CONSERVATION OF TIPTON KANGAROO RATS (*DIPODOMYS NITRATOIDES NITRATOIDES*): EFFECTS OF COMPETITION AND POTENTIAL FOR TRANSLOCATION

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ABSTRACT

The Tipton kangaroo rat (*Dipodomys nitratoides nitratoides*), is an endangered subspecies of the San Joaquin Valley kangaroo rat, found in the Tulare basin of the San Joaquin Valley. *Dipodomys n. nitratoides* and the larger Heermann's kangaroo rat (*Dipodomys heermanni)* are often found sympatrically throughout the San Joaquin Valley. However, potential competitive interactions and the nature of population fluctuations between these two species are largely unknown. Because I thought that *D. heermanni* could be negatively affecting a translocated population *D. n. nitratoides* on Allensworth Ecological Reserve, Tulare County, California, I initiated a study on potential competitive interactions between these two species. In this study my objectives were to (1) determine whether the presence of *D. heermanni* affects space use and foraging behavior of *D. n. nitratoides* and (2) compare *D. n. nitratoides* abundance and population trends between areas with and without *D. heermanni*. I found that in an exclusion area where *D. heermanni* were removed, *D. n. nitratoides* increased exponentially since the start the study, whereas on a control site with both species, *D. n. nitratoides* decreased significantly. My results suggest that *D. heermanni* are competitively depressing a population of translocated *D. n. nitratoides* on the study site. Furthermore, eliminating competitive effects of larger, coexisting species during reintroduction or translocation efforts for *D. n. nitratoides* may be an important factor in success. To further test optimal translocation and reintroduction methods for protected kangaroo rats in the San Joaquin Valley, possibly an important conservation strategy, I translocated the group of non-protected *D. heermanni* that was removed from the exclusion area during the competitive interactions part of my study. During this part of my research, my objective was to determine whether soft-release methods, which involve a 30-day acclimation period in a wire mesh cage, help to improve survivorship of translocated kangaroo rats. My results indicated that hard-released individuals had higher survivorship than soft and semi soft-released individuals. I believe that one of the factors that may have contributed to the success of hard-released individuals was the high number of available burrows on the translocation site, often not found at sites, which provided refugia for translocated individuals.

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INTRODUCTION

Tipton kangaroo rats (*Dipodomys nitratoides nitratoides*) belong to the family Heteromyidae, which, in the San Joaquin Valley faunal region, includes several species of pocket mice (*Perognathus* and *Chaetodipus* spp.) and kangaroo rats (*Dipodomys* spp.). All members of the family Heteromyidae have fur-lined cheek pouches, which are used to collect and carry seeds (Brylski 1993). Furthermore, heteromyids are adapted for arid or semi-arid environments and thus receive all necessary water from food sources (Schmidt-Nielsen and Schmidt-Nielsen 1949, 1950; French 1993). In addition, kangaroo rats have evolved bipedal locomotion with body adaptations, such as long hind limbs and a long, tufted tail, for balance (Merriam 1894; Grinnell 1920, 1921).

Within arid areas of southwestern North America, including the San Joaquin Desert (Germano et al. 2011), multiple species of heteromyids typically coexist in similar habitat utilizing similar resources (Brown 1973; Williams and Kilburn 1992). Kangaroo rats in the San Joaquin Desert include the giant (*D. ingens*) and San Joaquin (*D. nitratoides*) kangaroo rats, which are endemic to some of the most arid portions of the valley, as well as the Heermann's kangaroo rat (*D. heermanni*), which uses a broader range of plant communities and soil types (Williams and Kilburn 1992), and also occurs outside of the San Joaquin Desert. These kangaroo rats are prey for a variety of predators. Some common native predators of kangaroo rats in the San Joaquin Valley include coyotes (*Canis latrans*), San Joaquin kit foxes (*Vulpes macrotis mutica*), long-tailed weasels (*Mustela frenata*), American badgers (*Taxidea taxus*), and various species of owls and snakes (Grinnell 1932; Culbertson 1946; Hawbecker 1951; Daly et al. 1990; Nelson et al. 2007).

The San Joaquin kangaroo rat consists of three subspecies that are found in different portions of the valley. These subspecies are based on Merriam (1984) and Grinnell's (1920, 1921) original work on the taxonomy of kangaroo rats in California, and further analysis by later researchers including Boolootian (1954), Hoffmann (1975), and Williams (Williams et al. 1993). These subspecies are the Tipton (*D. n. nitratoides),* Fresno *(D. n. exilis)*, and short-nosed (*D. n. brevinasus)* kangaroo rats, which are distributed through parts of Fresno, Kern, Kings, San Benito, San Luis Obispo, Santa Barbara, and Tulare counties (Boolootian 1954; USFWS 1998). Morphologically, *D. n. brevinasus* is the largest of the subspecies (Boolootian 1954) and *D. n. exilis* is the smallest (Best 1991; Williams et al. 1993); however, distinguishing between the three sub-species morphologically requires measurements that are only possible to obtain through dissection (Williams et al. 1993; USFWS 1998). Field identification of the three subspecies is based on geographic location. Results of a recent study using genetic techniques combined with morphological analysis indicate that *D. n. exilis* warrants separate sub-specific status, but that *D. n. nitratoides* and *D. n. brevinasus* probably should be considered as one sub-species (Patton et al. unpubl. data).

Dipodomys n. nitratoides once ranged over most of the Tulare basin of the San Joaquin Valley (Fig. 1). Their historic range extended north from the southern portions of historic Tulare Lake in Kings County, to Kettleman and Lost Hills in the western portion of the San Joaquin Valley in Tulare and Kern counties (Williams et al. 1993; USFWS 1998). The southern and eastern extent would have been the foothills of the

