessation of management can quickly result in vegetation conditions that are not conducive to PPM occupancy, so habitat quality can quickly be lost.

To increase genetic diversity within the extant populations, new genetic material must be introduced via managed migration due to the speed at which genetic diversity is being lost from genetic drift. The likelihood of successful genetic rescue within any of the populations is uncertain, as specific requirements must be met for introductions to lead to increased genetic health. Results from population crosses in captivity and translocations of captive bred PPM and other subspecies of PELO suggest the requirements for genetic rescue can be achieved but genetic rescue has not yet been attempted (Table 6).

The impacts of climate change are expected to increase in frequency, intensity and severity over time, with variability in precipitation (e.g. periods of drought and heavy rainfall) expected to increase in the future. Although, predicting impacts to PPM from climate change is complicated because drought has potential to benefit PPM by reducing cover of shallow-rooted nonnative grasses, and high rainfall can increase availability of seed resources, both drought (low rainfall in the spring) and high rainfall years (especially winter rainfall) have been linked to population declines of PPM (Brehme et al. 2021, pp. 11–12; USFWS 2010, pp. 30–32). Thus, it is likely that increased variability in the timing and amount of precipitation due to climate change will contribute to more frequent or severe population fluctuations that increase the risk of direct extirpations or loss of genetic variation from population bottlenecks. Based on an expectation that the severity of impacts from climate change will intensify over time, we assume that over the next 10-20 years periods of drought or above-average rainfall will be of a similar magnitude to what has been endured by PPM since its rediscovery, and the adverse impacts from climate change will start to be realized over the second time step.

As the definitions for each resiliency level indicate a population's probability of persistence over time, we assume that populations with very low resiliency will have a very high risk of extirpation by the first timestep, unless their resiliency can be increased. We also assume that genetic degradation will continue unless effective population size(s) can be increased to  $N_e \geq 100$  (e.g., through genetic rescue) so we project that the likelihood of extirpation of the extant populations will increase over time if the effective population size(s) are not increased above this threshold. We also anticipate that stochastic environmental variation and associated population fluctuations will increase the likelihood of extirpation by the second timestep. Therefore, the likelihood of extirpation may increase over time, even if the resiliency category, based on

population size and genetics, does not change. In our analyses, populations with a very high risk of extirpation are factored in as potentially extirpated.

**Table 6.** Requirements that must be met for genetic rescue (augmentation of extant wild populations) to successfully increase resiliency, including what evidence exists for these requirements. LAPM signifies Los Angeles Pocket Mice (*Perognathus longimembris brevinasus*).

| Requirement for Genetic Rescue                                                          | Notes                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Source: captive individuals</i>                                                      |                                                                                                                                                                                                                                                                                                                                                                                               |
| Successful breeding in captivity.                                                       | Captive breeding has been successful (Shier et al 2022, p. 2).                                                                                                                                                                                                                                                                                                                                |
| Appropriate captive genetics for outbreeding that allow for fitness in wild.            | Outcrossed captive-bred mice exhibit favorable short-term survivorship and reproduction following their release in the wild; long-term fitness is uncertain due to low observed overwinter survivorship during some years. (Shier et al. 2022, pp. 48–52).                                                                                                                                    |
| Successful augmentation of captive to wild populations (survival of individuals).       | While captive-bred mice have successfully been released and reproduced following their release at the Laguna Coast site, there has been no attempt thus far to genetically augment an extant wild population.                                                                                                                                                                                 |
| Successful reproduction in wild (breeding happens, offspring fit, survival maintained). | While captive-bred mice have successfully been released and reproduced following their release at the Laguna Coast site, there has been no attempt thus far to genetically augment an extant wild population.                                                                                                                                                                                 |
| <i>Source: wild individuals</i>                                                         |                                                                                                                                                                                                                                                                                                                                                                                               |
| Wild population robust enough to support removal of enough (≥50) individuals.           | Recent population estimates suggest the MCBCP populations could withstand the removal of enough individuals for a wild-to-wild translocation, but past efforts to locate large numbers of individuals for translocation have been unsuccessful. Thus, there remains some uncertainty about the robustness of population estimates and impact of removing individuals from extant populations. |
| Interbreeding among extant populations is possible.                                     | Results from captive breeding program suggest population crosses in wild are possible.                                                                                                                                                                                                                                                                                                        |
| Translocated animals able to survive and reproduce in wild.                             | No wild-to-wild translocations have been attempted for PPM, but such translocations have been successful in the short-term for LAPM (Wang and Shier 2021, entire).                                                                                                                                                                                                                            |
| Wild/wild crosses increase genetic diversity and/or improve fitness of wild population. | Interbreeding among extant populations in captivity has created a captive population with higher genetic diversity than extant populations. Preliminary evidence suggests fitness of Dana Point animals should improve with genetic augmentation.                                                                                                                                             |

## Redundancy

With only three extant populations, population redundancy is an important aspect of the future viability of PPM. In the next 10 to 20 years, the number of extant populations may be

increased through population creation or decreased through the loss of one or more of the extant populations. The successful establishment of new populations is dependent on multiple factors, and the loss of extant populations could be caused by a catastrophic event or a longer-term population decline that leads to a catastrophic outcome. The continued presence of any newly established populations at our second timestep, 30 to 50 years in the future, will depend on their resiliency and management.

### *Additional translocated populations*

Based on current efforts to: 1) captively breed and translocate PPM to the Laguna Coast and Wire Mountain sites (Shier 2015, entire; Shier et al. 2024b, entire); 2) identify additional suitable receiver sites, seek landowner permission and prepare the habitat for introductions, (Chock et al. 2022, entire; USFWS 2024, entire); and 3) draft plans for wild to wild translocations (Edgarian et al. 2023, entire), we expect the likelihood of successfully establishing one or more self-sustaining populations will become clear within the next 10 to 20 years. To be successful, several requirements must be met, many of which are still uncertain (Table 7).

Two additional sites are accessible and proposed to be ready for translocation over the next 5 years (North San Mateo and James Dilley Greenbelt Preserve). Should additional populations be successfully established, we assume that the resiliency of these populations will be low initially due to the relatively small number of founders (e.g., less than 100 individuals) used to create them. We also assume that, like the extant populations, created populations will be limited by the amount of habitat they can occupy due to constraints on the amount of potentially suitable habitat available and the management required to sustain habitat suitability over time. Based on genetic management of the captive population and/or translocation of founders from Santa Margarita, we assume that, initially, and with continued genetic management, an effective population size above 50 ( $N_e \geq 50$ ) is achievable for these population creation efforts, but do not anticipate that the size of these populations measured as acres of occupied habitat will exceed the low resiliency threshold (i.e., habitat will remain below 100 ha) across either timestep.

**Table 7.** Requirements that must be met for the establishment of new populations of Pacific pocket mouse, which would increase redundancy, including what evidence exists for these requirements. LC signifies Laguna Coast; WM signifies Wire Mountain; NSM signifies North San Mateo; Dilley signifies James Dilley Greenbelt Preserve. LAPM signifies Los Angeles Pocket Mice (*Perognathus longimembris brevinasus*).

| Requirement for Est. of New Populations                                                                           | Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Appropriate sites available, supported by landowner for foreseeable future.                                       | 7 sites selected, 4 accessible.                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Appropriate habitat available (habitat existing or restored and managed appropriately for foreseeable future).    | 7 sites selected, 4 accessible, 2 under active implementation. The 2 sites being implemented (LC and WM) will require ongoing management to create and maintain habitat for introduced mice. The two remaining sites (NSM and Dilley) will need management before translocation is pursued. All release sites will require ongoing habitat management.                                                                                                                                     |
| Appropriate/successful threat management (temporary enclosures at release sites, long-term management if needed). | Fencing should be possible to install at most if not all prospective translocation sites and will likely reduce but not eliminate external threats. 2 of the receiver sites (WM, NSM) are exposed to threats from recreation and adjoining land uses so ongoing threat management is likely necessary. The remaining 2 sites (LC, Dilley) face relatively low external threats but are exposed to high natural predation and vegetation succession, which could degrade habitat over time. |
| <i>Captive to wild</i>                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Successful breeding in captivity.                                                                                 | Captive breeding has been successful (Shier et al 2022, p. 2).                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Appropriate captive genetics for introduction that allow for fitness in wild.                                     | Captive bred individuals have high survivorship, reproduce successfully, and have high genetic diversity. Captive mice introduced at LC have shown high short-term survival (King et al. 2022, p. 11; Shier et al. 2022, pp. 48–52).                                                                                                                                                                                                                                                       |
| Successful introduction of captive animals into wild (survival of individuals).                                   | Mice released at LC show ability to survive, but over winter survival has been zero in some years (King et al. 2022, p. 11).                                                                                                                                                                                                                                                                                                                                                               |
| Successful reproduction in wild (breeding happens, offspring fit, survival maintained).                           | Offspring produced at LC three consecutive years (King et al. 2022, p. 11).                                                                                                                                                                                                                                                                                                                                                                                                                |
| <i>Wild to wild</i>                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Appropriate wild genetics for introduction that allow for fitness at new sites.                                   | Extant populations appear to be self-sustaining (MacKenzie and Bratt 2023, entire), but no data on whether these genetics convey survivorship in new locations.                                                                                                                                                                                                                                                                                                                            |
| Successful introduction of wild animals into new area (survival of individuals, especially over winter).          | No wild-to-wild translocations have been attempted for PPM. Translocations have been successful for LAPM, but long-term survival has not been established (Wang and Shier 2021, entire).                                                                                                                                                                                                                                                                                                   |
| Successful reproduction (breeding happens, offspring fit, survival maintained).                                   | No wild-to-wild translocations have been attempted for PPM. Translocated LAPM successfully bred following release (Wang and Shier 2021, entire).                                                                                                                                                                                                                                                                                                                                           |
| Removal of individuals from extant population does not affect population resiliency.                              | Impact of removing individuals from extant populations for wild to wild translocations on viability and genetic health of source populations has not been assessed and is likely to vary with source population.                                                                                                                                                                                                                                                                           |

### *Catastrophic impacts (all populations)*

While changes in military training impacts, habitat management, genetic factors and climate change can affect the resiliency of a population, catastrophic impacts could affect the future redundancy of the subspecies by causing the extirpation of one or more populations. Catastrophic impacts (or random stochastic events that have catastrophic impacts) could include prolonged periods of drought, particularly heavy or prolonged rainfall events, extreme fires, extreme storm events, outbreak of disease or other pathogens, or other unforeseen events.

### **Scenarios**

To project the future condition of the PPM, we define four scenarios that capture the range of plausible futures for the subspecies. Because the four variables that will define future resiliency (occupied habitat and genetic health ( $N_e$ ), along with threats/stressors and population size) will be determined by the amount of management that is possible and implemented, we define these scenarios based on a range of management capacity. We define management in these scenarios as habitat management (prescribed fire, mechanical or chemical vegetation treatments, seeding/planting), threat management (access limitations, training limitations, etc.), and genetic management (translocations, genetic rescue, captive breeding, etc.). These management scenarios reflect management practices that are already being conducted or are proposed, and all four scenarios are considered plausible. The four scenarios considered are: No Change in Management, Moderate Management Increase, Large Management Increase (likely reflecting the maximum amount of management that could be feasible), and Management Decrease. Each scenario's general assumptions, requirements (and therefore, likelihood), and treatment of the four metrics (habitat, threats/stressors, genetic diversity, and population size) are outlined below. The success of additional translocated populations (Laguna Coast, Wire Mountain, North San Mateo, and James Dilley Preserve) are also projected for each scenario.

We look at each scenario at two timesteps (10 to 20 years and 30 to 50 years); however, we expect the level of management under each scenario will be fully in place by the end of the first timestep (10 to 20 years) and sustained during the second timestep (30 to 50 years). We do not expect the amount of habitat that can be managed, the threats present, and whether genetic rescue is performed to change between these timesteps. Although there is some potential that increased variability in the timing and amount of rainfall from climate change could impact PPM, due to uncertainty about the net effect of climate change on PPM, we have assumed there will be no significant change in the magnitude of this threat over the time range of our analysis. Because continued loss of genetic diversity is predicted with low contemporary effective population sizes, if no genetic management is performed, we anticipate that resiliency will continue to decline within the populations due to a loss of fitness from inbreeding depression in the smallest populations, and a loss of adaptive potential within populations with an  $N_e \geq 100$ .

While contemporary effective population size can potentially be stabilized and increase with a significant population expansion without genetic rescue, this does not restore genetic variation that has already been lost. Therefore, for all populations where low genetic diversity is suggested from low contemporary effective population size and there is capacity for genetic rescue as part of the management scenario, we assume that genetic rescue can improve population resiliency to at least a low level (e.g.,  $N_e \geq 50$ ). We further assume that, once initiated as part of a management scenario, genetic management will continue to be performed throughout

the period of this analysis to optimize the effective population size of the individual populations and the subspecies as a whole. Otherwise, due to the isolation and small size of the extant populations, cessation of genetic management would be anticipated to return the populations to ongoing genetic degradation .

We assess the likely changes to each PPM population at each timestep (10 to 20 years and 30 to 50 years) under each scenario in terms of habitat, threats/stressors, genetic diversity, and population size, and interpret how that will affect future population resiliency. We provide an estimate of the future average area occupied based on the current average area occupied (using the average of the last 5 years as the baseline/current, as well as the range of values since 2012) and given the anticipated changes under each scenario. Estimates of average area occupied in the future are meant to represent a potential range of values.

In addition to population resiliency, we also project the extirpation risk for each population, based on the definitions for each resiliency category (see Section 5.2) and the additive effects from genetic degradation (if applicable) and other threats and stressors. In our analyses, populations with a very high risk of extirpation have the potential to become extirpated across the time intervals considered.

### ***Scenario 1: No Change in Management***

In this, the status quo scenario, management practices stay the same, genetic rescue is not implemented, threats and stressors at Dana Point increase in association with development of the adjoining hotel site and increased use of the public access trail, and there are no appreciable changes to threats/stressors elsewhere.

### ***Scenario 2: Moderate Management Increase***

This scenario represents increased management practices based on current management actions and a moderate increase in management capacity. Under this scenario, threats/stressors at Dana Point increase in association with development of the adjoining hotel site and continued growth in use of the public access trail. On Camp Pendleton threats and stressors from military training and human land use remain at current levels. Otherwise, habitat management practices at all sites continue and increase moderately. Due to funding and logistical constraints, it is assumed this will not quite double the amount of habitat management/enhancement that is currently being performed within each population. Under this scenario, genetic rescue is initiated and conducted for all populations where it is warranted. It is further assumed that resources directed towards population creation will be sustained, during the first timestep (10 to 20 years).

### ***Scenario 3: Large Management Increase***

This scenario is intended to approximate what we believe is the maximum feasible capacity for management, where it is assumed enough funding is secured to double the amount of habitat that is currently being managed (i.e., restored and enhanced) for PPM at all locations where there is room for such expansion. As with the Moderate Management Increase scenario, threats and stressors at Dana Point increase from development of the adjoining hotel site but increased regulation of use of the public access trail is accommodated and habitat management efforts are expanded on City of Dana Point property. On Camp Pendleton, threats and stressors from military training and human land use remain at current levels but there is an increase in the

habitat management effort. This scenario also includes capacity for genetic rescue, leading to its implementation within all populations where it is warranted. Overall, with the increased capacity for habitat management, it is assumed that habitat suitability of all areas currently occupied by PPM (5-year average) will be maintained and areas that have historically been documented to be occupied by PPM since 2012 will have potential to be recolonized. Finally it is assumed that additional population creation efforts will be initiated by the first timestep (10 to 20 years).