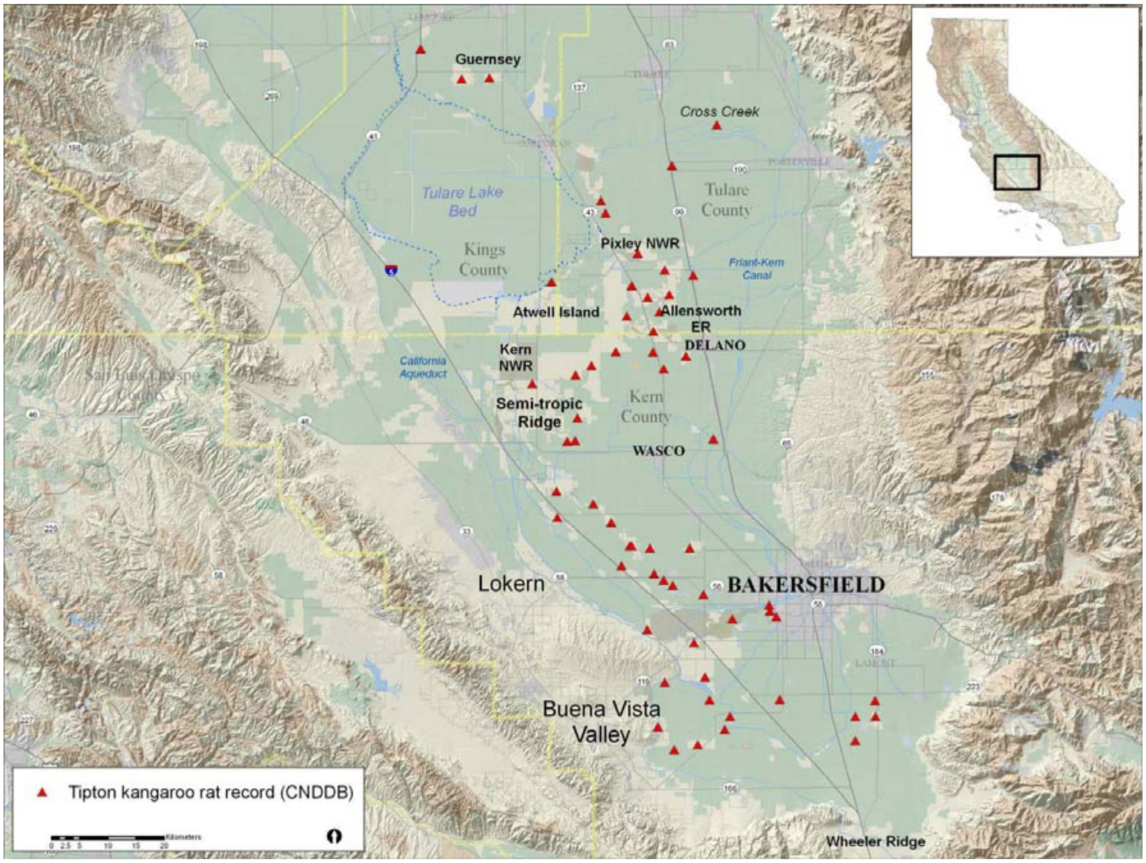

FIGURE 1. Historic locations of *Dipodomys nitratoides nitratoides* in the San Joaquin Valley, California. Locations from the California Natural Diversity Database (CNDDB). (Map prepared by Scott Phillips of the Endangered Species Recovery Program, California State University, Stanislaus).

Tehachapi Mountains and the shoreline of Buena Vista Lake (Williams et al. 1993; USFWS 1998). Today, *D. n. nitratoides* is limited to natural habitat on the San Joaquin Valley floor east of the California Aqueduct (Williams and Kilburn 1992). Relatively flat land with open vegetation structure and alluvial fan-floodplain soils that are not easily prone to flooding is considered the ideal habitat for this species (Williams and Kilburn 1992; USFWS 2010).

Dipodomys n. nitratoides was listed as endangered in 1988 under the federal Endangered Species Act and in 1989 under the California Endangered Species Act. The primary reason for its endangerment, as for most listed species in the San Joaquin Valley, is loss of habitat through conversion of natural lands primarily to agriculture and urbanization. In 1985 it was estimated that roughly 3–4% of the historic geographic range of Tipton kangaroo rats was still inhabited (Williams and Germano 1992). Current threats to the species include habitat conversion, habitat degradation, and fragmentation of current populations. One source of habitat degradation is non-native grasses that create a heavy layer of thatch in native habitats (often after average or above-average precipitation seasons), which impedes kangaroo rat locomotion and avoidance of predators (Single et al. 1996; Goldingay et al. 1997; Cypher 2001; Germano et al. 2001). The United States Fish and Wildlife Service (USFWS) 5-year review for *D. n. nitratoides* determined that only approximately 10 sites support the species (USFWS 2010). The 1998 Recovery Plan (USFWS 1998) and the 5-year review for *D. n. nitratoides* (USFWS 2010) identified several recovery actions for *D. n. nitratoides*. These actions include studies on competitive effects from the larger *D. heermanni*, range-wide population monitoring, habitat protection, and studies on habitat management strategies and restoration.

While range-wide surveys and long-term monitoring plots have been used in the San Joaquin Valley to monitor populations of heteromyids, little has been reported on competitive interactions between species of heteromyids. Competition from larger kangaroo rats has been identified as a potential threat to conservation and recovery of *D. n. nitratoides* (USFWS 1998; Germano and Saslaw, unpubl. report). *Dipodomys n. nitratoides* and *D. heermanni* are often found sympatrically throughout the San Joaquin Valley, yet no study has been done to determine whether *D. heermanni* may competitively suppress the smaller *D. n. nitratoides*. Furthermore, another goal of the

Recovery Plan (USFWS 1998) is to determine whether certain habitat management prescriptions may give *D. n. nitratoides* a competitive advantage over *D. heermanni*.

Another concern for the remaining populations of *D. n. nitratoides* is whether translocation or reintroduction can be a beneficial tool for conservation of this sub-species. Because this species occurs in so little of its historic range, any additional loss of occupied habitat jeopardizes its recovery. Since being listed in 1988, projects that eliminate occupied habitat for this species continue to be permitted under the California and Federal Endangered Species Acts. Personnel in both state and federal agencies charged with this species' protection have advocated translocation of individuals displaced by project activities as a means of mitigating this habitat loss. However, few studies have adequately assessed the translocation potential of this species from both a salvage and reintroduction perspective (Germano 2001; Germano 2010).

In 2006, an opportunity to assess translocation success for *D. n. nitratoides* arose when a development project was approved on a site that supported a large population of *D. n. nitratoides*. In this study, 144 *D. n. nitratoides* were translocated from a site south of Bakersfield in Kern County to Allensworth Ecological Reserve, near the city of Delano in Tulare County, California (Germano and Saslaw, unpubl. report). Preliminary results indicated that translocated Tipton kangaroo rats did successfully reproduce and a small (n = 10–15) but consistent population was persisting on the translocation site (Germano et al., unpubl. report). However, soon after the translocation, the number of *D. heermanni* on the site, which initially consisted of only a few individuals, grew significantly throughout the study period. Because I thought that *D. heermanni* could be negatively affecting the translocated *D. n. nitratoides* population on the site, I initiated a study on competitive interactions between *D. n. nitratoides* and *D. heermanni* to determine if numbers of *D. n. nitratoides* were suppressed by *D. heermanni*.

Another of my research goals was to further test optimal translocation and reintroduction methods for San Joaquin Valley kangaroo rats by replicating the 2006 *D. n. nitratoides* translocation study. To complete this part of my research project, I translocated a population of *D. heermanni* that was removed from an exclusion area during the competitive interactions part of my study.

The results of my research are presented in three chapters. The first chapter, *An experimental test of competitive interactions between Tipton (*Dipodomys nitratoides nitratoides*) and Heermann's (*D. heermanni*) kangaroo rats in the San Joaquin Valley, California* summarizes the research I completed on competition. The second chapter, *Survival of translocated Heermann's kangaroo rats (*Dipodomys heermanni*) using hard and soft release methods in the San Joaquin Valley, California,* details the work I completed on translocation methods. These two chapters are each formatted to be submitted as separate journal publications. The final chapter provides a synthesis of the research completed as part of this thesis project, as well as recommendations for future translocations or reintroductions of *D. n. nitratoides*.

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AN EXPERIMENTAL TEST OF COMPETITIVE INTERACTIONS BETWEEN TIPTON (*DIPODOMYS NITRATOIDES NITRATOIDES*) AND HEERMANN'S (*D. HEERMANNI*) KANGAROO RATS IN THE SAN JOAQUIN VALLEY, CALIFORNIA

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ABSTRACT

Potential competitive interactions and the nature of population fluctuations between and among the endangered Tipton kangaroo rat (*Dipodomys nitratoides nitratoides)* and the larger Heermann's kangaroo rat (*D. heermanni)* are largely unknown. Because we thought that *D. heermanni* could be negatively affecting a translocated population *D. n. nitratoides* at a site in the San Joaquin Valley of California, we initiated a study of potential competitive interactions between these two species. Our objectives were to (1) determine whether the presence of *D. heermanni* affects space use and foraging behavior of *D. n. nitratoides* and (2) compare *D. n. nitratoides* abundance and population trends between areas with and without *D. heermanni.* We erected a 1.5-ha exclusion area on the northern portion of our study site and used a southern portion of the site as our control. We placed radio-transmitters on five *D. n. nitratoides* and five *D. heermanni* and followed them intensively inside the exclusion area to compile data on space use. During radio-tracking we also recorded any intraspecific and interspecific behavioral interactions. In October 2009, we removed all *D. heermanni* from inside the exclusion area (n = 29). From February to November 2010, we trapped both the exclusion area and control site every two to three months to measure population abundance of *D. n. nitratoides*. Mean home range size for *D. heermanni* was 602.2 ± 334.1 m^2 and for *D. n. nitratoides* was 1606.1 ± 926.1 m^2. During behavioral observations, we observed 23 interspecific interactions between *D. n. nitratoides* and *D. heermanni*. The majority of these involved either a chase (n = 9), where a *D. n. nitratoides* was chased away from an area by a *D. heermanni,* or mutual tolerance (n = 10), where the two species foraged < 5 m apart. Abundance of *D. n. nitratoides* increased exponentially since the start of the study in the exclusion area (P=0.006), but decreased significantly on the control area (P=0.041). Our results suggest that *D. heermanni* are competitively depressing the population of translocated *D. n. nitratoides* on our study site. Thus, consideration of competitive effects of larger, coexisting species during translocation or reintroduction efforts for *D. n. nitratoides* may be an important factor to translocation success. We suggest that if sites with appropriate habitat for *D. n. nitratoides* lacking competitors cannot be identified, it may be necessary to remove competitors in order for initial populations of *D. n. nitratoides* to become established.

INTRODUCTION

Competition plays an important role in the structure of populations in an ecological community. The competitive exclusion principal, developed through experiments by Gause (1934) and the mathematical models of Lotka-Volterra, states that no two species using similar resources can coexist sympatrically. In fact, for species competing for similar resources to form a stable coexistence, resource partitioning must occur (Gause 1934; Tilman 1977). Partitioning of resources can occur through various forms, such as segregation of space, habitat, time, and food (Schoener 1974).

Granivore-dominated rodent communities found in southwestern North America have provided a model system for studying community structure and competition (see reviews by Brown and Harney 1993; Randall 1993). One reason for this is that in the arid west, it is not uncommon to find six or more sympatric species using similar resources (Brown 1973; Brown and Lieberman 1973). Much research has been done on how sympatric desert rodents experiencing interference competition partition for both abiotic and biotic environmental factors. For example, differences in use of habitat types are well documented (Brown 1975; Price 1978; Price and Brown 1983) especially among quadrapedal species, which typically prefer rocky or dense shrub-dominated areas, and bipedal species, which prefer open areas (Rosenzweig and Winakur 1969).

Interspecific competition is an important biotic factor in any ecological community and affects the population structure of desert rodents (Munger and Brown 1981; Brown and Munger 1985; Brown and Harney 1993). A study excluding several species of kangaroo rats from long-term monitoring plots in southeastern Arizona demonstrated that small, quadrapedal heteromyid and murid species increased in the absence of larger bipedal competitors, while, at the same time, insectivores (*Onychomys* sp.) remained unchanged (Murger and Brown 1981; Heske et al. 1994). Also, research has shown that species will shift microhabitat use, often using a greater variety of microhabitats, when other sympatric species are added or removed (Price 1978; Larsen 1986). This suggests that interspecific interference competition, which is defined as competition through direct interaction, such as aggressive encounters between competitors (Pianka 1978), affects not only habitat use but also resource allocation and species distributions (Brown and Harney 1993). Most previous studies have looked at competition between different functional groups (biped heteromyid and quadraped heteromyid or quadraped murid); competitive effects between species in the same functional group would be expected to be more pronounced (Brown and Harney 1993). In one study that reciprocally removed two species of kangaroo rats (*Dipodomys merriami* and *D. ordii*) in central New Mexico, no increase in population density in either species was observed (Schroder and Rosenzweig 1975); however, this may have been because researchers were unable to maintain significant reductions of target species (Brown and Harney 1993).

Behaviorally, both interspecific and intraspecific competition affects social structure and spacing of individuals in desert rodent communities (Randall 1993). Research on behavioral interactions between species has shown that larger species of heteromyids typically dominate smaller species through interference competition (Blaustein and Risser 1976; Frye 1983; Basset 1995; Perri and Randall 1999). Yet, at the same time, aggression is costly and avoidance may allow for coexistence of sympatric species (Perri and Randall 1999).

We studied competitive interactions between Tipton (*D. n. nitratoides*) and Heermann's kangaroo rats (*D. heermanni*), two species that are typically found sympatrically in the San Joaquin Valley of California. *Dipodomys n. nitratoides* is a subspecies of the nominate San Joaquin kangaroo rat (*D. nitratoides*), and is one of the smallest kangaroo rat species (ca. 35 g). They are limited to the relatively flat land within the Tulare basin of the San Joaquin Valley with an open vegetation structure and alluvial fan-floodplain soils that are not prone to flooding (Williams and Kilburn 1992). *Dipodomys heermanni* is a medium-sized species (ca. 70 g) that ranges widely throughout central California and are found in a variety of habitat types (Williams and Kilburn 1992). The San Joaquin Valley subspecies, *Dipodomys heermanni tularensis*, is widespread and relatively abundant in all but the wetter habitats in the southern San Joaquin Valley, and is not listed as a protected species either federally or by California.

Dipodomys n. nitratoides was listed as endangered in 1988 under the federal Endangered Species Act and in 1989 under the California Endangered Species Act (USFWS 1988; CDFG 1989). The primary reason for its endangerment, like for most listed species in the San Joaquin Valley, is loss of habitat through conversion of natural lands, primarily to agriculture. In 1985 it was estimated that roughly 3–4% of the historic geographic range of *D. n. nitratoides* was still inhabited (Williams and Germano 1992). Current populations continue to decline or are unstable (Uptain et al. 1999; USFWS 2010) due to habitat conversion, habitat degradation, and fragmentation of current populations.

Since being listed in 1988, projects that eliminate occupied habitat for *D. n. nitratoides* continue to be permitted. Personnel in both the state and federal agencies charged with this species protection have permitted translocation of individuals displaced by project activities as a means of mitigating habitat loss. However, few studies have adequately assessed the translocation potential of this species from both a salvage and reintroduction perspective (Germano 2001). In 2006, an opportunity to assess translocation success arose when a development project was approved near the city of Lamont in Kern County on native habitat that supported a large population of *D. n. nitratoides*. In this study, 144 *D. n. nitratoides* were translocated to Allensworth

Ecological Reserve, near the city of Delano in Tulare County (D. Germano and L. Saslaw, in litt.). These individuals were released in two groups on either side of an intermittently wet canal that bisected the reserve. Several methods were employed in this study to assess the success of this large-scale translocation. These included analysis of hard and soft-release methods using radio telemetry, long-term monitoring over a 3-year period, and genetic analysis to assess relatedness of offspring to translocted individuals. Preliminary results indicated that translocated *D. n. nitratoides* did successfully reproduce on the site based on the presence of juveniles that were genetically related to founders (Germano et al., in litt). A small (n = 15) but consistent population was persisting on the translocation site (Germano et al., in litt.). However, soon after the translocation, the number of *D. heermanni* on the site, which initially consisted of only one individual caught in a trap in 2006 (California Department of Fish and Game, unpubl. data), grew significantly throughout the study period to a high of 215 individuals caught in traps in the fall of 2009.

Potential competitive interactions and the nature of population fluctuations between and among *D. n. nitratoides* and *D. heermanni* are largely unknown. Because we thought that *D. heermanni* could be negatively affecting the translocated *D. n. nitratoides* population on the site, we initiated a study on potential competitive interactions between these two species. Our objectives were to (1) determine whether the presence of *D. heermanni* affects space use and foraging behavior of *D. n. nitratoides*, and (2) compare *D. n. nitratoides* abundance and population trends between areas with and without *D. heermanni.*

MATERIALS AND METHODS

Study Area

We studied kangaroo rats at the Allensworth Ecological Reserve in southern Tulare County, approximately 60 km north of Bakersfield, California. Allensworth consists of a patchwork of parcels that total 2,142 ha. The parcels, which are owned and managed by the California Department of Fish and Game, consist of some continuous large parcels (> 500 ha) as well as some non-continuous smaller parcels that are intermixed with conservation, agricultural, and grazing lands in private ownership (California Department of Fish and Game, in litt.). Parcels on the reserve are both fenced and unfenced; thus, trespass grazing by adjacent landowners' cattle occurs on some parcels within the reserve.