#### ***Scenario 4: Management Decrease***

This scenario reflects what might happen if there is a decrease in management over time due to a decline in funding, habitat management cannot be performed consistently enough to maintain current levels of habitat suitability, and genetic rescue is not implemented. Because there is endowed funding for habitat management at Dana Point, the scenario for this site is the same as the No Change scenario where the amount of annual habitat management continues, but threats and stressors increase from development of the adjoining hotel site, use of the public access trail, and there is a continued loss of fitness from inbreeding depression. On Camp Pendleton it is assumed that the area that has potential to remain occupied is limited to areas that would be maintained without habitat management, using the low estimate since 2012 as a point of reference. The South San Mateo and Santa Margarita populations will also continue to be impacted by genetic erosion with the former population suffering from a loss of fitness due to inbreeding depression. It is also assumed that there is a loss of capacity to maintain habitat suitability within any of the created populations and they will be vulnerable to a loss of genetic variation over time.

### **6.3 Results**

We first provide the relevant limitations or other considerations for each population that will factor into the scenarios. We then present the results for each scenario and the applicable projected future condition of the subspecies in terms of the three Rs.

#### **Population Limitations/Considerations**

The current condition of each PPM population provides specific opportunities that can be pursued for increasing population resiliency but also limitations on how much resiliency can be improved (e.g., the amount of habitat available for enhancement, types of management that are practicable). Accordingly, the potential, likely, or anticipated changes that could be made in each of the four metrics over the next 10 to 20 years (and out to 30 to 50 years) are summarized in Table 8 for the three extant populations.

**Table 8.** Summary of the opportunities, limitations, and other considerations regarding the four current metrics that could alter the resiliency within each population and the status and possible and/or most likely changes that may occur in the future timeframe. These represent opportunities for or limitations to increasing resiliency of the populations and other considerations that we factor into the outcome of each scenario.

| Population      | Habitat                                                                                                                                                                                                                                                                                                                                                                                | Threats/Stressors                                                                                                                                                                                                                                                                                              | Genetic Diversity                                                                                                                                                                                                                                                                    | Population Size                                                                                                                                                                                                                                                                                                                 |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Dana Point      | Habitat enhancements limited to manual methods (no large machines or fire). Increase in quantity of habitat possible, but very limited by small parcel size even if population can expand into City property.                                                                                                                                                                          | Limiting trail use could alleviate significant source of disturbance; subject to current litigation. New development (hotel) likely to increase threats/stressors.                                                                                                                                             | Low diversity could be mitigated by genetic rescue but unique chromosome no. could delay implementation. Specific requirements for genetic rescue must be met (Table 5).                                                                                                             | Population size has potential to increase in response to habitat management and genetic rescue, but overall population size is constrained by surrounding development and small amount of available habitat.                                                                                                                    |
| South San Mateo | Use of fire precluded. Habitat creation/management limited to mechanical (machines) and chemical treatments (thinning, dethatching, herbicide, seeding). Area is available for population expansion.                                                                                                                                                                                   | No major changes anticipated.                                                                                                                                                                                                                                                                                  | Low diversity could be mitigated by genetic rescue. Specific requirements for genetic rescue must be met (Table 5).                                                                                                                                                                  | There is available habitat for population expansion in response to habitat management and genetic rescue, but ability to expand habitat occupancy is constrained by funding, surrounding infrastructure, development, and habitat attributes (e.g. steep terrain).                                                              |
| Santa Margarita | Edson habitat managed by fire; with potential to increase the area burned in Edson and Oscar One, but use of fire is constrained in areas with power lines and by logistical factors (weather, resource availability). Significant opportunities for additional manual and mechanical habitat improvement within Edson and Oscar One constrained by use of area for military training. | Training impacts are not anticipated to change. The impact of training on the population could be reduced if the area where training occurs is reduced or habitat can be created/enhanced in surrounding areas and the population successfully expands away from actively used portions of the training areas. | Population does not appear to be vulnerable to inbreeding depression but genetic management appears necessary to prevent continued loss of genetic diversity. It may be possible to increase contemporary effective population size ( $N_e$ ) with significant population expansion. | Habitat increase or improvement could lead to population increase. Because much of the area supports dense nonnative annual grasslands, the potential for habitat creation will depend on funding availability, the ability to convert nonnative grasslands to habitat, and compatibility with co-occurring land use practices. |

### *Dana Point*

**Habitat.** Habitat manipulations are limited primarily to manual methods (e.g., no mowers or use of heavy machinery), making management financially costly and time intensive. Expanding the current amount of habitat is limited by surrounding development and the size of the preserve (11.7 ha (29 ac), a portion of which (e.g., 4 ha (10 ac.) is uninhabitable due to topographic relief. There is around 8 ha (20 ac) of adjoining City owned open space where PPM habitat expansion could be pursued but where clay loam soils may limit the amount of habitat that can be made suitable to support PPM (Merrill 2023, pers. comm). Due to habitat fragmentation and isolation, habitat management will be needed to sustain suitable conditions at this site in perpetuity. Currently, nonnative grasses are not prevalent at Dana Point, so less management is likely necessary to maintain habitat suitability here relative to the MCBCP populations, where nonnative grasses are widespread and the dominant vegetation cover over large areas.

**Threats/Stressors.** Efforts by the land manager to better regulate the intensity of trail use to reduce the impact of recreational use on PPM is subject to current litigation. Resolution of this litigation could provide the public continued access to the trail from 7:00 AM to sunset or could result in more restricted hours and days of operation. The proposed hotel development (Dana Point Real Estate 2024, entire), adjacent to PPM habitat, is anticipated to proceed under any scenario and will likely increase threats and stressors from artificial light, noise pollution, increased human activity on the trail system, and, possibly increased trespass within the Preserve. Therefore, human associated disturbances within the conserved habitat are likely to increase in the future. Threats and stressors may be minimized and mitigated by the design of adjoining development and habitat management practices, but the benefit to population resiliency may be minor relative to the increased impacts from human use.

**Genetic Diversity.** While genetic rescue has been recommended for this population to reduce the threat of inbreeding depression (Shier et al. 2022, pp. 48–52), concerns about the potential to introduce outbreeding depression by outcrossing among populations with chromosomal differences has prompted efforts to collect additional Dana Point mice for captive breeding before attempting genetic rescue. Specifically, it is recommended that offspring from crosses of Dana Point and MCBCP mice bred in captivity be backcrossed with animals from Dana Point to produce outcrossed animals that have the same chromosome number as Dana Point residents before performing genetic augmentation. Those individuals would then be introduced to Dana Point to reduce the risk of introducing outbreeding depression during genetic augmentation. If genetic rescue is attempted using this or another strategy, it is not guaranteed to successfully increase population resiliency, although results from crosses of animals with different chromosome number in captivity suggest that the potential cost from outbreeding depression in animals with admixed karyotypes is outweighed by the fitness benefits from the boost in genetic diversity associated with outbreeding (see Table 5; Shier et al. 2022, pp. 48–52; Wilder et al. 2005.a, entire).

**Population size.** Overall, the population size possible at Dana Point is limited by the amount of habitat available, as PAO for this population is already relatively high (see Table 1). It is uncertain whether all of the available habitat can be managed so that it is suitable and occupied by PPM all the time (Merrill et al. 2023, p. 26). Thus, while there is potential for the resiliency of

Dana Point population to increase, it is unlikely that resiliency will increase to a point where the risk of extirpation during population “bust” years is negligible. Although this population has rebounded following past population contractions, it has become alarmingly small twice since its rediscovery, and genetic variation has been lost during these population bottlenecks (Merrill 2020, p. 12; Miller 2017, p. 3) suggesting it could decline again and be extirpated in the future, from a catastrophic event, long term population decline, and/or loss of fitness from inbreeding depression.

**Summary.** Although there is potential to increase the size and stability of the Dana Point population, under any scenario the limited amount of habitat that is available for this population to expand into limits the maximum resiliency of this population. Genetic rescue could help mitigate future genetic bottlenecks, inbreeding depression, and genetic erosion, but will not overcome habitat limitation. Threats are likely to increase incrementally from current conditions due to proposed adjoining development, use of the public access trail and other human associated disturbances.

### *South San Mateo*

**Habitat.** Current habitat management began in 2018 and includes about 10 ha (25 ac) of manual and chemical efforts to manage shrub and nonnative grasses (see Figure 12). While this management could be expanded, prescribed fire is not available as a management option at this site due to infrastructure (power lines, water reservoirs) and adjoining housing, thus management is limited to more time and labor-intensive methods such as mowing, thinning, chemical treatments, and seeding/planting. It appears likely that habitat management will be needed to sustain and maximize habitat quality across much of this site.

**Threats/Stressors.** Impacts from adjoining residents, military training and infrastructure operations and maintenance are relatively minor so threats and stressors in this area are primarily associated with vegetation senescence and invasion of nonnative annual grasses. Other than changes to the vegetation community from vegetation succession and nonnative plant invasions no major changes in land use are expected that would significantly alter resiliency.

**Genetic Diversity.** While genetic rescue has been recommended for this population (Shier et al. 2022, pp. 48–52), a specific proposal that details the methods and timing for performing genetic augmentation at South San Mateo has not yet been developed. Should genetic rescue be approved and carried out, it appears to have a good potential for boosting genetic variation and reducing the potential for inbreeding depression based on results from the captive breeding program (see Table 5; Shier et al. 2022, pp. 48–52). Without genetic augmentation and the maintenance of habitat, this population will continue to suffer from inbreeding depression and genetic erosion.

**Population size.** Increasing the population appreciably at South San Mateo likely is possible, but is constrained by funding availability and logistical consideration, such as the level of effort and staffing required to increase and sustain the quantity and quality of suitable habitat for PPM.

**Summary.** There is some ability to increase resiliency in the South San Mateo population, but maintaining and expanding habitat management to increase the size of this population size is constrained by the availability of funding and effort required. Other than the

threat of vegetation senescence and potential for proliferation of nonnative grasses in response to disturbance and concerns from inbreeding depression, threats at this site are not a major concern and are unlikely to change in the foreseeable future. Genetic rescue could help increase genetic diversity and potentially improve the fitness of this population.

### *Santa Margarita*

**Habitat.** Habitat within the Edson Range portion of the Santa Margarita population is currently managed by prescribed fire, although it is uncertain whether prescribed fire will be able to increase the population back to levels seen prior to 2017, as fire has only recently been reinstated as a management tool, and the ability to implement prescribed fire has been limited by logistical factors (e.g., availability of fire agency personnel, wind speed, fuel moisture, etc.) (see Table 1). There are additional areas that could be burned in Edson Range, and there are areas that could benefit from additional types of habitat management. For example, a 3 ha (8 ac) area of nonnative grassland has been proposed to be mowed and restored for PPM when scheduling and funding allow.

Current management in the Oscar One training area portion of the Santa Margarita population has focused on the creation of 6 ha (15 ac) of habitat by the removal of dense nonnative annual grasses and enhancement of an experimental corridor through coastal sage scrub and grassland to try to connect the created habitat to occupied habitat in Edson Range (Figure 13). While this project is very recent, track tube monitoring suggests that PPM are responding positively to clearing of the nonnative grasses and enhancement of the movement corridor. High tension power lines limit the ability to use prescribed fire in a large portion of Oscar One, but there are portions of this area that could be burned, including an 8 ha (20 ac) area where prescribed burning has been approved but not yet scheduled (Figure 13). Where manual and mechanical vegetation treatments are required, such as underneath powerlines, this work is time and labor intensive, which suggests it could be difficult to sustain funding for these efforts over the long term. Currently, MCBP does not foresee additional large funding sums for management continuing in the future (Thomas 2024, pers. comm.). Given the level of effort required to manage habitat for PPM in Oscar One via the removal of nonnative grasses, the population may be most easily expanded by implementation of prescribed fire within Edson Range and portions of Oscar One where prescribed fire can be implemented. However, there are logistical barriers and constraints to the implementation of prescribed fire as well, including operational difficulties (qualified burn boss availability and staffing, timing with military training schedule), climate challenges (fuel moisture, vegetation phenology, smoke management, wind conditions), and fuel challenges (fuel management and loading, training-induced fires, fuel types and invasive species issues) (Zych 2024, pers. comm.). The potential expansion of the population into areas recently mechanically and chemically treated in Oscar One is promising, but the level of effort required to maintain this habitat over the long time is likely to be significant.

**Threats/Stressors.** Training-related threats in this area are not anticipated to change, suggesting current impacts to PPM from military training will continue. The overall impact of training could potentially be ameliorated by performing habitat management to expand and promote a change in the distribution of the population away from the training area. Threats and impacts from training may also have potential to be reduced with decreases in training intensity or if impacted habitat that is no longer being used for training could be restored; however, without a change in the training footprint, this is unlikely.

**Genetic Diversity.** Although it does not appear this population is currently vulnerable from inbreeding depression, genetic data shows it has recently undergone a loss of genetic diversity and remains at risk of continued genetic erosion,. Genetic augmentation is not currently proposed for this population but genetic rescue is a strategy that could be explored for maintaining and increasing genetic diversity within this population (e.g., with animals from South San Mateo). A significant expansion of this population via creation of additional habitat could also be used to stabilize and possibly increase its contemporary effective population size. With appropriate genetic management, it may be feasible to maintain the effective size of this population above the threshold at which it is vulnerable to a loss of fitness from inbreeding depression, but it is uncertain whether the effective population size can be increased sufficiently to mitigate its risk from genetic erosion. Nevertheless, genetic management via managed migration and/or population expansion appears to be necessary to combat genetic erosion and the risk of this population developing inbreeding depression.

**Population Size.** The Santa Margarita population is the largest population with the smallest percent of area occupied. While spatially the Santa Margarita area has the greatest area for supporting population expansion, the ability to enhance habitat to improve its suitability for PPM is constrained by use of much of this area for military training, and the amount of funding and effort required to convert areas dominated by nonnative annual grasses to suitable PPM habitat. This population recently (2017) suffered a decline, and has not yet rebounded. Given active on-going land management and favorable environmental conditions, this population likely retains the ability to expand into previously occupied areas and, with increased management, may have potential to maintain a higher average area of occupancy than the most recent 5-year average.

**Summary.** The Santa Margarita population appears to have the greatest potential for population expansion, but this depends on reducing threats and impacts from competing land uses (e.g., the footprint and intensity of military training), and funding and capacity to manage and enhance habitat through implementation of prescribed fire (e.g., within Edson Range) and/or mechanical and chemical vegetation management methods.

### Scenario 1: No Change in Management

**Resiliency:** Over the next two time steps, management is projected to continue as currently implemented without implementation of genetic rescue. Over the next 10 to 20 years we project that risks from inbreeding depression and genetic erosion will increase in all populations, such that population resiliency will be very low in the smallest two populations and moderate in the Santa Margarita population. Based on the current level of threats to the populations, the two smaller populations will face a very high risk of extirpation and the Santa Margarita population will face a moderate to high risk of extirpation (Table 9). By 30 to 50 years in the future, we expect genetic diversity will continue to erode and inbreeding depression will become more severe in the smaller populations, with potential for the effective size of the Santa Margarita population to fall below 100. We also anticipate that the impacts from climate change may increase the frequency or severity of population fluctuations. Accordingly, the very high risk of extirpation for the two smaller populations could lead to their extirpation. Though the risk of extirpation of the Santa Margarita population is likely to increase incrementally, this population is anticipated to persist.

**Redundancy:** Over the next 10 to 20 years, based on current population creation efforts we project that one new population is likely to be established. Though the subspecies is made up of small populations that will remain at risk of extirpation from low resiliency and catastrophic events, the creation of an additional population has potential to maintain or improve species redundancy. However, by 30 to 50 years, without continued investment in genetic and habitat management, the newly established population and the extant populations will face a high to very high risk of extirpation. In the future, the subspecies is likely to occur among 1 to 4 populations and redundancy could be reduced with the loss of any populations that would further reduce their ability to withstand catastrophic events.

**Table 9.** Changes to the four metrics under Scenario 1 (No Change scenario) and the resulting resiliency category for each population in the next 10 to 20 and 30 to 50 years. The shading of the Resiliency boxes indicates extirpation risk: gray indicates populations that are possibly extirpated by that timestep; dark red indicates that the risk of extirpation is very high, and pink indicates a high risk of extirpation.

| Population                     | Management                                                                               | Threats/Stressors                                                                      | Genetic Diversity                                                                            | Pop. Size<br>(Avg. Occ.<br>Ha) | Resiliency<br>10 to 20 yrs | Resiliency<br>30 to 50 yrs |
|--------------------------------|------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|--------------------------------|----------------------------|----------------------------|
| Dana Point                     | Habitat management continues as current.                                                 | Trail use continues or increases. New development (hotel) increases threats/stressors. | No genetic rescue; more potential bottlenecks. Diversity likely to decline ( $N_e < 12.3$ ). | 5                              | very low                   | very low                   |
| South San Mateo                | 10 ha managed/year.                                                                      | No major changes anticipated.                                                          | No genetic rescue. Diversity likely to decline ( $N_e < 21.3$ ).                             | 38                             | very low                   | very low                   |
| Santa Margarita                | Prescribed fire continues; continued 8 ha management (corridor and intensive treatment). | Training unlikely to change.                                                           | No genetic rescue. Diversity likely to decline ( $N_e < 255$ ).                              | 113 to 121*                    | moderate                   | moderate/low               |
| New established population (1) | Required.                                                                                | Unknown (low)                                                                          | $N_e \geq 50$                                                                                | < 50                           | low                        | low                        |

\*Hectares may decline by second timestep due to decreased fitness from genetic erosion, climate change and persistent and threats/stressors.

## Scenario 2: Moderate Management Increase

**Resiliency:** Under this scenario, implementation of genetic rescue is assumed to proceed, reducing the threat from inbreeding depression and raising the resiliency of the two smallest populations to low, and maintaining a moderate level of resiliency within the Santa Margarita population over the next 10 to 20 years. This level of resiliency is also anticipated to be maintained over the next 30 to 50 years. Management at Dana Point cannot add much more

habitat, as an average of 5 ha (12 ac) is currently occupied in an area where only about 8 ha (20 ac) are available, and threats from adjoining development and increased use of the public access trail are likely to increase. South San Mateo would likely add some habitat management, which is projected to boost habitat occupancy within this management unit by about 26 percent, but overall habitat occupancy will remain below 100 ha (247 ac). At Santa Margarita, realization of the benefits from the 8 ha (20 ac) of management along with an additional 9 ha (22 ac) of planned management could increase habitat occupancy from 113 to 130 ha (279 to 321 ac). However, because this population will continue to occupy less than 200 ha, and threats from military training are anticipated to persist, it is projected to have a moderate level of resiliency with a moderate to high risk of extirpation (Table 10).

**Redundancy:** In this scenario, half or fewer of the population creation attempts are assumed to become established. Assuming two additional population creation efforts are attempted beyond the two introduction efforts underway, we project two additional populations have potential to become established in the next 10 to 20 years. Assuming genetic management maintains the genetic health of these populations over time, redundancy is projected to be maintained or improved with the potential for up to 5 populations to be maintained across both timesteps.

### Scenario 3: Large Management Increase

**Resiliency:** Under the Large Management Increase scenario, over the next 10 to 20 years genetic rescue is anticipated to reduce the threat from inbreeding depression and raise the resiliency of the two smallest populations to low, and maintain a moderate level of resiliency within the Santa Margarita population. Over the next 30 to 50 years, this level of sustained management is also anticipated to maintain these resiliency levels within the populations (Table 11). Dana Point habitat management would be expanded into the 8 ha (20 ac) of adjacent city property and threats/stressors from adjoining development (e.g., invasive ants, domestic animals, night-time lighting) and trail use are at least partially mitigated. While additional habitat management could potentially more than double the size of this population, the total amount of habitat occupied will remain well below the 100-ha threshold needed to achieve moderate population resiliency. At South San Mateo, doubling the amount of habitat management also would not bring the occupied area above 100 ha (Table 11). At Santa Margarita, the more intensive management in Oscar One is anticipated to more than double the current area that is managed (manual and mechanically) from 8 to 20 ha (20 to 49 ac), and the use of prescribed fire is anticipated to extend into portions of Oscar One. Considering the recent population decline and fluctuations at Santa Margarita, we project that a large management increase has potential to return previously occupied areas to suitable habitat, resulting in an average area occupied of up to 260 ha (642 ac) or more (260 is the average during the four highest years, 2013 to 2016). Although this would boost the area occupied above 200 ha, it is uncertain whether genetic management has a reasonable likelihood of increasing the effective population size to  $N_e \geq 500$ . Based on the increase in habitat occupancy we project this population will have a moderate resiliency and moderate risk of extirpation over the next 10 to 20 years, but due to the persistent threats from genetic erosion, habitat degradation in association with military training activities and impacts from climate

change, over the next 30 to 50 years it could face a moderate to high risk of extirpation (Table 11).

**Redundancy:** Under this scenario, all attempted translocations are projected to be successful leading to the potential creation of 4 additional populations. Although these populations are projected to have a high risk of extirpation due to their small size following creation, their creation is projected to improve species redundancy by distributing the species among a greater number of populations, and will increase the likelihood that one or more populations will survive a catastrophic event.

**Table 10.** Changes to the four metrics under a Moderate Management Increase scenario and the resulting resiliency category for each population in the next 10 to 20 and 30 to 50 years. The shading of the Resiliency boxes indicates the extirpation risk: pink indicates a high risk of extirpation.

| Population                      | Habitat Management                                                                                     | Threats/Stressors                                                                     | Genetic Diversity                         | Population Size (Avg. Occupied ha) | Resiliency 10 to 20 yrs | Resiliency 30 to 50 yrs |
|---------------------------------|--------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|-------------------------------------------|------------------------------------|-------------------------|-------------------------|
| Dana Point                      | Management increases some, to a few ha/year                                                            | Trail use continues or increases. New development (hotel) increases threats/stressors | Genetic rescue (and $N_e \geq 50$ )       | 5 to 6                             | low                     | low                     |
| South San Mateo                 | Continued 10 ha, plus 0 to 10 additional ha                                                            | No major changes anticipated                                                          | Genetic rescue (and $N_e \geq 50$ )       | 38 to 48                           | low                     | low                     |
| Santa Margarita                 | Prescribed fire continues; continued management of 8 ha (corridor and intensive treatment), 9 ha added | Training unlikely to change                                                           | $N_e \geq 255$ ; potential genetic rescue | 113 to 130                         | moderate                | moderate                |
| New established populations (2) | Required                                                                                               | Unknown (low)                                                                         | $N_e \geq 50$                             | < 50                               | low                     | low                     |

**Table 11.** Changes to the four metrics under a “Large Management Increase” scenario and the resulting resiliency category for each population in the next 10 to 20 and 30 to 50 years.

The shading of the Resiliency boxes indicates extirpation risk: pink indicates a high risk of extirpation, and light pink indicates a moderate or low risk of extirpation.

| Population                      | Habitat Management                                                                                   | Threats/Stressors                                                                                                       | Genetic Diversity                         | Population Size (Avg. Occupied ha) | Resiliency 10 to 20 yrs | Resiliency 30 to 50 yrs |
|---------------------------------|------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|------------------------------------|-------------------------|-------------------------|
| Dana Point                      | Management expands within and beyond the preserve into City property. 10 ha continues,               | Trail use is restricted .<br>New development (hotel) impacts partially mitigated.<br>Threats stay the same or decrease. | Genetic rescue (and $N_e \geq 50$ )       | 6 to 14                            | low                     | low                     |
| South San Mateo                 | additional 10 to 20 ha                                                                               | No major changes anticipated                                                                                            | Genetic rescue (and $N_e \geq 50$ )       | 45 to 55                           | low                     | low                     |
| Santa Margarita                 | Prescribed fire continues; 8 ha management (corridor and intensive treatment) continued, 20 ha added | Training unlikely to change.                                                                                            | $N_e \geq 255$ ; potential genetic rescue | 140 to 260+                        | moderate                | moderate                |
| New established populations (4) | Required                                                                                             | Unknown (low)                                                                                                           | $N_e \geq 50$                             | < 50                               | low                     | low                     |

#### Scenario 4: Management Decrease

**Resiliency:** Management at Dana Point has endowed funding, so it is anticipated that there will be no appreciable change in the number of hectares that are managed at this site under this scenario. However, we assume that there will be increased impacts to PPM from use of the trail and adjoining development. Without genetic rescue and with increased threats, long term population fitness is anticipated to continue to decline, and given recent bottlenecks and very small population size, we expect that in 10 to 20 years, population resiliency will remain very low and this population could be lost (Table 12). At South San Mateo, it is anticipated that without significant habitat management, some patches of habitat will remain, resulting in around 25 ha (62 ac) or less of occupied habitat on average, using the lowest level of occupancy estimated over the last 5 years as a point of reference. Without genetic management to decrease the risk of inbreeding depression, and with the decrease in the quality of available habitat, we expect this population will continue to have very low resiliency and could possibly become extirpated by the first timestep. At Santa Margarita, while management would stop, prescribed and training-induced fire is likely to continue, meaning Edson Range would presumably remain occupied to some extent, as would areas in Oscar One where the population has persisted over

recent years without habitat management. Thus, we estimate the amount of occupied habitat could range between 50 ha (124 ac) (the lowest area occupied at Edson Range (28 ha; 69 ac) plus the lowest area occupied at Oscar One (22 ha; 54 ac)) and 109 ha (269 ac) (the highest area occupied at Edson Range in the last 5 years (87 ha; 215 ac) plus the lowest area occupied at Oscar One (22 ha; 54 ac)). Without genetic management to ameliorate the risk from genetic erosion, we anticipate this population will sustain an effective population size of  $N_e \geq 100$  over the next 10 to 20 years but has potential to fall below this threshold over the next 30 to 50 years. Because there is no anticipated change in the threats to this population from military training, we anticipate this population will have a moderate to low resiliency and face a moderate to high risk of extirpation over the next 10- 20 years and will have a moderate to low level of resiliency and face a high risk of extirpation over the next 30-50 years. (Table 12).

**Redundancy:** No new populations are established under this scenario. As Dana Point and South San Mateo are possibly extirpated by 10 to 20 years, redundancy will decrease, with the potential for just the largest population to persist. By 30 to 50 years, the Santa Margarita population will face a high risk of extirpation.

**Table 12.** Changes to the four metrics under a Decreased Management scenario and the resulting resiliency category for each population in the next 10 to 20 and 30 to 50 years.

The shading of the Resiliency boxes indicates extirpation risk: dark gray indicates populations that are possibly extirpated and pink indicates a high risk of extirpation is high.

| Population                  | Habitat Management                                 | Threats/Stressors                                                                    | Genetic Diversity                                                                            | Population Size (Avg. Occupied ha) | Resiliency 10 to 20 yrs | Resiliency 30 to 50 yrs |
|-----------------------------|----------------------------------------------------|--------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|------------------------------------|-------------------------|-------------------------|
| Dana Point                  | Habitat management continues as current.           | Trail use continues or increases. New hotel development increases threats/stressors. | No genetic rescue; more potential bottlenecks. Diversity likely to decline ( $N_e < 12.3$ ). | 5                                  | very low                | very low                |
| South San Mateo             | Current 10 ha. not sustained.                      | No major changes anticipated                                                         | No genetic rescue. Diversity likely to decline ( $N_e < 21.3$ ).                             | 0 to 25                            | very low                | very low                |
| Santa Margarita             | Prescribed fire continues; Other management stops. | Training unlikely to change.                                                         | No genetic management implemented. Diversity declines ( $N_e < 255$ )                        | 50 to 109*                         | moderate**              | moderate/low            |
| No additional populations . |                                                    |                                                                                      |                                                                                              |                                    |                         |                         |

\*Hectares may decline by second timestep due to decreased fitness from genetic erosion and climate change impacts.

\*\*Population presumed extant.

## Future Condition

Using the results of each of the future scenarios, we summarize the future condition of the PPM in terms of resiliency (and likelihood of extirpation) for each population and population redundancy under each of our four scenarios at both timesteps (Figure 22).

### *Resiliency*

Because resiliency levels in this analysis are defined primarily by just two metrics, moving between these levels requires that the thresholds for each metric are met (see Table 3). However, smaller shifts in the amount of occupied habitat, threats, and effective population size may incrementally change resiliency and extirpation risk to some extent. This assessment considers populations with very low resiliency as having a “very high” risk of extirpation which can result in the populations becoming “possibly extirpated.” An assignment of “possibly extirpated” indicates we think there is greater than a 50 percent likelihood those populations could become extirpated over the time interval considered given the continued exposure of those populations to identified threats and stressors.

Given that each scenario predicts the outcome of habitat management and threat reduction given different realities (no change, two levels of management increase, and a plausible decrease in management), we assume that the management projected under each scenario is sustained across the two time steps and there is no substantial reduction to threats or stressor levels based on changes to management during the second timestep. Conversely, depending on the scenario, we project that resiliency could decrease during the second timestep without genetic management, as a loss of adaptive potential and fitness from inbreeding depression due to genetic erosion are likely to decrease habitat occupancy and the ability of populations to rebound from decline. Additionally, although there remains some uncertainty regarding the net effects to the populations from climate change, our projection that negative impacts are likely to emerge during the second timestep (e.g., in association with increased variability in rainfall and population fluctuations), suggest the populations will face an elevated risk of extirpation by 30 to 50 years in the future.

Based on current conditions and the constraints on each population in terms of the ability to increase habitat, and reduce threats and stressors, we project that resiliency can only be appreciably increased for the three extant populations under scenarios where genetic diversity is increased (Figure 22). Added habitat alone, given the amount we propose is possible, is not sufficient to improve the level of resiliency of any of the extant populations under any scenario.