Vegetation communities at Allensworth are classified as Valley Sink Scrub, Valley Saltbush Scrub, and California Annual Grassland (Holland 1986). These communities consist of non-native grasses and forbs mixed with common and spiny desert saltbush (*Atriplex polycarpa* and *A. spinifera*, respectively), iodine bush (*Allenrolfea occidentalis)*, and bush seepweed (*Suaeda moquinii*). Soils at Allensworth are primarily sandy to fine-loamy and typically highly alkali with moderate to poor drainage (Natural Resource Conservation Service, http://www.ca.nrcs.usda.gov/mlra02/wtulare/index.html).

The San Joaquin Valley has a Mediterranean climate with hot, dry summers and cool, wet winters (NOAA 2005). Weather data recorded at nearby Wasco show annual mean maximum and minimum temperatures in July are 37º C to 17º C, respectively (NOAA 2005). In December, the mean maximum is 19º C and mean minimum is 1º C

(NOAA 2005). Virtually all rainfall occurs in the winter months from November to April and averages 18.6 cm per year (NOAA 2005).

Allensworth is considered one of the core protected areas for *D. n. nitratoides* in the Upland Species of the San Joaquin Valley Recovery Plan (USFWS 1998). Yet, since 1994, relatively few *D. n. nitratoides*, as well as other endangered species, such as the blunt-nosed leopard lizard (*Gambelia sila*) and San Joaquin kit fox (*Vulpes macroitis mutica*), have been detected on the reserve (M. Potter, pers. comm.). A relatively cool and wet winter in 1994–1995 contributed to declines of kangaroo rats on several sites throughout the region, and surface flooding and dense vegetative growth at Allensworth likely had a negative effect on *D. n. nitratoides* populations (Single et al. 1996).

Construction of Study Plot

This study used one control and experimental study plot. On our experimental plot, we constructed a 1.5-ha exclusion area on the north side of a periodically wet canal that bisected the translocation study area of Allensworth Ecological Reserve. The south side of the canal served as our control plot. We used 6.4 mm hardware cloth that was 1.23 m tall to construct an exclusion area 122 m by 122 m square. We used a self propelled trencher to create a trench in which we buried the hardware cloth 30–50 cm deep, leaving 73–93 cm as an above ground barrier. We used t-posts and rebar in corners and approximately every 9–15 m for structural support.

Rainfall was average (ca. 15.5 cm) in the 2009–2010 winter in the southern San Joaquin Valley (National Oceanic and Atmospheric Administration, http://www.wrh.noaa.gov/hnx/bflmain.php), which led to a dense covering of herbaceous annual plants at Allensworth. The control site was trespass grazed by a small herd of cattle from an adjacent landowner in the spring of 2010. Because dense herbaceous vegetation is detrimental to kangaroo rat populations (Germano et al. 2001), we managed vegetation inside the exclusion area to approximate the reduction in herbaceous cover achieved by cattle on the control site. In May and June 2010, we used a gas-powered push mower and hand-held weed whackers to create areas of open habitat inside the exclusion area that resembled the vegetation structure of the control area.

Field Methods

<u>Trapping and Marking Individuals</u>

We trapped *D. n. nitratoides* and *D. heermanni* using Sherman live traps that we baited with birdseed, which consisted mostly of millet,to which we added wadded paper towels as bedding material. We opened and baited traps in the late afternoon and checked traps at first light the following morning unless temperatures were predicted to be lower than 10º C, in which case we checked traps approximately four hours after opening them. If conditions were predicted to be very cold, we also used a small palm-sized ball of polyester batting in traps instead of paper towel.

We marked kangaroo rats inside the exclusion area and *D. n. nitratoides* on the control site using Passive Integrated Transponder (PIT) tags under the skin dorsally towards the neck (Williams et al. 1997). Kangaroo rats that we intensively followed inside the exclusion area were also ear tagged using Monel #1 tags and each ear tag was covered with small pieces of white or orange reflective tape so that these individuals could be visually recognized for behavioral observations (Randall 1991). Any *D. n. nitratoides* that we caught surrounding the exclusion area at the start of the project in fall

2009 were placed inside the exclusion area to supplement the small number of *D. n. nitratoides* that we caught inside.

Assessing **s**pace use and behavior

To determine whether the presence of *D. heermanni* influenced *D. n. nitratoides* space use and behavior, we radio-transmittered, tracked, compiled and quantified behavioral observations, and calculated mean home range size for both species. At the end of August 2009, we captured five *D. n. nitratoides* and paired them with five *D. heermanni* that were caught in adjacent traps inside the exclusion area. These 10 individuals were radio-collared, and if they were not originally from the exclusion area, were released inside the exclusion area. We custom fitted each of these 10 kangaroo rats with 2-g radio transmitters (Model BD-2, Holohil Systems, Ltd., Carp, Ontario, Canada) using aluminum beaded chain that was fitted around the neck of individuals (Harker et al. 1999). To ensure proper fit and habituation of individuals to radio collars, we monitored individuals in 19 L plastic buckets for 24–36 hours. Two *D. heermanni* were predated within the first week of the study. Because we were able to retrieve their radio transmitters, we refitted two new *D. heermanni* that we caught adjacent to radio-collared *D. n. nitratoides* and monitored them for the remainder of the behavioral study period.

We tracked kangaroo rats with a three-element Yagi antenna and Communications Specialist R-1000 receiver (Communications Specialists, Inc, Orange, CA, USA) for 19 monitoring days from 21 August to 25 September 2009. The majority of night monitoring took place from sunset (~1930) until 2330–0130. However, we also tracked kangaroo rats 0400–0600 on three monitoring days. A monitoring day included a day burrow location followed by 2–6 hours of night monitoring. Night locations included either a visual of the target individual using a night vision scope or the indirect light of a headlamp, or just a burrow location if the individual was underground. We recorded day burrow and night locations with a GPS equipped handheld computer (Juno ST Trimble, Trimble Navigation, Ltd, Westminster, CO, USA).

We used a night vision scope and a handheld digital sound recorder to observe and vocally record behaviors of kangaroo rats at night. During each monitoring night, we began by targeting one individual and intensively following it for either one hour, until it disappeared (we lost track of the individual), or it went into a burrow. Depending on the length of the first observation, we then located and followed other individuals using the same methods. Typically we located all individuals 2–5 times during a monitoring day.

As we intensively followed an individual, we sequentially recorded behavior. We specifically intended to gather information on any aggressive interactions between and among *D. n. nitratoides* and *D. heermanni*. We considered there to be an interaction between kangaroo rats if they were within 15 m of each other and there was an acknowledgement of the presence of another individual. Acknowledgment occurred when kangaroo rats stopped movement or foraging behavior and slightly raised their head to scan the area, which indicated that kangaroo rats took note of the presence of other neighboring individuals. If we recorded mutual tolerance between individuals, acknowledgment occurred between the individuals, but no aggressive behavior was observed. If we recorded a chase between individuals, the chase was considered an interaction no matter how far apart individuals were or if there was acknowledgment before the chase began.