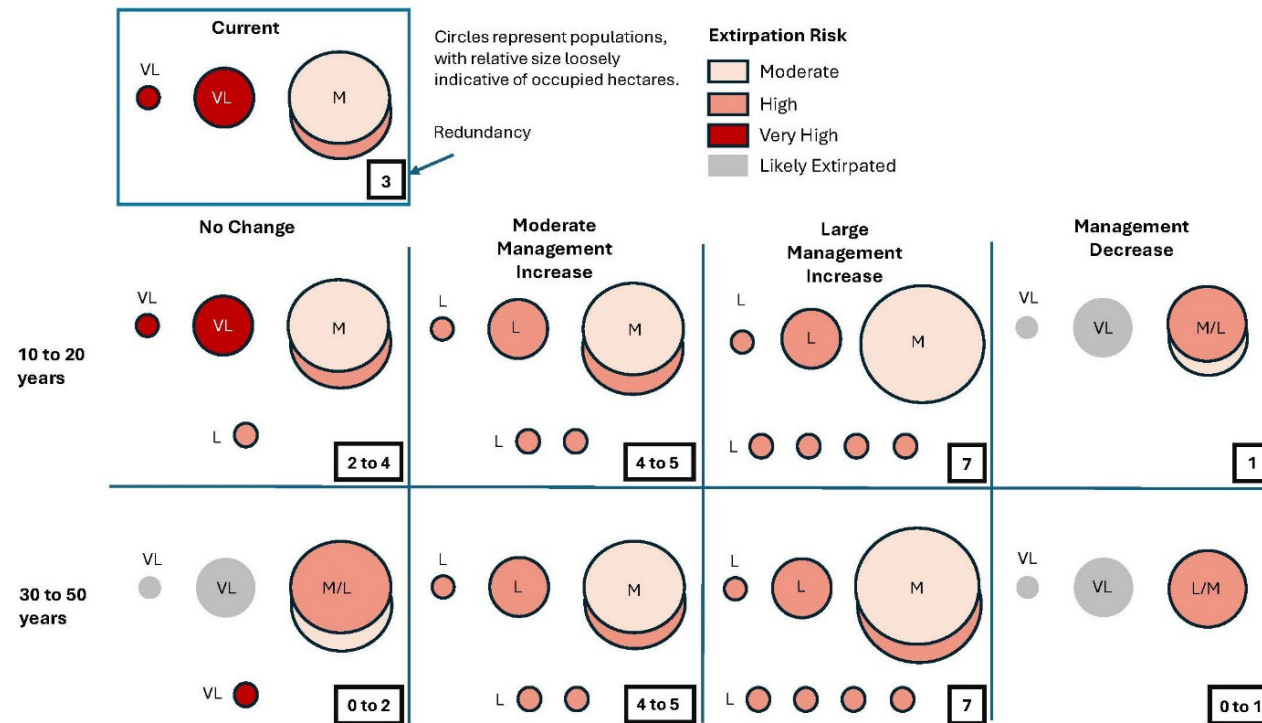


**Figure 19.** Depiction of the future condition of the Pacific pocket mouse at two timesteps (10 to 20 years and 30 to 50 years in the future) under four potential management scenarios, indicating number of populations, relative population size, resiliency, redundancy, and extirpation risk.

Populations are depicted within each scenario from left to right: Dana Point, South San Mateo, and Santa Margarita. Newly established populations are depicted along the bottom of each scenario. Resiliency is indicated by letter (VL = very low, L = low, M = moderate). Extirpation risk is based on resiliency and the added impacts of potential genetic degradation, climate change and threats and stressors over time.

For the Management Decrease and No Change scenarios that do not include genetic rescue, the Dana Point and South San Mateo populations exhibit very low resiliency. Due to the very high risk of extirpation associated with this level of resiliency, projections indicate that under decreased management both populations could be extirpated within the first timestep, and under the No Change scenario both populations could become extirpated by the second time step. For the population that is anticipated to be created under the No Change scenario, we assume that a starting effective population size of  $N_e \geq 50$  will provide it low resiliency within the first time step; however, without continued genetic management, genetic erosion is projected to reduce resiliency to very low resiliency within the second time step.

Under the No Change scenario, the Santa Margarita population is assessed to have moderate resiliency at the first time step, but the combined effects from genetic erosion, climate change and ongoing threats from military training activities could reduce its resiliency to moderate-low resiliency within 30 to 50 years. Under the Management Decrease scenario, although the effective size of this population is likely to remain above 100 within the first time step, reduced habitat management could cause habitat occupancy to fall below 100 ha, giving it a moderate to low resiliency score. Based on an incremental increase in impacts from genetic erosion, reduced habitat management and climate change, this population is also projected to have low to moderate resiliency during the second timestep.

Under both management increase scenarios, genetic rescue is anticipated to improve the resiliency of the Dana Point and South San Mateo populations, raising them from Very Low to Low resiliency within the first time step and maintained this level during the second timestep. The two and four additional populations created under the Moderate and Large Management increase scenarios, respectively, are each qualified as having Low Resiliency (i.e.  $N_e \geq 50$ ) at the first time step. Continued genetic management is anticipated to sustain this level of resiliency during the second time step. Because there is considerable uncertainty regarding the feasibility to increase the effective population size of the Santa Margarita population above 500, we do not anticipate that a high level of resiliency can be achieved for this population over the next 50 years—even under the Large Management Increase scenario where it may be feasible to increase habitat occupancy above 200 ha. Thus, both increased management scenarios are projected to maintain moderate resiliency for this population across both time steps.

Overall, while the moderate resiliency rankings for the Santa Margarita population suggest a moderate risk of extirpation under scenarios and times when it qualifies for this ranking based on the occupied habitat and effective population size metrics, ongoing impacts to the habitat from military training activities (e.g., soil compaction, high fire frequencies, facilitation of nonnative grass and weed invasions) combined with environmental stochasticity suggest there is an increased potential for rapid shifts in population size and habitat suitability, as was observed in Edson Range between 2018 and 2021. Thus, based on the threat factors for this population, we have qualified it as having a moderate to high risk of extirpation, even when it is assessed as having moderate resiliency. For times when the area occupied or effective population size metrics suggest this potential has low resiliency, as under both time steps under the management decrease scenario and the second timestep under the no change scenario, it faces a high risk of extirpation.

## *Redundancy*

Although the close proximity of the extant populations suggests a climatic event could present an equal threat to each of the populations, in addition to attempts to increase the size of the extant populations through habitat management, 11 sites have been assessed for the ability to improve species redundancy via population creation. (Chock et al. 2022, entire; Edgarian et al. 2023, entire; GSRC and SDZWA 2023, entire). While additional sites may be considered in the future, active translocation efforts are currently being pursued at two of these sites (Laguna Coast and Wire Mountain) and translocation efforts are proposed to be performed at two other sites (Dilley and North San Mateo) in the next few years. At the most suitable of the 11 sites evaluated (Laguna Coast), where captive bred animals have been released almost annually since 2016, a self-sustaining population has yet to become established. Habitat management has been required to prepare and maintain habitat suitability for PPM at each of the active translocation sites, and similarly will be required prior to and following introductions to the other two sites. Of the remaining seven sites evaluated, the landowners of the two most suitable sites have so far not expressed a willingness to accept a PPM introduction, and the remaining five sites are assessed as having limited habitat suitability. Thus, within the next few years it appears likely that a total of four population creation efforts will be attempted, which, under a best case scenario, could lead to the establishment of up to 4 more populations. Of course, if none of these efforts prove successful, there is the possibility that no additional PPM populations will be created in the foreseeable future (Figure 22).

The cumulative probability of a catastrophic event that would have population-level impacts increases over time as does the potential that climate change could have negative consequences for the PPM populations. This indicates that the risk of extirpation for each population will increase over time. Populations that are small or become small due to low population recruitment from environmental or demographic stochasticity, or a loss of fitness from inbreeding depression, face a higher risk of extirpation from these impacts. Such catastrophic events could include a series of years with climatic conditions that fail to satisfy the subspecies' needs (amount/timing of rainfall impacts food, open space, etc.), the introduction of disease or other pathogens, an exceptionally intense fire or a fire at the wrong time of year, or a high-impact weather event. These events could occur singularly or happen together to compound the impacts to the species. Thus we project that the likelihood of a catastrophic impact leading to the extirpation of the subspecies is greatest under the Management Decrease scenario, which could lead to the creation of 0 to 1 new populations, and redundancy will be most improved under the Large Management Increase scenario which will maximize the area of habitat occupancy within each of the extant populations and could result in the creation and maintenance of up to four additional populations (Figure 22). Of course, under each of the scenarios, species redundancy will be compromised with extirpation of one or more of the extant or created populations.

## *Representation*

Linkage disequilibrium-based effective population size estimates suggest that isolation of populations that were once larger and more connected and population bottlenecks have resulted in a loss of representation and genetic diversity compared to historical levels (Wilder et al. 2025, p. 836). Signs of genomic erosion over the past several decades consistent with strong genetic drift in the remnant populations include lower genome-wide heterozygosity and increased long

runs of homozygosity in the Dana Point and South San Mateo populations relative to the Santa Margarita population (Wilder et al. 2025, p. 835). Theory suggests, based on recent effective population size estimates, that the Dana Point and South San Mateo populations could experience 4.1 and 2.3 percent losses of heterozygosity per generation, respectively (Wilder et al. 2025, p. 835). Potential deleterious consequences from genetic drift and inbreeding are further suggested by elevated levels of genetic load in these populations, estimated by homozygous-derived alleles that cause non-synonymous changes within evolutionary conserved protein coding genes (Wilder et al. 2025, p. 835). Burdens of genetic load are greater in the Dana Point and South Mateo populations and the frequency of deleterious alleles has increased in these populations over time (Wilder et al. 2025, p. 835).

Although representation within PPM has been compromised by contraction of the species range and genomic erosion, existing levels of representation may have potential to be maintained with population expansion, the creation of additional populations and genetic rescue as projected under the Modest and Large Management Increase scenarios. Genetic rescue would increase heterozygosity within and among populations and facilitated gene flow could help to prevent further genetic erosion. This would decrease the risk of inbreeding depression and maintain or increase the subspecies' adaptive capacity to persist in place over time under changing environmental conditions. Facilitated gene flow among populations also helps to ensure that unique alleles are represented across the extant populations, so that if one population is lost, its unique alleles are not lost with it. However, even with improved genetic management, it is anticipated that the subspecies capacity to respond to changing environmental conditions will remain constrained by the fragmented nature of its habitat and its inability to shift its distribution in space over time.

We expect representation will continue to decline under a No Management or Management decrease scenario at both timesteps, from genetic drift and inbreeding.

### *Summary*

In summary, if management does not increase or if there is a decrease in management, there is a very high risk of losing two or more populations, in the next 10 to 20 years. By 30 to 50 years, under a No Management or Management Decrease scenario, all populations are at high risk of extirpation.

However, resiliency and redundancy have the potential to increase in the next 10 to 20 years, under the Moderate and Large Increase in Management scenarios with the Santa Margarita population as the only population with moderate resiliency (Figure 22). The success of increased management will depend on the ability of habitat management to improve and maintain habitat suitability over the long term and the ability of genetic management to maintain or, ideally, increase genetic diversity within and among the individual populations. Given limitations on habitat availability, the improvement of species redundancy will require the successful creation of new populations and the ability to sustain management at those sites into the future (see Table 6 and Table 7). While research is being performed to improve the likelihood of translocation success, the success of those efforts cannot be predicted and may be beyond the ability of managers to control. Any newly created populations will inherently have low resiliency following initial establishment, and, given the isolated nature and management effort that will be needed to expand the size of those populations, we anticipate they will remain at high risk of

extirpation over time. Thus, these populations may periodically become extirpated and need to be reestablished. Representation is currently low and will need to be protected from further declines by establishing new populations and conducting genetic rescue and management of the extant populations.

Given the need for ongoing habitat and genetic management, and existing constraints on habitat availability and management capacity, we anticipate that subspecies viability has the greatest potential to be improved over the next 10 to 20 years.

## **6.4 Limitations and Uncertainties**

The recent rediscovery of the PPM and the highly fragmented nature of its natural habitat provides limited information about the historical extent of occupied habitat, along with population densities and abundance that occurred naturally on the landscape before invasive species and incompatible land uses became prevalent. Therefore, it is difficult to project the likelihood of population persistence under current conditions. Our ability to project future subspecies resiliency with certainty is limited by uncertainties about demographic, genetic, and habitat requirements for resiliency.

Uncertainties regarding the PPM populations include but are not limited to:

- Unknown historical habitat and population sizes, and connectivity among subpopulations. Did the subspecies historically persist in small populations? How connected were populations historically?
- Unknown level of genetic diversity required for resiliency. While effective population size is a well-established metric for population resiliency over time, it is not a direct metric for genetic diversity, and the thresholds used in this assessment are not necessarily firm cutoffs for resiliency categories. Some populations may be able to persist despite low genetic diversity, at least for some time. Genetic rescue is considered warranted for Dana Point and South San Mateo, but whether it is warranted at Santa Margarita is less clear. Recent genetic data and the estimated effective size of this population indicates it has and likely will continue to lose genetic diversity due to drift, suggesting some form of genetic management is likely to be needed in the future.
- Unknown true area of occupancy. While the monitoring protocol on MCBP is designed to be predictive of the entire population, the actual extent of potentially suitable habitat and extent of habitat occupancy in a given year is estimated and unknown; note that area of occupancy is the basis for the resiliency analysis.

Further, our projections are limited due to uncertainties surrounding the future of different management and recovery actions, specifically:

- The likelihood of new population establishment is unknown. While the Laguna Coast site has not yet become self-sustaining after 8 years of repeated effort, lessons learned can be implemented at new sites that may make them easier to establish, or these efforts may face similar or even greater challenges in becoming established. It is also uncertain which or how many sites will be made available in the future to support population creation efforts. Increased urbanization of the

region will continue to limit if not decrease the number of potential sites available. Therefore, future redundancy may be overestimated in the scenarios that project new populations.

- We do not know the likelihood of implementing additional management (habitat management, translocations, genetic rescue), as future actions will require funding, permission from landowners, staffing and availability of resources (e.g., captive bred or wild animals) to be implemented. Some funding for population creation efforts has been secured, but the capacity for long-term habitat management is uncertain and likely to face funding limitations. Management is likely to be constrained by weather, training needs, or other issues that may arise over time. Dana Point has endowed funding so a certain level of management there is certain to continue into the future. Some funding has been secured for current management at MCBCP, but generally, funding for habitat management on the installation is often project related and/or relies on congressional appropriations from the defense department.
- There is uncertainty over which forms of management will be implemented within each population. The discretion as to what methods to apply will be the responsibility of land managers, and decisions may change annually due to funding, weather, training needs, or other issues.
- It is unknown whether the contemporary effective population size can be increased for these populations to a level that is adequate for improving near term or long-term resiliency. Contemporary effective population size may increase with population expansion, but opportunities for appreciable population expansion are limited by habitat availability and suitability. However, all three populations have low genetic diversity compared to the captive population, where all three wild populations have been interbred, suggesting that genetic diversity can be increased by genetic rescue (Wilder 2024, pers. comm.).
- The responses of PPM to all potential management efforts are unknown. While some management efforts have shown success in creating habitat that is colonized by PPM, much of the management has only been recently initiated, and it is uncertain whether the benefits from habitat management can be sustained over the long term. Some methods may also be more effective than others depending on the location, prevalence of nonnative invasive grasses, weather, and existing population demographics.
- The estimate of occupied hectares is based on current estimates and current management, but how much additional management will be carried out and how the PPM will respond is unknown. Thus, average hectares occupied predicted for the future condition scenarios may be over- or under-estimated.
- The future of funding for the captive breeding program is uncertain. Originally intended to be a short-term endeavor to achieve three population reintroductions, funding for this program is secured only until July of 2027 and not guaranteed thereafter. Loss of funding for this program could affect the pace or ability to implement future reintroduction efforts and genetic rescue. Under the Moderate and Large Management Increase scenarios, genetic management is projected to be

needed in perpetuity; if the captive breeding program ends, the source of animals for genetic rescue will be limited to the remaining extant populations.

## **6.5 Conclusions**

The PPM currently exists as three small, isolated populations that have low resiliency relative to what they had historically. While populations are known to fluctuate greatly from year to year and within a season, all three populations have seen declines in population size in the past two decades, with all three at risk of extirpation. With only three extant populations, current population redundancy is greatly reduced from historical levels. The adaptive capacity of this subspecies is believed to be low based on low estimated effective population sizes of the extant populations and the fragmented nature of available habitat, which limit the subspecies' ability to persist in place or shift in space in response to changing environmental conditions.

In areas with an abundance of nonnative vegetation or a lack of fire or other disturbances, habitat quality has the potential to decline without management intervention, especially in areas where nonnative grasses can dominate. Vegetation in areas can rapidly become too dense to support PPM. Recent management efforts have demonstrated that habitat can be improved with management and that populations can expand into newly created habitat. However, these efforts require significant funding and staffing, and can be constrained by logistical factors (e.g., ability to implement prescribed fire and schedule management activities within military training areas,), suggesting they may be difficult to sustain over the long term.

At least one population (Dana Point) has been at Very Low resiliency for several decades (likely since its rediscovery in 1993). This population has continued to persist for more than 30 years, despite this very low resiliency. Thus, while a population with Very Low resiliency has a high chance of extirpation, this is not indicative of the certainty of extirpation. Maximizing the resiliency of the Dana Point population will require a sustained increase in management to maximize the area occupied by PPM and increased genetic diversity to help reduce further genetic erosion. Due to a lack of area to expand into because of surrounding development, moderate resiliency as defined in this document may not be attainable for this population.

Moderate resiliency may also not be attainable for South San Mateo under the presented scenarios due to habitat limitations and management requirements. With only 105 ha of estimated total available habitat within this management unit, this population is unlikely to occupy 100 ha or more of habitat on average. Maximizing resiliency of this population will require ongoing habitat management and genetic rescue.

Although two of the three extant populations of PPM are likely unable to reach Moderate or High resiliency under any scenario due to habitat availability and surrounding land use constraints, these populations contribute to the overall redundancy and representation of the subspecies, and should not be discounted as unlikely to persist over time. While their persistence is not guaranteed, both populations will have the best chance if occupied habitat and genetic diversity are maximized, with continued management and annual monitoring.

Santa Margarita has moderate resiliency and this level of resiliency can likely be maintained into the future, provided habitat management activities are sustained and increased, particularly in areas where nonnative grasses are dominant. Despite the large management area delineated (885 ha) at Santa Margaria, creating additional habitat within this management area will be costly, labor intensive, faces logistical constraints (e.g., ability to meet environmental

conditions for prescribed fire) and must be coordinated with use of the area for military training. While there has been a proposal to move land navigation training out of the Santa Margarita management area, MCBCEP does not currently recognize this as a possibility. Overall, the ongoing threat to the Santa Margarita population from military training suggests that while this population currently has moderate resiliency, it faces a moderate to high risk of extirpation, due to the potential for rapid changes in habitat suitability at this locale.

The establishment of additional populations in the No Change, Management Increase, and Recovery scenarios are important for improving the viability of PPM over time by increasing redundancy and providing additional populations to help “rescue” others if they become bottlenecked or extirpated. While new populations are likely to be constrained by habitat availability, these new populations have potential to provide needed redundancy to sustain the subspecies over time. Any new populations and the currently extant populations with low or very low resiliency are likely to be at risk of extirpation, so the subspecies will have the best chance of persistence if the habitat and genetic health of each population is managed.

Therefore, the future of the PPM depends on the management of each population such that habitat is always available and accessible, and populations are genetically diverse enough and large enough to withstand years when weather patterns or other factors result in population declines. Increased redundancy and representation are needed to maintain subspecies viability should some populations become extirpated. Because two of the extant populations and additional populations established on the landscape are expected to have, at best, low resiliency across all projected scenarios and timesteps, their persistence may be determined by the timing or intensity of catastrophic events, and a certain degree of chance. Additional populations have the potential to greatly improve subspecies’ redundancy, but the ability to successfully establish additional populations has yet to be achieved and remains uncertain.

## REFERENCES CITED

- ACS Habitat Management. 2021. Year 5 Annual Report: Implementation of Pacific Pocket Mouse Habitat Enhancement and Restoration for MILCON P-1044 MCBCP Base Camp Pendleton, California. Prepared for Naval Facilities Engineering Command Southwest. 59 pp.
- Adsit-Morris, D., C. Brehme, T. Edgarian, and R. Fisher. 2024. Update on PPM Monitoring and Vegetation Management. Presentation to PPM Working Group meeting.
- Asmus, J.L. (Environmental Security, MCBCP.). 2024. Personal communication. Email correspondence to Tiffany McFarland (Texas A&M Natural Resource Institute), dated May 6, 2024.
- Bailey, V. 1939. The solitary lives of two little pocket mice. *Journal of Mammalogy* 20:325-328.
- Barry, S., S. Larson, and M. George. 2006. California native grasslands: a historical perspective a guide for developing realistic restoration objectives. *Journal of Environmental Management*. 91(12): 7-11.
- Bartholomew, G. and T. Cade. 1957. Temperature regulation, hibernation, and aestivation in the little pocket mouse, *Perognathus longimembris*. *Journal of Mammalogy* 38:60- 72.
- Beatley, J.C. 1969. Dependence of desert rodents on winter annuals and precipitation. *Ecology* 50(4):721-724.
- Beier, P. 2005. Effects of Artificial Night Lighting on Terrestrial Mammals. *In* C. Rich and T. Longcore, (Eds). *Ecological Consequences of Artificial Night Lighting*. Washington, DC: Island Press. Pp. 15–42.
- Bennett, V.J., V.S. Quinn, and P.A. Zollner. 2013. Exploring the implications of recreational disturbance on an endangered butterfly using a novel modelling approach. *Biodiversity Conservation* 22:1783-1798.
- Bolger, D.T., A.C. Alberts, R.M. Sauvajot, P. Potenza, C. McCalvin, D. Tran, S. Mazzoni, and M.E. Soulé. 1997. Response of rodents to habitat fragmentation in coastal southern California. *Ecological Applications* 7(2):552-563.
- Brehme, C.S. (U.S. Geological Survey). 2023. Personal communication. Comment during 2023 annual Pacific pocket mouse working group meeting.
- Brehme, C.S. (U.S. Geological Survey). 2024. Personal communication. Conversation during recurring PPM SSA call in 2024.
- Brehme, C.S. (U.S. Geological Survey). 2025. Personal communication. Presentation of monitoring results during February 13, 2025, Pacific pocket mouse working group meeting.
- Brehme, C.S. and R.N. Fisher. 2009. 2008 Survey Results for the Pacific Pocket Mouse: North and South San Mateo, MCBCP Base, Camp Pendleton; with additional analyses to

- inform long-term monitoring design. Prepared for AC/S Environmental Security, MCBCP Base, Camp Pendleton. 40 pp.
- Brehme, C.S. and R.N. Fisher in collaboration with Burnham, K., P. Meserve, W. Spencer, W. Miller, M. Pavelka, and D. Deutschman. 2009. Pacific Pocket Mouse Monitoring Plan for MCBCP Base Camp Pendleton: Short Term Studies and Long Term Goals. 2009. Prepared for Wildlife Management Branch, AC/S Environmental Security, MCBCP Base Camp Pendleton. 88 pp.
- Brehme, C.S., J. A. Tracey, T.A. Matsuda, and R.N. Fisher in collaboration with Burnham, K., Meserve, P., Spencer, D. Deutschman, W. Miller, and M. Pavelka. 2011. Pacific Pocket Mouse Monitoring Protocol for MCBCP Base Camp Pendleton. Prepared for Wildlife Management Branch, AC/S Environmental Security, MCBCP Base Camp Pendleton. 55 pp.
- Brehme, C.S., J.A. Tracey, L.R. McClenaghan, and R.N. Fisher. 2013. Permeability of roads to movement of scrubland lizards and small mammals. *Conservation Biology* 27:710–720.
- Brehme, C.S., J. Sebes, T. Matsuda, D. Clark, and R.N. Fisher. 2014. MCBCP Pacific Pocket Mouse Monitoring Results for 2013 and Multi-year Trend Analysis from 2012 to 2013. Prepared for AC/S Environmental Security, MCBCP Base, Camp Pendleton. 70 pp.
- Brehme, C.S., J. Sebes, T. Matsuda, D. Clark, and R.N. Fisher. 2015. Pacific Pocket Mouse Monitoring 2014, MCB, Camp Pendleton. Prepared for AC/S Environmental Security, MCBCP Base, Camp Pendleton. 48 pp.
- Brehme, C.S., D.T. Adsit-Morris, T.K. Edgarian and R.N. Fisher. 2018. MCBCP Base, Camp Pendleton Pacific Pocket Mouse Monitoring Results and Trend Analysis for 2017. Prepared for Environmental Security Department, MCBCP Base, Camp Pendleton. 71 pp.
- Brehme, C.S., D.T. Adsit-Morris, T.K. Edgarian and R.N. Fisher. 2019. MCBCP Base, Camp Pendleton Pacific Pocket Mouse Monitoring Results for 2018 with Trend Analysis from 2012 to 2018. Prepared for AC/S Environmental Security, MCBCP Base, Camp Pendleton. 56 pp.
- Brehme, C.S., D.T. Adsit-Morris, T.K. Edgarian and R.N. Fisher. 2020. Permit Report: Pacific Pocket Mouse Monitoring Results for 2019 on MCBCP Base, Camp Pendleton. Draft Final. Prepared for U.S. Fish and Wildlife Service, California Department of Fish and Wildlife. 24 pp.
- Brehme, C.S., K. Merrill, D.T. Adsit-Morris, T.K. Edgarian, and R.N. Fisher. 2021. Draft Final: Dana Point Headlands (CNLM, City of Dana Point) Pacific Pocket Mouse Monitoring Results for 2020. Prepared for U.S. Fish and Wildlife Service, California Department of Fish and Wildlife. 42 pp.
- Brehme, C.S., D.T. Adsit-Morris, T.K. Edgarian and R.N. Fisher. 2022. Permit Report: Pacific Pocket Mouse Monitoring Results for 2021 on MCBCP Base, Camp Pendleton. Draft Final. Prepared for U.S. Fish and Wildlife Service, California Department of Fish and Wildlife, MCBCP Base, Camp Pendleton. 29 pp.
- Brehme, C.S., D.T. Adsit-Morris, T.K. Edgarian and R.N. Fisher. 2023a. Permit Report: Pacific Pocket Mouse Monitoring Results for 2022 on MCBCP Base, Camp Pendleton. Draft

- Final. Prepared for U.S. Fish and Wildlife Service, California Department of Fish and Wildlife, MCBCP Base, Camp Pendleton. 22 pp.
- Brehme, C.S., S.K. Thomsen, D. Adsit-Morris, and R.N. Fisher. 2023b. Interactions among rainfall, fire, forbs and nonnative grasses predict occupancy dynamics for the endangered Pacific pocket mouse (*Perognathus longimembris pacificus*) in a Mediterranean-type ecosystem. *Global Ecology and Conservation*, 47:1-11.
- Brehme, C.S., D.T. Adsit-Morris, T.K. Edgarian and R.N. Fisher. 2024. Permit Report: Pacific Pocket Mouse Monitoring Results for 2023 on MCBCP Base, Camp Pendleton. Draft Final. Prepared for U.S. Fish and Wildlife Service, California Department of Fish and Wildlife, MCBCP Base, Camp Pendleton. 29 pp.
- Brown, J.S., B.P. Kotler, R.J. Smith, and W.O. Wirtz. 1988. The effects of owl predation on the foraging behavior of heteromyid rodents. *Oecologia* 76:408-415.
- Brown, J.H. and B.A. Harney. 1993. Population community ecology of heteromyid rodents in temperate habitats. *In*: H. Genoways and J. Brown (Eds.). *Biology of the Heteromyidae*. Special Publication No. 10. The American Society of Mammalogists. Pp. 618-651.
- Brylski, P., W.B. Miller, S. Dodd, and S. Montgomery. 2009. Pilot Monitoring Project for the Pacific Pocket Mouse, 2008 CNLM Dana Point Preserve Orange County, California. Prepared for the Center for Natural Lands Management. 35 pp.
- Brylski, P., W.B. Miller, S. Dodd, and S. Montgomery. 2010. Draft addendum to the pilot monitoring project for the Pacific pocket mouse, 2009, CNLM Dana Point Preserve, Orange County, California. Prepared for the Center for Natural Lands Management. 36 pp.
- Burt W. H. and R.P. Grossenheider. 1980. A field guide to the mammals North America north of Mexico. Houghton Mifflin Company, New York.
- [CEPA] California Environmental Protection Agency. 2006. Climate Action Team Report to Governor Schwarzenegger and the Legislature. California Environmental Protection Agency, Sacramento, CA.
- Callison, J., J.D. Brotherson and J.E. Bowns. 1985. The effects of fire on the blackbrush (*Coleogyne ramosissima*) community of southwestern Utah. *Rangeland Ecology & Management/Journal of Range Management Archives*, 38(6):535-538.
- Carlsen, T.M., Espeland, E.K., Paterson, L.E., MacQueen, D.H., 2017. Optimal prescribed burn frequency to manage foundation California perennial grass species and enhance native flora. *Biodiversity and Conservation* 26(11):2627–2656.
- Carranza, L.A. 2014. CNLM annual report of management activities for the 2013–2014 fiscal year on the Dana Point Preserve, owned and managed by CNLM (CNLM No. S033). Prepared for: U.S. Fish and Wildlife Service (10-B-0615), California Department of Fish and Wildlife, City of Dana Point, Center for Natural Lands Management. 55 pp.
- Cayan, D., M. Dettinger, I. Stewart, and N. Knowles. 2005. Recent changes towards earlier springs: early signs of climate warming in western North America? U.S. Geological Survey, Scripps Institution of Oceanography, La Jolla, California.

- Cayan, D.R., E.P. Maurer, M.D. Dettinger, M. Tyree, and K. Hayhoe. 2008. Climate change scenarios for the California region. *Climatic Change* 87:21-42.
- Cayan, D., M. Tyree, D. Pierce, and T. Das. 2012. Climate change and sea level rise scenarios for California vulnerability and adaptation assessment. California Energy Commission Publication CEC-500-2012-008.
- Chock, R.Y., D.M. Shier, and G.F. Grether. 2018. Body size, not phylogenetic relationship or residency, drives interspecific dominance in a little pocket mouse community. *Animal Behaviour* 137:197–204.
- Chock, R.Y., G.F. Grether, and D.M. Shier. 2019. Cache pilfering in a granivore guild: implications for reintroduction management. *The Journal of Wildlife Management* 83:1607–1616.
- Chock, R.Y. and D.M. Shier. 2020. Receiver Site Selection for PPM Reintroductions Using the SWOT Process Year 1 Report. 20 pp.
- Chock, R.Y. and D.M. Shier. 2021. Receiver Site Selection for PPM Reintroductions Using the SWOT Process Year 2 Report. 27 pp.
- Chock, R.Y., W.B. Miller, S.N. King, C.S. Brehme, R.N. Fisher, H. Sin, P. Wilcox, J. Terp, S. Tremor, M.R. Major, and K. Merrill. 2022. Quantitative SWOT analysis: A structured and collaborative approach to reintroduction site selection for the endangered Pacific pocket mouse. *Journal for Nature Conservation*, 70:1-10.
- Chock, R.Y. 2024. PPM receiver site selection: Wire Mountain. PPM Working Group Presentation. 12 pp.
- Clarke, J.A. 1983. Moonlight's influence on predator/prey interactions between short-eared owls (*Asio flammeus*) and deer mice (*Peromyscus maniculatus*). *Behavioral Ecology and Sociobiology*. 13:205-209.
- Clemesha, R.S. 2020. Progress Report on Cooperative Agreement W9126G-17-2-0029 for period ending December 31, 2019. Prepared for US Army Corps of Engineers. 7 pp.
- CLEO Incident Report. 2017. Case control number 17-18. 33 pp.
- Conlisk, E., Syphard, A.D., Franklin, J., Regan, H.M., 2015. Predicting the impact of fire on a vulnerable multi-species community using a dynamic vegetation model. *Ecological Modelling* 301:27–39.
- Corbin, J. D., M. A. Thomsen, T. E. Dawson, and C. M. D'Antonio. 2005. Summer water use by California coastal prairie grasses: Fog, drought, and community composition. *Oecologia* 145:511–521.
- Cox, R.D. and E.B. Allen. 2008. Composition of soil seed banks in southern California coastal sage scrub and adjacent exotic grassland. *Plant Ecology* 198(1):37–46.
- Cramer, K. and J. Chapman. 1990. Reproduction of three species of pocket mice (*Perognathus*) in the Bonneville Basin, Utah. *Great Basin Naturalist* 50(4):361-365.