We calculated home ranges of *D. n. nitratoides* and *D. heermanni* from the total number of GPS data points for each individual using the Hawths Tools Extension for ArcView 9.2 (Beyer 2004). We determined size of home ranges using 95% Minimum Convex Polygons (MCP). We used a minimum of 29 locations for each individual. One of the five *D. n. nitratoides* monitored had only 18 location records before it went missing and we excluded this individual from the final statistical analysis. We used the Mann-Whitney rank test ($\alpha = 0.05$) in the program MINITAB to compare home range size of *D. n. nitratoides* and *D. heermanni*.

Comparing Abundance and Population Trends

To compare *D. n. nitratoides* abundance and population trends in areas with and without *D. heermanni*, we removed *D. heermanni* from the exclusion area by trapping over five nights at the end of September 2009. Because three of the five *D. n. nitratoides* that we radio tracked either were predated or went missing during the behavioral study, we again trapped outside the exclusion plot and moved two *D. n. nitratoides* caught outside to inside the exclusion area to supplement the small *D. n. nitratoides* population ($n = 4$). We also trapped for one night in November 2009 at the remaining marginal habitat on the original Lamont salvage site and caught nine *D. n. nitratoides*. We released these animals at dusk into inactive burrows inside the exclusion area, increasing the population of known *D. n. nitratoides* inside the exclusion area to 13 individuals.

From February to November 2010, we trapped both the exclusion area and control site every two to three months to measure the population abundance of *D. n. nitratoides*. We trapped for three to four nights during each trapping session. Any *D. heermanni* captured inside the exclusion area during any of these trapping sessions were removed.

We used regression analysis (α = 0.05) to compare the change in numbers of *D. n. nitratoides* inside the exclusion area to the control site.

RESULTS

Space Use and Behavior

The average size of home ranges for the five radio-transmittered *D. heermanni* was 602.2 ± 334.1 m^2 and for the five radio-transmittered *D. n. nitratoides* in the exclusion area 1606.1 ± 926.1 m^2. The mean number of locations for radio-tracked *D. heermanni* was 42.8 and for *D. n. nitratoides* was 43.2. Excluding the *D. n. nitratoides* that had only 18 location records before it went missing, the average home range of *D. n. nitratoides* was 1921.6 ± 1124.1 m^2. Even though the home range size of *D. n. nitratoides* was three times larger than that of *D. heermanni*, home range sizes did not differ significantly (W=19.0, P=0.176).

We recorded 1627 min of focal observation time of radio-transmittered kangaroo rats. During this time we observed 23 interspecific interactions between species of kangaroo rats and one interspecific interaction between a *D. n. nitratoides* and a San Joaquin pocket mouse (*Perognathus inornatus*). We also recorded 18 intraspecific interactions among *D. heermanni*, but no interactions among *D. n. nitratoides*. In *D. n. nitratoides*-*D. heermanni* encounters, there were nine instances when a *D. n. nitratoides* was chased away from an area by a *D. heermanni*. In four encounters, a *D. heermanni* approached an area where a *D. n. nitratoides* was foraging and the *D. n. nitratoides* retreated from the area before a chase was initiated. In the remaining 10 interactions, there was mutual tolerance. In seven of these instances, the two species foraged < 5 m apart, and in the remaining three interactions they foraged < 15 m apart. In the one interaction observed between a *D. n. nitratoides* and *P. inornatus*, the *D. n. nitratoides* chased the *P. inornatus* away from the shrub where it was foraging and then proceeded to forage under that shrub. The majority of the intraspecific interactions among *D. heermanni* involved a chase between two individuals (17 instances). Typically, when another *D. heermanni* began foraging near the home burrow or mound of a resident *D. heermanni*, the resident would chase the intruder. Because we knew the home burrow locations of radio-transmittered individuals, typically the resident *D. heermanni* was the radio-transmittered individual. There was one intraspecific interaction between *D. heermanni* where mutually tolerant foraging (< 5 m apart) occurred. No fighting behavior was observed between or among either species.

Population Trends

After we removed 29 *D. heermanni* from the exclusion area in September 2009, we caught one or two inside the exclusion area in February and March 2010 and these individuals were also removed (Table 1, Fig. 2). By the summer of 2010, *D. heermanni* were no longer detected inside the exclusion area and did not reappear throughout the remainder of the study. At the same time, the number of *D. heermanni* on the control site remained high, although their numbers in 2010 were about one third of what they were in mid 2009 (Table 1, Fig. 3).

The number of *D. n. nitratoides* grew by 500% in the exclusion area from February 2010 to October 2010. The number of *D. n. nitratoides* in the control area remained consistently low, with only one or two individuals trapped from May 2010 – October 2010. The number of *D. n. nitratoides* increased exponentially since the start of the study in the exclusion area ($F_{0.05, 1, 4} = 29.20$, $P=0.006$; $R^2 = 0.88$), but decreased significantly in the control area ($F_{0.05, 1, 3}$ = 11.99, P=0.041; R^2 = 0.80; Fig. 4). While the *P. inornatus* population on the control area increased slightly (Fig. 3), the population in the exclusion area grew by 450% (Table 1, Fig. 2), although this increase was not significant ($F_{0.05, 1, 2}$ = 2.45, P=0.258; R^2 = 0.55).

TABLE 1. Number of *Dipodomys nitatoides nitratoides* (TKR), *Perognathus inornatus* (PM), and *Dipodomys heermanni* (HKR) caught on control and exclusion areas at Allensworth Ecological Reserve, Tulare County, California from August 2009–October 2010. We removed HKR from the exclusion area in September 2009 (n = 29). We also list the number of juvenile *D. n. nitratoides*, which we tracked on both control and exclusion plots. We considered *D. n. nitratoides* juveniles (juv) if they weighed ≤ 30 g.

	Exclusion Area				Control Area			
	TKR		HKR	PM	TKR		HKR	PM
Trap Period	Total	# juv	Total	Total	Total	# juv	Total	Total
Aug/Sept 2009	5	0	31	6	8	2	112	12
Feb. 2010	11	4	1	0	5	0	67	0
May 2010	8	0	2	6	1	0	27	0
July 2010	14	1	0	12	2	0	45	1
Oct. 2010	30	7	0	33	1	1	46	6