- Dana Point Real Estate. 2024. The Strand at Headlands Hotel. Website for development project. <[https://dplanternvillage.com/portfolio\\_page/the-strand-at-headlands-hotel-dana-point/](https://dplanternvillage.com/portfolio_page/the-strand-at-headlands-hotel-dana-point/)> Accessed March 28, 2024.
- Dertien, J.S., C.L. Larson, and S.E. Reed. 2021. Recreation effects on wildlife: a review of potential quantitative thresholds. *Nature Conservation* 44:51-68.
- [DOD] Department of Defense Environmental Security. 2019. Pacific Pocket Mouse (*Perognathus longimembris pacificus*) Management Plan MCBP Base Camp Pendleton, California. 34 pp.
- D'Antonio, C.M. and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/ fire cycle, and global change. *Annual Review of Ecology and Systematics* 23:63-87.
- D'Antonio, C.M., Malstrom, C., Reynolds, S.A., Gerlach, J., 2007. Ecology of invasive nonnative species in California grassland. *In*: Stromberg, M.R., Corbin, J.D., Antonio, C.M. (Eds.). *California grasslands: ecology and management*. Univ of California Press.
- Dice, L.R. 1945. Minimum intensities of illumination under which owls can find dead prey by sight. *American Naturalist* 79:385-416.
- Edgarian, T.K., C.S. Brehme, D. Adsit-Morris and R.N. Fisher. 2023. Draft Proposal Translocation Plan of Pacific Pocket Mouse (*Perognathus longimembris pacificus*) to North San Mateo. U.S. Geological Survey Western Ecological Research Center, San Diego. Unpublished report. 43 pp.
- Edmonds, V.W. and D.S. Fertig. 1972. Longevity of the pocket mouse, *Perognathus longimembris*. *Southwest Naturalist* 17(3):300-301.
- Egoscue, H.J., J.G. Bittmenn, and J. A. Petrovich. 1970. Some fecundity and longevity records for captive small mammals. *Journal of Mammalogy* 51(3):622-623.
- Eisenberg, J.F. 1963. The behavior of heteromyid rodents. *University of California Publications in Zoology* 69:1-100.
- Environmental Sciences Branch. 2013. Understanding and Improving Wildfire Decision Support for Marine Corps Base Camp Pendleton: User's Manual for the Simulated Response of Vegetation and At-Risk Species to Fire. Final Report April 2013. 176 pp.
- Esque, T.C., K.E. Nussear, K.K. Drake, A.D. Walde, K.H. Berry, R.C. Averill-Murray, A.P. Woodman, W.I. Boarman, P.A. Medica, J. Mack, and J.S. Heaton. 2010. Effects of subsidized predators, resource variability, and human population density on desert tortoise populations in the Mojave Desert, USA. *Endangered Species Research* 12: 167-177.
- Farzan, Y. 2024. Dana Point Landslide Leaves Mansion Precariously Perched On Cliff's Edge. LAist article, February 13, 2024. <<https://laist.com/news/climate-environment/dana-point-landslide-mansion-cliffs-edge>> Accessed March 10, 2025.
- Field, C.B., G.C. Daily, F.W. Davis, S. Gaines, P.A. Matson, J. Melack, and N.L. Miller. 1999. Confronting climate change in California. *Ecological impacts on the Golden State*. A

- report of the Union of Concerned Scientists, Cambridge, Massachusetts, and the Ecological Society of America, Washington, DC.
- Fischer, D. T., C. J. Still and A. P. Williams. 2009. Significance of summer fog and overcast for drought stress and ecological functioning of coastal California endemic plant species. *Journal of Biogeography*. 36:783–799.
- Fisher, R. (U.S. Geological Survey). 2023. Personal communication. Conversation with Dave McNaughton (Senior Natural Resources Specialist, NAVFAC SW: EV24 Marine Corps) in December 2023.
- Flake, L.D. and C.D. Jorgensen. 1969. Invasion of a “trapped-out” southern Nevada habitat by *Perognathus longimembris*. *The Great Basin Naturalist* 29(3):143-149.
- Frankham R. 2005. Genetics and extinction. *Biological Conservation* 126: 131–140.
- Frankham R., C.J.A. Bradshaw and B.W. Brook. 2014. Genetics in conservation management: revised recommendations for the 50/500 rules, Red List criteria and population viability analyses. *Biological Conservation* 170:56–63.
- Franklin, I.R., 1980. Evolutionary change in small populations. In: Soulé, M.E., Wilcox, B.A. (Eds.), *Conservation Biology: An Evolutionary-Ecological Perspective*. Sinauer, Sunderland, MA, pp. 135–149.
- French, A.R. 1976. Selection of high temperatures for hibernation by the pocket mouse, *Perognathus longimembris*: ecological advantages and energetic consequences. *Ecology* 57:185-191.
- French, N., B. Maza, and A. Aschwanden. 1967. Life spans of *Dipodomys* and *Perognathus* in the Mojave Desert. *Journal of Mammalogy* 48(4):537-548.
- French, N., B. Maza, H.O. Hill, A.P. Aschwanden, and H.W. Kaaz. 1974. A population study of irradiated desert rodents. *Ecological Monographs* 44:45-72.
- Gashwiler, J.S. 1959. Small mammal study in west-central Oregon. *Journal of Mammalogy* 40:128–139.
- Gelbard, J.L. and J. Belnap. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. *Conservation Biology* 17:420-432.
- Germano, D. J. 1997. Distribution and habitat affinities of the Pacific pocket mouse (*Perognathus longimembris pacificus*). Draft Final report prepared for the California Department of Fish and Game, contract No. FG5129WM. January 1997. 38 pp.
- Gillespie, I.G. and E.B. Allen. 2004. Fire and competition in a southern California grassland: impacts on the rare forb *Erodium macrophyllum*. *Journal of Applied Ecology* 41:643–652.
- Gilpin, M.E. 1987. Spatial structure and population vulnerability. In M. E. Soule (Ed). *Viable Populations For Conservation*. Cambridge University Press, Cambridge, Great Britain.
- Godfrey, S. 2018. Spatial Distribution of the Endangered Pacific Pocket Mouse (*Perognathus longimembris* ssp. *pacificus*) Within Coastal Sage Scrub Habitat at Dana Point Headlands Conservation Area. Thesis. University of Southern California. 90 pp.

- Greenberg, B. 2022. Dana Point Suing Nature Center over Blufftop Trail. Article, Dana Point Times. <https://www.danapointtimes.com/dana-point-suing-nature-center-over-blufftop-trail/> <Accessed October 31, 2023>
- [GSRC and SDZWA] Gulf South Research Corporation and San Diego Zoo Wildlife Alliance. 2023. Pacific Pocket Mouse Translocation Feasibility Study, MCBCP Base Camp Pendleton, California. Prepared for MCBCP Base Camp Pendleton, Environmental Security Department. Draft Report. 103 pp.
- Hafner, D. J. 2016. Subfamily Perognathinae, Genus Perognathus. *In*: Handbook of mammals of the world, vol. 6, Lagomorphs and Rodents I (Wilson, D. E., T. E. Lacher, Jr., and R. A. Mittermeier, eds.). Lynx Ediciones, Barcelona, Spain. Pp. 202–209
- Hall, E. 1981. The Mammals of North America. Second edition. John Wiley and Sons, New York.
- Halvorson, W.L., D. B. Fenn, and W. R. Allardice. 1988. Soils and vegetation of Santa Barbara Island, Channel Islands National Park, California, USA. *Environmental Management* 12: 109-118.
- Harvey, B.D. 2018. Influences on foraging preferences of the endangered Pacific Pocket Mouse (*Perognathus longimembris pacificus*): implications for a novel conservation strategy. University of California, Los Angeles. MS thesis. 66 pp.
- Hayden, P., J.J. Gambino, and R.G. Lindberg. 1966. Laboratory breeding of the little pocket mouse, *Perognathus longimembris*. *Journal of Mammalogy* 47:412–423.
- Hoban, S., Bruford, M., D’Urban Jackson, J., Lopes-Fernandes, M., Heuertz, M., Hohenlohe, P. A., Paz-Vinas, I., Sjögren-Gulve, P., Segelbacher, G., Vernesi, C., Aitken, S., Bertola, L. D., Bloomer, P., Breed, M., Rodriguez-Correa, H., Funk, W. C., Grueber, C. E., Hunter, M. E., Jaffe, R., ... Laikre, L. (2020). Genetic diversity targets and indicators in the CBD post-2020 Global Biodiversity Framework must be improved. *Biological Conservation*, 248, 108654. <https://doi.org/10.1016/j.biocon.2020.108654>
- Howard, W.E., R.L. Fenner, and H.E. Childs. 1959. Wildlife survival in brush burns. *Journal of Range Management* 12(5):230-234.
- Huey, L.M. 1939. The silky pocket mice of Southern California and northern Lower California, Mexico, with the description of a new race. *Transactions of the San Diego Society of Natural History* IX (11):47-54.
- Iacobellis, S., D. Cayan, J. Norris, and M. Kanamitsu. 2010. Impact of Climate Change on the Frequency and Intensity of Low-Level Temperature Inversions in California. Scripps Institution of Oceanography, University of California San Diego.
- Ingles, L.G., 1965. Mammals of the Pacific States: California, Oregon, and Washington. Stanford University Press, Stanford, California.
- [IPCC] Intergovernmental Panel on Climate Change. 2023. Key Findings of the IPCC Synthesis Report of the Six Assessment Report. 3 pages.

- Ivy, J.A. 2014. Population Modeling Report 2014 Update Establishing a Captive Population of the Pacific Pocket Mouse (*Perognathus longimembris pacificus*). Unpublished Report. 6 pp.
- Iwanowicz, D.D., A.G. Vandergast, R.S. Cornman, C.R. Adams, J.R. Kohn, R.N. Fisher, and C.S. Brehme. 2016. Metabarcoding of Fecal Samples to Determine Herbivore Diets: A Case Study of the Endangered Pacific Pocket Mouse. PloS One 11:e0165366.
- Jackson, L.E., Strauss, R.B., Firestone, M.K., Bartolome, J.W., 1988. Plant and soil N dynamics in California annual grassland. Plant Soil 110:9–17.
- Jameson, E.W. Jr., and H.J. Peeters. 1988. California Mammals. University of California Press, Berkeley, California.
- Jennings, Megan K., Dan Cayan, Julie Kalansky, Amber D. Pairis, Dawn M. Lawson, Alexandra D. Syphard, Udara Abeysekera, Rachel E.S. Clemesha, Alexander Gershunov, Kristen Guirguis, John M. Randall, Eric D. Stein, and Sula Vanderplank. (San Diego State University). 2018. San Diego County ecosystems: ecological impacts of climate change on a biodiversity hotspot. California’s Fourth Climate Change Assessment, California Energy Commission. Publication number: CCCA4-EXT-2018-010
- Johnstone, J.A. and T. E. Dawson. 2010. Climatic context and ecological implications of summer fog decline in the coast redwood region. Proceedings of the National Academy of Sciences, 107(10):4533-4538.
- Kalansky, Julie, Dan Cayan, Kate Barba, Laura Walsh, Kimberly Brouwer, Dani Boudreau. (University of California, San Diego). 2018. San Diego Summary Report. California’s Fourth Climate Change Assessment. Publication number: SUM-CCCA4-2018-009.
- Keeley, J E., M. Baer-Keeley, and C.J. Fotheringham. 2005. Alien plant dynamics following fire in Mediterranean-climate California shrublands. Ecological Applications 15:2109- 2125.
- Kenagy, G. 1973. Daily and seasonal patterns of activity and energetics in a heteromyid rodent community. Ecology 54:1201-1219.
- Kenagy, G. and G. Bartholomew. 1985. Seasonal reproductive patterns in five coexisting California desert species. Ecological Monographs 55(4):371-397.
- King, S., A. Navarro, J.P. Montagne, T. Wang, S. Leivers, and D.M. Shier. 2018. Conservation breeding and reintroduction of the Pacific pocket mouse (*Perognathus longimembris pacificus*). San Diego Zoo Institute for Conservation Research. Unpublished report. 50 pp.
- King, S., A. Greggor and D. Shier. 2022a. Pacific Pocket Mouse Recovery Efforts at Laguna Coast Wilderness Park – Summary. Prepared for OC Parks. 9 pp.
- King, S.N.D., R. Gosselin, A.L. Greggor, C. Williams, S. Hunjan, A.P. Wilder, M. Houck, and D.M. Shier. 2022b. Conservation breeding and reintroduction of the Pacific pocket mouse (*Perognathus longimembris pacificus*), 2021 Annual Report. San Diego Zoo Wildlife Alliance, Escondido, CA. 62 pp.

- King, S, A. Greggor, R. Gosselin, and D. Shier. 2023. Pacific Pocket Mouse Research MCBCP Base Camp Pendleton, CA (Agreement number N602473-20-2-0016). Final Report. 55 pp.
- Kotler, B.P. 1984. Risk of predation and the structure of desert rodent communities. *Ecology* 65(3):689-701.
- LaDochy, S. and M. Witiw. 2012. The continued reduction in dense fog in the southern California region: Possible causes. *Pure and Applied Geophysics* 169(5-6):1157-1163.
- LaForgia, M.L., M.J. Spasojevic, E.J. Case, A.M. Latimer, and S.P. Harrison. 2018. Seed banks of native forbs, but not exotic grasses, increase during extreme drought. *Ecology* 99(4):896–903.
- Larson, C.L., S.E. Reed, A.M. Merenlender, and K.R. Crooks. 2019. A meta-analysis of recreation effects on vertebrate species richness and abundance. *Conservation Science and Practice*. 1:e93. <https://doi.org/10.1111/csp2.93>.
- Lawrence, G.E. 1966. Ecology of vertebrate animals in relation to chaparral fire in the Sierra Nevada foothills. *Ecology* 47:278–291.
- Lawson, Dawn (Adjunct Faculty, Biology Department, San Diego State University). 2019. Telephone conversation with T.M. McFarland (Texas A&M NRI), April 2019.
- Lebassi-Habtezion, B., J. González, and R. Bornstein. 2011. Modeled large-scale warming impacts on summer California coastal-cooling trends. *Journal of Geophysical Research: Atmospheres* 116(D20).
- Loda, J., C. Winchell, M. Pavelka, and E. King. 1999. The role of vegetation in determining suitable habitats for the Pacific pocket mouse (*Perognathus longimembris pacificus*). Unpublished report prepared by the U. S. Fish and Wildlife Service for the MCBCP Base Camp Pendleton, Environmental Security, October 1999. 18 pp. + appendices
- Lucero, J. E. and R.M. Callaway. 2018. Native granivores reduce the establishment of native grasses but not invasive *Bromus tectorum*. *Biological Invasions*, 20(12):3491–3497.
- MacKenzie, D.I. and A.E. Bratt. 2023. Relationship between Abundance and Occupancy of Pacific Pocket Mouse. Report for USGS, Proteus Client Report: 176. Proteus, Outram, New Zealand. 81 pp.
- Matsuda, T. 2020. PPM ant pilot study. 14 pp. Presentation to PPM Working Group. (Cited in USFWS 2020)
- [MCBCP] MCBCP Base Camp Pendleton. 2018. Wildfire Prevention Plan Environmental Assessment.
- [MCBCP] MCBCP Base Camp Pendleton. 2021. MCBCP Western Recruiting Region Land Navigation Course: Biological Assessment. Draft Report. 50 pp.
- McNaughton, D.M. (Senior Natural Resources Specialist, NAVFAC SW: EV24 Marine Corps) . 2024. Personal communication. Comments on a draft of the PPM SSA dated February 5, 2024.

- Mearns, E.A. 1898. Description of three new forms of pocket-mice from the Mexican border of the United States. *Bulletin American Museum of Natural History*. Article XV. Vol. X: 299-302.
- Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver, and Z.-C. Zhao. 2007. *In* Global climate projections. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (Eds.). *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment*. Pp. 747–843. Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, and New York, NY.
- Merrill, K.C. 2019. CNLM annual report of management activities for the 2017–2018 fiscal year (October 1, 2017–September 30, 2018), Dana Point Preserve (S033). Center for Natural Lands Management, 35 pp.
- Merrill, K.C. 2020. PPM CNLM 2020 working group presentation. Center for Natural Lands Management.
- Merrill, K.C. 2022. CNLM Annual Report of Management Activities for the 2021 Fiscal Year (October 1, 2020 – September 30, 2021) Dana Point Preserve (S033). 22 pp
- Merrill, K.C. (Regional Preserve Manager - South Coast Center for Natural Lands Management). 2023. Pers. comm. Series of phone calls with Dianne Robinson and Tiffany McFarland (Research Associates, Texas A&M NRI). November 2023.
- Merrill, K.C. 2023a. Report for Permit TE-221411-6.1 & SCP-013986. Memorandum. 2 pp.
- Merrill, K.C. 2023b. CNLM's Dana Point Preserve (S033) Annual Report of Management Activities for the 2022 Fiscal Year (October 1, 2021 – September 30, 2022). 28 pp.
- Merrill, K.C., M.A. Labbe, and D.L. Rogers. 2023c. 2023 Habitat Management Plan for Public Access for the Dana Point Preserve. 106 pp.
- Merrill, K.C. 2024. CNLM Dana Point Preserve Pacific Pocket Mouse Enhancement Management Plan Fiscal Year 2023 Summary Report (October 01, 2022 – September 30, 2023). 16 pp.
- Merrill, K.C. (Regional Preserve Manager - South Coast Center for Natural Lands Management). 2024. Pers. comm. Comments on draft SSA document dated February 5, 2024.
- Meserve, P. 1976a. Food relationships of a rodent fauna in a California coastal sage scrub community. *Journal of Mammalogy* 57:300-319.
- Meserve, P. 1976b. Habitat and resource utilization by rodents of a California coastal sage scrub community. *Journal of Animal Ecology* 46:647-666.
- [MBA and LSA] Michael Brandman Associates and LSA Associates. 1997. Results of focused surveys for the Pacific pocket mouse Foothill Transportation Corridor-South. Unpublished report prepared for Foothill/Eastern Transportation Corridor Agency, Santa Ana, California, February 1997. 26pp. + Appendices.
- Miller, W.B. 2019. Biomonitor, Carlsbad Fish and Wildlife Office, USFWS. Email correspondence to Email correspondence to Mary Crawford, Fish and Wildlife Biologist,

- Carlsbad Fish and Wildlife Office. Dated December 18, 2019. Subject: PPM 5-year review and status of PPM Genetic Management Plan.
- Miller, W.B. 2023. Personal communication. Conversation during recurring PPM SSA call in 2023.
- Miller, W.B. 2024. Personal communication. Comments on draft SSA document, dated November 20, 2024.
- Miller, W.B. and M. Pavelka. 2008. Monitoring of the Pacific Pocket mouse (*Perognathus longimembris pacificus*) population in the Oscar One Training Area on MCBCP Base Camp Pendleton: 2003–2006 Draft Report. Prepared for Assistant Chief of Staff, Environmental Security, MCBCP Base, Camp Pendleton. 107 pp.
- Miller, W.B. and D.M. Shier. 2011. Genetic Management Plan for Captive Propagation of the Pacific Pocket Mouse (*Perognathus longimembris pacificus*): December 2011. 6 pp.
- Miller, W.B. 2017. Pacific pocket mouse monitoring performed at the Dana Point Preserve May 21–24, 2017, Dana Point, California. Carlsbad Fish and Wildlife Office, U.S. Fish and Wildlife Service. Memorandum 11 pp.
- Miller W.B., D.M. Shier, C.S. Brehme and S. Tremor. 2017. Little pocket mouse *Perognathus longimembris*. In: S. Tremor, D. Stokes, W.D. Spencer J. Diffendorfer, H. Thomas, S. Chivers, and P. Unitt (Eds.). San Diego county mammal atlas. Sunbelt Publications, El Cajon. Pp. 85-94.
- Minnich, R.A. and R.J. Dezzani. 1998. Historical decline of coastal sage scrub in the Riverside-Perris plain, California. *Western Birds* 29:366-391.
- Montgomery, S.J. 2003. 1998-1999 Pacific Pocket Mouse Surveys, MCBCP Base, Camp Pendleton. Prepared for Environmental Security, MCBCP. Draft Report. 42 pp.
- Montgomery, S.J. 2005. Results of monitoring surveys for the federally endangered Pacific pocket mouse, other rodents, and vegetation at the management ignited fire location, at the San Mateo North Pacific pocket mouse population site, MCBCP Base, Camp Pendleton, California. Unpublished report prepared by S. J. Montgomery for the MCBCP Base Camp Pendleton, Wildlife Management Branch, Environmental Security under contract N 68711-00-LT-00036. 42 pp. + tables, figures, and appendices.
- National Oceanic and Atmospheric Administration (NOAA). 2023. Sea Level Rise Viewer, online tool. <https://coast.noaa.gov/digitalcoast/tools/slr.html>, Accessed December 1, 2023.
- Natural Resources Assessment, Inc. 2003. Presence/absence trapping studies for the Pacific pocket mouse on the Foothill/Eastern Transportation Corridor South. Unpublished report prepared for PandD Consultants, San Diego, California. November 7, 2003. 13pp. + appendix.
- O'Farrell, T. P., R. J. Olson, R. O. Gilbert, and J. D. Hedlund. 1975. A population of Great Basin pocket mice, *Perognathus parvus*, in the shrub-steppe of south-central Washington. *Ecological Monographs* 45:1-28.

- O’Leary, J.F and W.E. Westman, 1988. Regional disturbance effects on herb succession patterns in coastal sage scrub. *Journal of Biogeography* 15:775–786.
- Oladi, R., M. Emaminasab, and D. Eckstein. 2017. The dendroecological potential of shrubs in north Iranian semi-deserts. *Dendrochronologia* 44:94–102.
- Ogden Environmental and Energy Services (Ogden). 1997. Pacific Pocket Mouse survey, Phase III, MCBCP Base, Camp Pendleton. Unpublished report. Prepared for Assistant Chief of Staff, Environmental Security. 46 pp.
- Parker, S.S. and J.P. Schimel. 2010. Invasive grasses increase nitrogen availability in California grassland soils. *Invasive Plant Science Management* 3(1):40–47.
- Parsons, D.J. and T.J. Stohlgren, T.J., 1989. Effects of varying fire regimes on annual grasslands in the southern Sierra Nevada of California. *Madrono* 36:154-168.
- Partlow, Joshua. 2024. Clifftop mansions stand on the brink after severe storms inundate California. *The Washington Post*, 23 February.  
<<https://www.washingtonpost.com/climate-environment/2024/02/21/california-landslides-home-dana-point/>> Accessed 29 February 2024.
- Patriot Joint Venture (JV). 2022. Final Project Report, Habitat Enhancement for Stephens’ Kangaroo Rat in the Juliet Training Area, MCBCP Base Camp Pendleton, San Diego, California. Unpublished report submitted by Patriot JV to the Strategic Planning Section, MCBCP Base Camp Pendleton and Naval Facilities Engineering Systems Command Southwest. DCN: PJV-2415-5120-0005
- Patton, J. L. 2005. Family Heteromyidae. *In*: Mammal species of the world. A taxonomic and geographic reference (Wilson, D. E., and D. E. Reeder, eds.). The Johns Hopkins University Press. Baltimore, U.S.A. Pp. 844–858.
- Patton, J. L., & R.N. Fisher. 2023. Taxonomic reassessment of the Little pocket mouse, *Perognathus longimembris* (Rodentia, Heteromyidae) of southern California and northern Baja California. *Therya*, 14(1):131-160.
- Persons, W.E. and P. Eason. 2017. Human activity and habitat type affect perceived predation risk in urban white-footed mice. *Ethology* 123:348–356.
- Pierce, D.W. 2004. Effects of North Pacific oscillation and ENSO on seasonally averaged temperatures in California. Climate Research Division, Scripps Inst. Of Oceanography. Cal. Energy Comm., PIER Energy-related Env. Res. CEC-500-2005-002.
- Price, M.V., N.M. Waser, and T.A. Bass. 1984. Effects of moonlight on microhabitat use by desert rodents. *Journal of Mammology* 65(2):353-356.
- Price, M.V., N.M. Waser, K.E. Taylor, and K.L. Pluff. 1995. Fire as a management tool for Stephens' Kangaroo rat and other small mammal species. *In* *Brushfires in California Wildlands: Ecology and Resource Management*, J.E. Keeley and T. Scott (Eds.). International Association of Wildland Fire. Fairfield, Washington, USA. Pp. 51–61.
- PRBO. 2011. Projected effects of climate change in California: Ecoregional summaries emphasizing consequences for wildlife. PRBO Conservation Science, Petaluma, CA.

- Prugh, L.R., N. Deguines, J.B. Grinath, K.N. Suding, W.T. Bean, R. Stafford, and J.S. Brashares. 2018. Ecological winners and losers of extreme drought in California. *Nature Climate Change* 8(9):819–824.
- Prugh, L.R., and C.D. Golden. 2014. Does moonlight increase predation risk? Meta-analysis reveals divergent responses of nocturnal mammals to lunar cycles. *Journal of Animal Ecology* 83:504-514.
- Qu, X., Hall, A., Klein, S.A. and P. M. Caldwell. 2014. On the spread of changes in marine low cloud cover in climate model simulations of the 21st century. *Climate dynamics*, 42(9-10):2603-2626.
- Quinn, R.D. 1979. Effects of fire on small mammals in the chaparral. *California-Nevada Wildlife Transactions*:125–133.
- Randall, J.A., 1993. Behavioural adaptations of desert rodents (Heteromyidae). *Animal Behaviour*, 45:263-287.
- Reichman, O.J. and M.V. Price. 1993. Ecological aspects of heteromyid foraging. *In*: H. Genoways and J. Brown (Eds.). *Biology of the Heteromyidae*. Special Publication No. 10. The American Society of Mammalogists. Pp. 539-574.
- Rieder, J.P., T.A.S. Newbold, and S.M. Ostoja. 2010. Structural changes in vegetation coincident with annual grass invasion negatively impacts sprint velocity of small vertebrates. *Biological Invasions* 12(8):2429–2439.
- [PPM SSA Expert Team] Pacific Pocket Mouse SSA Expert Team. 2024a. Meeting Minutes: Pacific Pocket Mouse SSA Expert Team. January 17, 2024.
- [PPM SSA Expert Team] Pacific Pocket Mouse SSA Expert Team. 2024b. Meeting Minutes: Pacific Pocket Mouse SSA Expert Team. January 31, 2024.
- [SDNHM] San Diego Natural History Museum. 2021. Final Pacific Pocket Mouse Survey Report and Habitat Analysis at MCBCP Base Camp Pendleton, California. Prepared for MCBCP Base Camp Pendleton, Environmental Security Department and Marine Corp Installation West. 154 pp.
- [SDZWA] San Diego Zoo Wildlife Alliance. 2023. Tiny Mouse, Big Deal. <https://stories.sandiegozoo.org/2023/02/21/tiny-mouse-big-deal/>. Accessed December 12, 2023.
- Shaffer, M.L. and B.A. Stein. 2000. Safeguarding our precious heritage. *In* *Precious heritage: the status of biodiversity in the United States*. Oxford University Press, New York. pp.301-321.
- Shier, D. 2007. Behavioral ecology and translocation of the endangered Pacific little pocket mouse (*Perognathus longimembris pacificus*): Report for Phase I and Phase II for the period May 2006-December 2006. Unpublished report prepared for Conservation and Research for Endangered Species Division of Applied Animal Ecology, Zoological Society of San Diego, Escondido, California. 13 pp.
- Shier, D. 2008. Behavioral ecology and translocation of the endangered Pacific little pocket mouse (*Perognathus longimembris pacificus*) for the period January 2007 to December

2007. Unpublished report prepared for an Interagency Agreement between U.S. Fish and Wildlife Service and CRES, Zoological Society of San Diego. Conservation and Research for Endangered Species, Division of Applied Animal Ecology, Zoological Society of San Diego, Escondido, California. 58 pp.
- Shier, D. 2009. Behavioral ecology and translocation of the endangered Pacific little pocket mouse (*Perognathus longimembris pacificus*) for the period January 2008 to December 2008. Unpublished report prepared for an Interagency Agreement between U.S. Fish and Wildlife Service and CRES, Zoological Society of San Diego. Conservation and Research for Endangered Species, Division of Applied Animal Ecology, Zoological Society of San Diego, Escondido, California. 56 pp.
- Shier, D. M. 2015. Release Plan for Reintroduction of Pacific Pocket Mice (*Perognathus longimembris pacificus*) to Laguna Coast Wilderness Park. Unpublished report. San Diego Zoo Institute for Conservation Research, Escondido, California. 18 pp.
- Shier, D.M. (SDZWA). 2023. Personal communication. Email. RE: (CNLM Ref S033) Cause of Death -- PPM on Trail at Dana Point Preserve. Summarizes necropsy report from pathologist. Sent to Pacific pocket mouse expert team on Tuesday June 20, 2023.
- Shier, D.M. 2024. Personal communication. Conversation from recurring PPM SSA call in 2024.
- Shier, D. 2025. Director of Recovery Ecology, San Diego Zoo Wildlife Alliance. Report on results of small mammal trapping surveys at Wire Mountain during USFWS-SDZWA Coordination Meeting. April 14, 2025.
- Shier, D.M., S. Leivers, S. King, R. Chock, A. Navarro, and J.P. Montagne. 2016. Captive breeding, anti-predator behavior and reintroduction of the Pacific pocket mouse (*Perognathus longimembris pacificus*) 2014–2016. Division of Applied Animal Ecology, San Diego Zoo Institute for Conservation Research. Unpublished report. 146 pp.
- Shier, D.M. and S. King. 2018. Conservation breeding and reintroduction of the critically endangered Pacific pocket mouse. San Diego Zoo Institute for Conservation Research Presentation. 45 pp.
- Shier D.M., A.K. Bird, and T.B. Wang. 2020. Effects of artificial light at night on the foraging behavior of an endangered nocturnal mammal. *Environmental Pollution* 263(114566):1-9.
- Shier, D.M., A. Wilder, W.B. Miller, C. Curry, S.N.D. King, R.Y. Chock, A. Greggor, and M.L. Houck, M.L. 2022. Draft Genetic Management Plan for the Pacific Pocket Mouse (*Perognathus longimembris pacificus*), Escondido, CA. 77 pp.
- Shier, D.M., A. Greggor, A Thatcher, S Trombley and S. King. 2024a. Pacific pocket mouse Breeding and Reintroduction Update. PPM Working Group Presentation. 63 pp.
- Shier, D.M., S. King, H. Sin, W.B. Miller, K. Rice., S. Trombley and A. Greggor. 2024b. Reintroduction Plan for the Pacific Pocket Mice (*Perognathus longimembris pacificus*) into Wire Mountain Site on MCB Camp Pendleton. San Diego Zoo Wildlife Alliance. Escondido, CA. Unpublished report. 25 pp.
- Shier, D. M., A.L. Greggor, S. Trombley. 2025. Draft Proposal for Reintroduction of Pacific Pocket Mice into Wire Mountain on MCB Camp Pendleton. Unpublished document