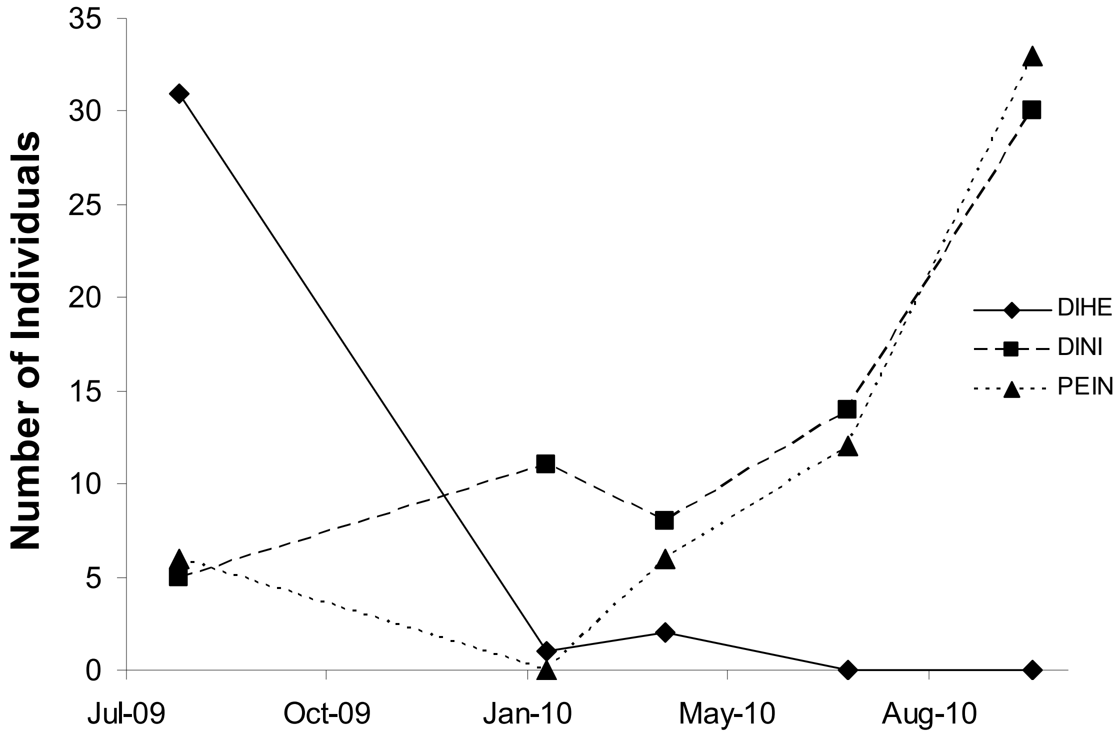

FIGURE 1. Number of heteromyids caught inside the exclusion area at Allensworth Ecological Reserve, Tulare County, California from August 2009–October 2010 (DIHE = *Dipodomys heermanni*; DINI = *D. nitratoides nitratoides*; PEIN = *Perognathus inornatus*). We removed *D. heermanni* from the exclusion area in September 2009 (n = 29). In November 2009, we supplemented numbers of *D. n. nitratoides* in the exclusion area with the addition of nine individuals.

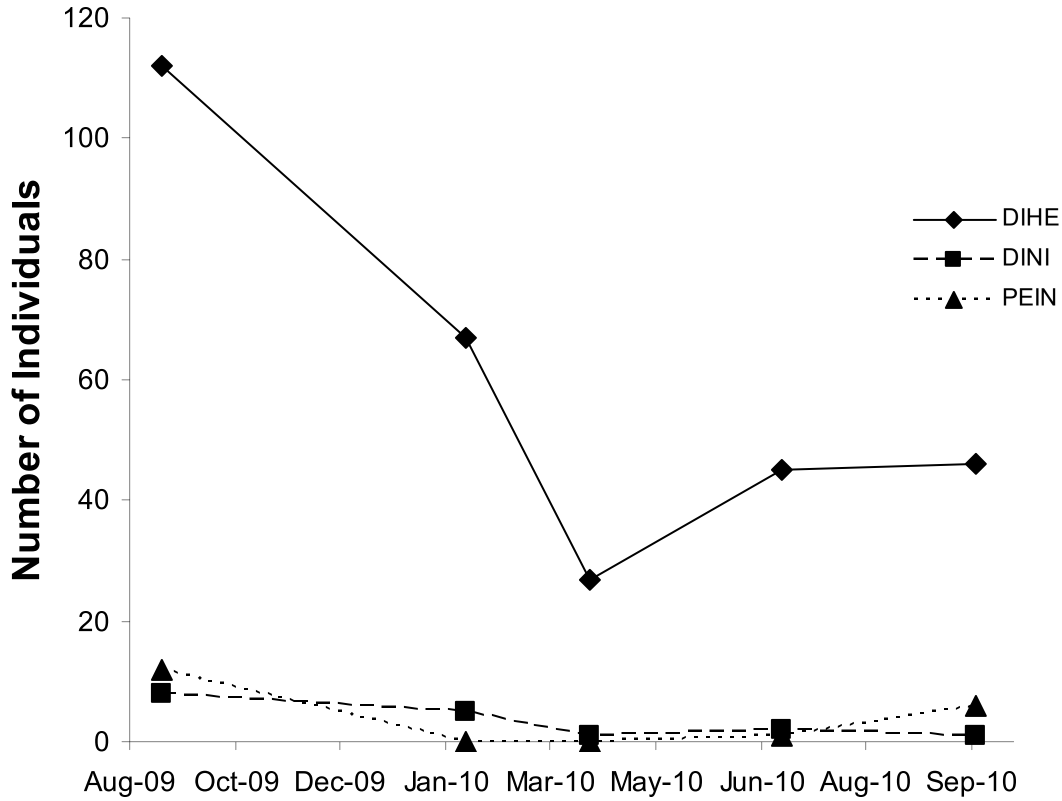

FIGURE 2. Number of heteromyids caught in the control area at Allensworth Ecological Reserve, Tulare County, California from August 2009–October 2010 (DIHE = *Dipodomys heermanni*; DINI = *D. nitratoides nitratoides*; PEIN = *Perognathus inornatus*).

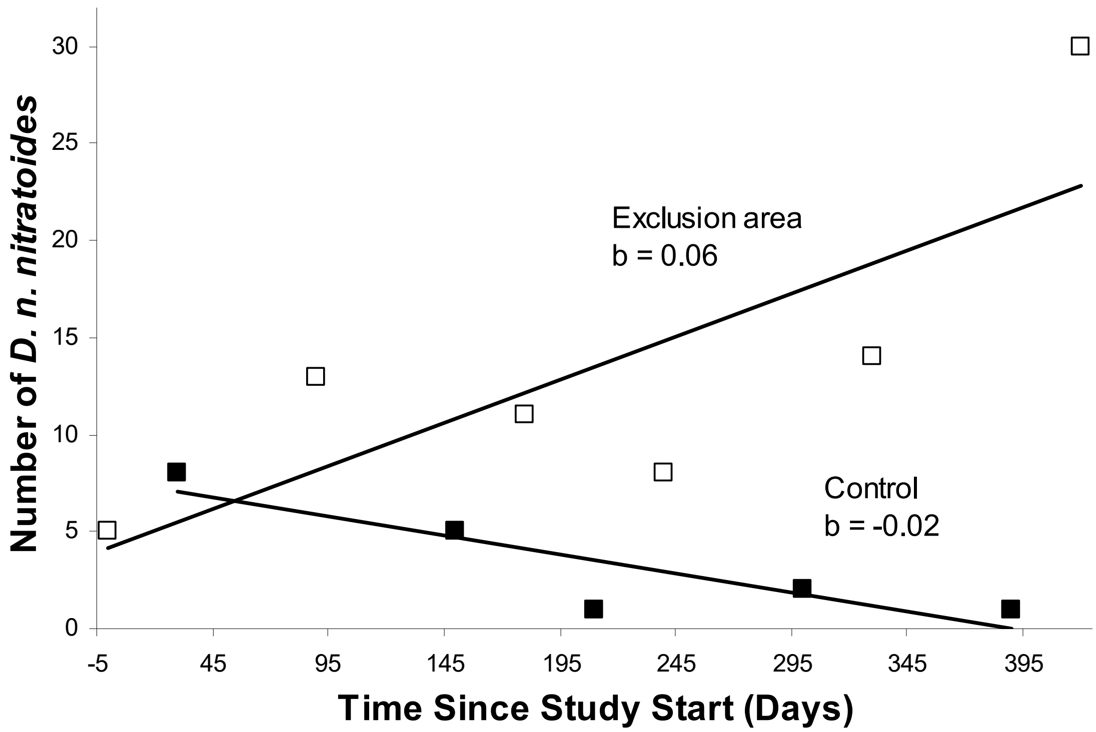

FIGURE 3. Linear relationship between the number of *Dipodomys nitratoides nitratoides* caught in the exclusion area (open squares) and on the control site (closed squares) and the length of study at Allensworth Ecological Reserve, Tulare County, California.

DISCUSSION

Our results suggest that *D. heermanni* are competitively depressing a population of translocated *D. n. nitratoides* at Allensworth Ecological Reserve. The removal of *D. heermanni* from our exclusion area coincided with an increase of 450–500% in numbers of *D. n. nitratoides* and *P. inornatus* in little more than one year. At the same time, the number of *D. heermanni* on the control plot, although less than in 2009, remained abundant. Although *D. n. nitratoides* continued to be present on the control plot, only one or two individuals were trapped from May 2010 through October 2010 and there was a significant decrease in abundance during the course of the study.

Because our control was not fenced, we trapped an area surrounding the control plot in November 2010 to be sure that *D. n. nitratoides* had not simply moved off the plot. The results of this trapping effort were similar to our results from trapping the control plot (35 *D. heermanni* and one *D. n. nitratoides*); thus, we do not think that *D. n. nitratoides* dispersed from the control plot. Also, the adjacent property to the south and west was converted to irrigated orchard in 2008; thus the available dispersal area for small mammals is limited.

The result of excluding the largest heteromyid in this community is similar to previous studies, demonstrating that competition is a strong force in heteromyid community structure. Typically, in past experiments, the removal of one or more species in different functional groups leads to an increase in the remaining species that utilize similar resources (Munger and Brown 1981; Heske et al. 1994; see review by Brown and Harney 1993). The 450% increase in the number of *P. inornatus* in our exclusion area is further evidence of competitive release between different functional groups. This type of competitive release has also been recorded during periods of kangaroo rat declines in the San Joaquin Valley. The winter of 1994–1995 was the fifth wettest on record in the valley, and lead to a dramatic decline in kangaroo rats (Single et al. 1996). Subsequent, but not sustained, increases in *P. inornatus* during this time may have been caused by competitive release (Cypher 2001).

Although competitive release between the same functional group is expected to be more pronounced (Brown and Harney 1993), both *D. n. nitratoides* and *P. inornatus* increased at similar rates in our exclusion area. However, this may be because of the short duration of our study and that the exclusion area had unsaturated levels of each species. Based on evidence that larger heteromyids typically dominate smaller species through interference competition (Blaustein and Risser 1976; Frye 1983; Basset 1995; Perri and Randall 1999), we would expect that, over time, the larger *D. n. nitratoides* would dominate the smaller *P. inornatus*.

In the areas of the San Joaquin Valley where *D. n. nitratoides* and *D. heermanni* exist sympatrically, interspecific interference competition between these two species plays an important role in community structure. We attempted to further tease out the nature of these competitive interactions through home range analysis and behavioral observations. Our home range estimates were limited by small sample size, with only five *D. heermanni* and five *D. n. nitratoides* individuals with radio-transmitters, and only four *D. n. nitratoides* surviving long enough to gather enough data to assess home range. Because of such a small sample size and limitations of transmitters, we were not able to consider differences between sex or season. However, while not statistically significant, it did appear that *D. n. nitratoides* foraged over a larger area, and *D. heermanni* tended to forage in the vicinity of their home burrow or burrows. This appears to be consistent with data on other kangaroo rat species, which suggest that home range size and sociality are inversely rated to body size (Randall 1993; Shier and Yoerg 1999). For example, males and females of one of the largest species of kangaroo rats, *D. spectabilis*, have non-overlapping territories and defend one to several large mounds (Schroder 1979; Randall 1984; Randall et al. 2002). *Dipodomys ingens*, the largest kangaroo rat, have similar behaviors, and, instead of mounds, defend individual territories, called precincts, which are similar in size to a *D. spectabilis* mound (Braun 1985; Randall 1997). Both species are larder hoarders and defend stored caches (Randall 1997). In one study on the Carrizo

Plain, *D. ingens* had small home ranges (60–350 m^2) and were active for an average of only 20 min/night (Braun 1985).

Dipodomys heermanni, which is intermediate in size among *Dipodomys* species, appears to display territoriality and primarily larder hoards (Tappe 1941; pers. obser.). Average home range size for *D. h. arenae* in coastal dune scrub habitat differed between males and females but averaged 375–962 m^2 (Shier and Randall 2004), which is similar to the home range size calculated in our study, which was 268–946 m^2. *Dipodomys merriami*, which is similar in size to *D. nitratoides*, but which occurs allopatrically in the southwestern deserts to the east, displays less territoriality, is less aggressive toward conspecifics, and tends to have overlapping home ranges between and among sexes (Randall 1989, 1991, 1993). Average home range size for *D. merriami* in Arizona was 705–1671 m^2 (Perri and Randall 1999), which is similar to the home range size calculated in our study for *D. n. nitratoides*, which was 794–3046 m^2. Past studies have also suggested that smaller *Dipodomys* scatter hoard and rely on memory to recover seeds rather than defense of larder hordes (Jacobs 1992), which also explains the trend toward larger home ranges.

Our behavioral observations confirm previous assessments that larger heteromyids use aggressive interference to outcompete smaller species (Blaustein and Risser 1976; Frye 1983; Basset 1995; Perri and Randall 1999). Although laboratory experiments with paired individuals of either conspecifics or different species often result in agonistic behaviors (Blaustein and Risser 1976; Bleich and Price 1995; Perri and Randall 1999), we did not observe any aggressive contact between heteromyids during behavioral observations in the field during the fall of 2009. Our field observations of interactions between and among *D. n. nitratoides* and *D. heermanni* are similar to findings by Perri and Randall (1999), and suggest that avoidance, rather than aggression, mediates most interactions and allows for some level of coexistence between species. In fact, we observed chase behavior more often intraspecifically (among *Dipodomys heermanni*) than interspecifically (between *D. heermanni* and *D. n. nitratoides*). Again, this is similar to Perri and Randall's (1999) study, where the slightly larger *D. ordii* displaced conspecifics significantly more than it displaced the smaller *D. merriami*. Perri and Randall (1999) suggest that intraspecific competition between larger and more territorial species is likely a stronger force in these communities than interspecific competition, unless populations are dense and resources are limited.

Different behavioral strategies used by large and small kangaroo rats may help reduce interspecific competition. Previous studies have also suggested body size ratios between coexisting granivorous rodents typically differ by > 1.5, and this difference in size leads to differences in space and habitat use, which promotes coexistence (Brown 1973; Bowers and Brown 1982; Brown and Harney 1993). However, in our study, even though *D. heermanni* and *D. n. nitratoides* differed in body sizes and behavioral strategies, we found that numbers of the smaller *D. n. nitratoides* were decreasing in an area with *D. heermanni* and increasing exponentially on a nearby site with no *D. heermanni*, suggesting competitive release.

Previous studies of *D. ordii* and *D. merriami* have suggested that these two species are so similar that neither may have a competitive advantage (Schroder 1987). Thus, one factor in *D. n. nitratoides-D. heermanni* dynamics may be that *D. n. nitratoides* only have a competitive advantage over *D. heermanni* in certain habitats. In 2009, when we initiated our study, *D. n. nitratoides* were being trapped at record high levels in other areas of the San Joaquin Valley where *D. n. nitratoides* and *D. heermanni* exist sympatrically (D. Germano, pers. observ.; G. Warrick, pers. comm.). In the early 1990s, *D. n. nitratoides* were the dominant species captured at Allensworth Ecological Reserve (Uptain et al. 1999). A dramatic decline in their numbers occurred in 1995, which was largely attributed to an extremely wet and cold winter that affected kangaroo rats across the valley (Single et al. 1996). Numbers of *D. n. nitratoides* have never recovered on Allensworth. At other sites in the valley, *D. n. nitratoides* appear to have larger populations than *D. heermanni* in areas with alkali playas, soft alkaline soils, and low levels of non-native grasses (D. Germano, pers. observ.). Perhaps because of their small size, larger home ranges, and preference to scatter horde under most conditions (see Murray et al. 2006), even small increases in ground cover affects their success and potential ability to compete with *D. heermanni* for resources and territory.