- prepared for submittal to U.S. Fish and Wildlife Service and California Department of Fish and Wildlife. San Diego Zoo Wildlife Alliance, Escondido, CA. 8pp.
- Shier, D.M., A.L. Greggor, S. Leivers, and S.N.D. King. In Review. Factors that affect conservation breeding in the endangered Pacific pocket mouse, *Perognathus longimembris pacificus*. Conservation Science and Practice.
- Smith, D.R., N.L. Allan, C.P. McGowan, J.A. Szymanski, S.R. Oetker, and H.M. Bell. 2018. Development of a Species Status Assessment Process for Decisions under the U.S. Endangered Species Act. *Journal of Fish and Wildlife Management* 9:302–320.
- Snyder, J.D. 2012. Acting Assistant Field Supervisor, Carlsbad Fish and Wildlife Office, USFWS. Email correspondence to Mr. Jeffery Paull, Deputy Director, Environmental Security Department, MCIWEST-MCBCP Base. Dated December 4, 2012. Subject: Activities resulting in unauthorized impacts to Pacific pocket mouse on MCBCP Base Camp Pendleton, San Diego County, California.
- Soulé, M.E., 1980. Thresholds for survival: maintaining fitness and evolutionary potential. In: Soulé, M.E., Wilcox, B.A. (Eds.), *Conservation Biology: An Evolutionary-Ecological Perspective*. Sinauer, Sunderland, MA, pp. 151–169.
- Spencer, W.D., C. Schaefer, S. Dodd, S.J. Montgomery, and C. Holland. 2000. Pacific pocket mouse studies program, Phase II report, Final. Unpublished report prepared for Foothill/Eastern Transportation Corridor Agency and U. S. Fish and Wildlife Service. May 2000. 44pp. + appendices.
- Spencer, W.D. 2005. Recovery research for the endangered Pacific pocket mouse: An overview of collaborative studies. U.S. Forest Service Gen. Tech. Rep. PSW-GTR-195: 107-125.
- Steven R, C. Pickering and J.G. Castley. 2011. A review of the impacts of nature based recreation on birds. *Journal of Environmental Management* 92:2287-2294.
- Stromberg, M.R., C.M. D'antonio, T.P. Young, J. Wirka, and P.R. Kephart. 2007. California grassland restoration. In *California grasslands: ecology and management*. University of California Press, Berkeley. Pp. 254-280
- Stylinski, C.D. and E.B. Allen. 1999. Lack of native species recovery following severe exotic disturbance in southern Californian shrublands. *Journal of Applied Ecology* 36: 544-554.
- 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.
- Syphard, A.D., J. Franklin, and J.E. Keeley. 2006. Simulating the effects of frequent fire on southern California coastal shrublands. *Ecological Applications* 16:1744-1756.
- Syphard, A.D., Brennan, T.J., Keeley, J.E. 2018. Chaparral Landscape Conversion in Southern California. In: Underwood, E., Safford, H., Molinari, N., Keeley, J. (eds) *Valuing Chaparral*. Springer Series on Environmental Management. Springer, Cham. [https://doi.org/10.1007/978-3-319-68303-4\\_12](https://doi.org/10.1007/978-3-319-68303-4_12).
- Tevis, L. 1956. Effect of a slash burn on forest mice. *The Journal of Wildlife Management* 20:405–409.

- Thatcher, A., Trombley, S. and D. Shier. 2024. San Diego Zoo Wildlife Alliance Pacific Pocket Mouse Conservation Breeding and Reintroduction Program Report for June 1 to 30, 2024. Prepared for the U.S. Fish and Wildlife Service, Carlsbad, California.
- Thomas, K.H. (MCB Camp Pendleton, Environmental Security, Planning Branch Head). 2024. Personal communication. Comments on a draft SSA document dated February 2, 2024.
- Thomson, D.M., A.D. Bonapart, R.A. King, E.L. Schultz, and C.R. Startin. 2020. Long-term monitoring of a highly invaded annual grassland community through drought, before and after an unintentional fire. *Journal of Vegetation Science* 31(2):307–318.
- Tremor, S. (San Diego Natural History Museum). 2025. Personal communication. Comment made during 2025 Pacific pocket mouse working group meeting, February 13, 2025.
- [USFWS] U.S. Fish and Wildlife Service. 1996. Biological Opinion on the Proposed Crucible Challenge Course, MCBCP Base, Camp Pendleton, San Diego County, California (1-6-96-F-35). Biological Opinion. 21 pp.
- [USFWS] U.S. Fish and Wildlife Service. 1998. Pacific Pocket Mouse (*Perognathus longimembris pacificus*) Recovery Plan. Portland, OR. 112 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2002. Summary of 2001 Dana Point Headlands Temporary Pacific Pocket Mouse Preserve Trapping Effort, City of Dana Point, Orange County, California. Memorandum. 14 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2007a. April 2007 Salvage Trapping for Pacific Pocket Mouse at the Dana Point Headlands Conservation Park, City of Dana Point, CA. Memorandum. 2 pp.
- [USFWS] U. S. Fish and Wildlife Service. 2007b. Habitat Disturbance at the Crucible Course and Status of the Pacific Pocket Mouse within the Oscar One Training Area, MCBCP Base Camp Pendleton, San Diego County, California. Email Correspondence. 3 pp.
- [USFWS] U. S. Fish and Wildlife Service. 2008. Monitoring of the Pacific Pocket Mouse (*Perognathus longimembris pacificus*) Population in the Oscar One Training Area on MCBCP Base Camp Pendleton: 2003-2006. Unpublished report prepared by the U. S. Fish and Wildlife Service for the MCBCP Base Camp Pendleton, AC/S Environmental Security under contract M-33200-04-MP-00054. 94 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2010. Pacific pocket mouse (*Perognathus longimembris pacificus*) 5-year review: summary and evaluation. Carlsbad Fish and Wildlife Office, Department of the Interior. 86 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2011. Intra-Service Formal Section 7 Consultation on the Amendment of a Section 10(a)(1)(A) Permit for Captive Breeding and Reintroduction/Population Augmentation of the Pacific Pocket Mouse. Memorandum. 42 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2014. Unauthorized Impacts to Pacific Pocket Mouse, MCBCP Base Camp Pendleton, San Diego County, California. Email Correspondence. 8 pp.

- [USFWS] U.S. Fish and Wildlife Service. 2016. USFWS species status assessment framework: an integrated analytical framework for conservation. Version 3.4.8, August 2016.
- [USFWS] U.S. Fish and Wildlife Service. 2017a. Formal Section 7 Consultation on the 51 Area Reservoir Repair at MCBCP Base Camp Pendleton, San Diego County, California. Email Correspondence. 46 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2017b. Pacific Pocket Mouse Trapping and Monitoring Surveys at the Dana Point Headlands 1993-2017. Unpublished Data. 3 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2019. Reinitiation of section 7 consultation for the 51 Area Reservoir repair at MCBCP Base Camp Pendleton, San Diego County, California. Carlsbad Fish and Wildlife Office, Department of the Interior. 43 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2020a. Biological Opinion for the Wildfire Prevention Plan for Marine Corps Base Camp Pendleton, San Diego County, California. Biological Opinion. 79 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2020b. Pacific pocket mouse (*Perognathus longimembris pacificus*) 5-year review: summary and evaluation. Carlsbad Fish and Wildlife Office, Department of the Interior. 34 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2021. Biological Opinion for the Southern California Edison Marine Corps Base Camp Pendleton Right-of-Way Maintenance Project, San Diego County, California. Carlsbad Fish and Wildlife Office, Department of the Interior. 59 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2022. Biological Opinion for Habitat Management Activities to be Performed in the Bravo-3, Edson Range, and Oscar-1 Training Areas on MCBCP Base Camp Pendleton, San Diego County, California. Biological Opinion. 43 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2023. Biological Opinion for Range 501 Maintenance Actions on MCBCP Base Camp Pendleton, San Diego County, California. Biological Opinion. 36 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2023. Intra-Service Formal Section 7 Consultation for the Issuance of an Amendment to the San Diego Gas and Electric's Endangered Species Act Section 10(a)(1)(B) Permit (PRT-809637) for the Subregional Habitat Conservation Plan Amendment, San Diego County and Portions of Orange and Riverside Counties, California. Carlsbad Fish and Wildlife Office, Department of the Interior. 582 pp.
- [USFWS] U.S. Fish and Wildlife Service. 2024. Informal Section 7 Consultation for the *Reintroduction Plan for the Pacific Pocket Mice (Perognathus longimembris pacificus) into Wire Mountain on MCB Pendleton*. Biological Opinion 7 pp.
- [USGS] U.S. Geological Survey. 2013. DRAFT Habitat Management and Restoration Guidelines for PPM. Unpublished Report. 9 pp.
- [USGS] U.S. Geological Survey. 2022. MCB, Camp Pendleton PPM Monitoring and Research Update 2022. Presentation. 59 pp.

- [USMC] U.S. MCBCP. 2007. Habitat disturbance at the Crucible Course within Oscar-1 Training Area. Letter to Mr. Jim Bartel, January 4, 2007. 2 pages.
- Valliere, J.M., G.M. Bucciarelli, A. Bytnerowicz, M.E. Fenn, I.C. Irvine, R.F. Johnson, and E.B. Allen. 2020. Declines in native forb richness of an imperiled plant community across an anthropogenic nitrogen deposition gradient. *Ecosphere* 11(2):e03032.
- Valone, T.J., Brown, J.H., Jacobi, C.L., 1995. Catastrophic decline of a desert rodent, *Dipodomys spectabilis*: insights from a long-term study. *Journal of Mammalogy* 76 (2):428–436.
- Vandergast, A.G., C.S. Brehme, D. Iwanowicz, R.S. Cornman, D. Adsit-Morris, and R.N. Fisher. 2023. Fecal metabarcoding of the endangered Pacific pocket mouse (*Perognathus longimembris pacificus*) reveals a diverse and forb rich diet that reflects local habitat availability. *Ecology and Evolution* 13(9):e10460.
- Vanderplank, S. 2014. Endemism in an Ecotone: From Chaparral to Desert in Baja California, Mexico. Pages 205-218 *In*: Carsten Hobohm, Editor. *Endemism in Vascular Plants*. Springer Publishing, Dordrecht.
- Vernadero Group Inc. 2020. Final Report, 2020 Fifth Annual Baseline Investigation of Tortoise Predators for the MCBCP Air Ground Combat Center Twentynine Palms, California. 55 pp.
- Von Bloeker, Jr., J.C. 1931. *Perognathus pacificus* from the type locality. *Journal of Mammalogy* 12:369-372.
- Von Bloeker, Jr., J.C. 1932. A new race of *Perognathus longimembris* from southern California. *Proceedings of the Biological Society of Washington* 45: 127-129.
- Wang T., and D.M. Shier. 2017. Effects of anthropogenic lighting on Pacific pocket mouse (*Perognathus longimembris pacificus*) foraging behavior, persistence and fitness; Prepared for Wildlife Management Branch, Environmental Security Department, MCBCP Base Camp Pendleton. San Diego Zoo Institute for Conservation Research, Escondido, CA. 45 pp.
- Wang, T.B., and D.M. Shier. 2021. Translocation of the Los Angeles pocket mouse to a protected reserve in California, USA. Pages 184-188 *In*: *Global conservation translocation perspectives: 2021 Case studies from around the globe*. Edited by P.S. Soorae. IUCN SSC Conservation Translocation Specialist Group, Environment Agency - Abu Dhabi & Calgary Zoo, Canada, Gland, Switzerland.
- White, T.H., Y. de Melo Barros, P.F. Develey, I.C. Llerandi-Román, O.A. Monsegur-Rivera, and A.M. Trujillo-Pinto. 2015. Improving reintroduction planning and implementation through quantitative SWOT analysis. *Journal for Nature Conservation* 28:149–159.
- Wilder, A.P. (Geneticist, San Diego Zoo Wildlife Association). 2024. Personal communication. Series of emails to T. McFarland (Natural Resources Institute, Texas A&M) June 5 and September 25, 2024.
- Wilder, A.P. and C. Curry. 2020. Characterizing functional genomic diversity in Pacific pocket mice captively bred for reintroduction. Prepared for California Department of Fish and Wildlife. Final report. 31 pp.

- Wilder, A.P., A.Y. Navarro, S.N. King, W.B. Miller, S.M. Thomas, C.C. Steiner, O.A. Ryder, and D.M. Shier. 2020. Fitness costs associated with ancestry to isolated populations of an endangered species. *Conservation Genetics*. 21:589-601.
- Wilder, A.P., D.M. Shier, S.N.D. King, O. Dudchenko, E.R. Funk, A. Misuraca, M. Houck, W.B. Miller, C.J. Curry, J. Fronczek, R. Khan, D. Weisz, R.N. Fisher, E.L., Aiden, O.A. Ryder, C.C. Steiner. 2025. Fitness benefits of genetic rescue despite chromosomal differences in an endangered pocket mouse. *Science* 389:835–839 + Supplementary Materials.
- Williams, D.F., H.H. Genoways and J.K. Braun. 1993. Taxonomy and systematic. *In*: H.H. Genoways and J.H. Brown (Eds.). *Biology of the Heteromyidae*. Special Publication No. 10. The American Society of Mammalogists. Pp. 38-196.
- Williams, A. P., R. E. Schwartz, S. Iacobellis, R. Seager, B. I. Cook, C. J. Still, G. Husak, and J. Michaelson. 2015. Urbanization causes increased cloud base height and decreased fog in coastal Southern California, *Geophysical Research. Letters*. 42:doi:10.1002/2015GL063266.
- Zych, A. (Resource Management Branch Head, Environmental Security Department, MCI West-MCB Camp Pendleton). 2024. Personal Communication. Comments on a draft SSA document dated February 2, 2024.