Management Recommendations

In natural communities of the San Joaquin Valley where *D. heermanni* and *D. n. nitratoides* exist sympatrically, interspecific interference competition appears to be an important factor to consider for translocation efforts and overall conservation of the endangered *D. n. nitratoides*. We recommend that more research be conducted on the population dynamics of *D. n. nitratoides* and *D. heermanni* in areas with different habitat types and/or management regimes to determine if there are certain habitats where *D. n. nitratoides* have a competitive advantage. Translocation and reintroduction efforts for *D. n. nitratoides* must consider the competitive effects of larger, coexisting species. If sites with appropriate habitat for *D. n. nitratoides* and without competitors cannot be identified, it may be necessary to remove competitors for initial populations of *D. n. nitratoides* to become established. Patterns of day burrow use suggest that kangaroo rats may prefer to avoid the home ranges of other species (Perri and Randall 1999). Thus, it may be possible that once a *D. n. nitratoides* population is established on a site, their abundance and spacing mechanisms may allow them to better compete and coexist with *D. heermanni*.

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3

SURVIVAL OF TRANSLOCATED HEERMANN'S KANGAROO RATS (*DIPODOMYS HEERMANNI*) USING HARD AND SOFT RELEASE METHODS IN THE SAN JOAQUIN VALLEY, CALIFORNIA

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ABSTRACT

Translocation of endangered kangaroo rats in the San Joaquin Valley, California has often been advocated as a mitigation strategy for populations impacted by land development activities. Since the 1990s, several small scale translocations for the Tipton kangaroo rat (*Dipodomys nitratoides nitratoides*) have been attempted and these have been largely unsuccessful. However, in 2006 a large-scale translocation of *D. n. nitratoides* using both hard and soft-release methods and post-release monitoring suggested that a self-sustaining population was persisting on the translocation site. Also, while not statistically significant, it appeared that soft-released individuals, which were given a 30-day acclimation period in a wire-mesh cage, had a higher survival rate. Because we wanted to replicate this experiment to further test the effectiveness of soft release methods for translocating kangaroo rats, we translocated 43 *D. heermanni* using the same methods as the successful 2006 *D. n. nitratoides* study. We predicted that our study would further support that soft-release of translocated kangaroo rats is an effective way to improve survival. To determine survivorship of hard and soft-released individuals, we placed radio-transmitters on 10 hard-released and 11 soft-released individuals. Two

of the soft-released individuals died in their cage within the first four days and seven dug out of their cage within the first 10 days. These seven individuals were reclassified as semi soft-releases. Only two individuals remained in their cage the entire 30-day acclimation period. Our results indicate that hard-released individuals had the highest rate of survivorship (60%; MICROMORT probability of survival 0.61-1.00), while survival was lowest for soft and semi soft-released individuals (27%; MICROMORT probability of survival 0.18-0.34). One of the factors that may have contributed to the success of hard-released individuals in our study was the unusually high number of available gopher (*Thomomys bottae*) burrows on the translocation site, which provided immediate refugia for translocated individuals.

INTRODUCTION

Wildlife relocation has been used as a management tool primarily to solve human-wildlife conflict, to supplement game populations, and for conservation purposes (Fischer and Lindenmayer 2000). In response to biodiversity declines and increasing species extinction rates (Wilson 2002), translocation and reintroduction have often been proposed and used as conservation tools for rare and endangered species (Griffith et al. 1989; Wolf et al. 1996). Translocation and reintroduction can have various meanings in different contexts. In this study, we define translocation and reintroduction based on the International Union for Conservation of Nature (IUCN) definitions. Thus, translocation is the human-mediated movement of wild animals from one part of their range to another and reintroduction is the movement of individuals to areas within their historic range where they have been extirpated (IUCN 1998).

The number of translocation or reintroductions completed annually has been growing in the last two decades (Griffith et al. 1989; Fischer and Lindenmayer 2000), and appears to be a popular and attractive solution for restoring or expanding extirpated populations (Wolf et al. 1996). In some cases, translocation has been proposed by resource agencies as a mitigation strategy for species that are impacted by land development activities (O'Farrell 1999; Germano 2001; Edgar et al. 2005; Ashton and Burke 2007; Germano 2010). In several cases, translocation or reintroduction has been a successful conservation strategy. For example, successful reintroduction of the Perdido Key beach mouse (*Peromyscus polionotus trissyllepsis*) to a portion of its range where it had been extirpated likely significantly reduced its risk of extinction (Holler et al. 1989). However, in most cases where translocation has been attempted, the eventual outcome has not been determined, and if it has been determined, it is usually unsuccessful (Fischer and Lindenmayer 2000; Armstrong and Seddon 2008).

Wildlife endemic to the southern San Joaquin Valley of California has been affected by anthropogenic driven change to natural communities beginning as early as the 1850's (Werschkull et al. 1992). Because of this, several species or subspecies of kangaroo rats (*Dipodomys* spp.) have been state and federally listed as endangered due largely to habitat loss. Listed species include the Giant kangaroo rat (*D. ingens*) and two subspecies of the San Joaquin kangaroo rat (*D. nitratoides)*, both of which occur in the most arid portions of the valley and currently persist on only 2–4% of their historic ranges (Williams and Germano 1992). The only kangaroo rat species in the southern San Joaquin Valley that is not listed as either endangered, threatened, or a California species of special concern, is the Heermann's kangaroo rat (*D. heermanni*), which in the Tulare basin of the San Joaquin Valley is classified as the subspecies *D. h. tularensis*. *Dipodomys heermanni tularensis* is a medium sized species (ca. 70 g) that ranges widely throughout most of the San Joaquin Valley in all but the wetter habitats (Williams and Kilburn 1992).

Also in the San Joaquin Valley is the Tipton kangaroo rat (*D. n. nitratoides)*, one of three recognized subspecies of *D. nitratoides*, and which has been the focus of translocation efforts since the early 1990s because of its protected status. It is one of the smallest kangaroo rat species (ca. 35 g) and was listed as endangered in 1988 under the federal Endangered Species Act and in 1989 under the California Endangered Species Act (USFWS 1988; CDFG 1989). The recent review by the USFWS (2010) suggests that *D. n. nitratoides* currently persists on only approximately 10 sites within their range and are declining (also see Uptain et al. 1999). Despite federal and state protections, projects that eliminate occupied habitat for *D. n. nitratoides* continue to be permitted. The second author has been involved in numerous translocation efforts for this species at the request of biologists in both state and federal resource agencies who have used translocation of individuals displaced by development activities as a means of mitigating these activities. In the 1990s, several small scale translocations of *D. n. nitratoides* were completed and were largely unsuccessful (Germano 2001). However, none of these translocations involved intensive post-release monitoring or firm parameters to determine success or failure (Germano 2001). In 2001, four *D. n. nitratoides* and seven *D. heermanni* were removed from a project site, fitted with radio-transmitters, and translocated to monitor survival (Germano 2010). In this study, only one individual, a *D. heermanni,* survived to the end of the study (45 days), again indicating that current translocation techniques are not effective (Germano 2010).

In 2006, an opportunity to assess translocation on a larger scale arose when a development project was approved on a site that supported a large population of *D. n. nitratoides*. In this study, 144 *D. n. nitratoides* were translocated to Allensworth Ecological Reserve in Tulare County, California, and several methods were used to assess success or failure of the translocated population (Germano et al. unpubl. report). These included an analysis of hard and soft-release methods using radio-telemetry, where a hard-release was a direct release onto the site and a soft-release included a 30 day acclimation periods inside a wire mesh cage, as well as long-term monitoring over a three year period and genetic analysis to assess relatedness of offspring to translocated individuals (Germano et al., unpubl. report). Preliminary results indicated that translocated *D. n. nitratoides* did successfully reproduce on the site based on the presence of juveniles that were genetically related to founders (Germano et al., unpubl. report). Also, although not statistically significant, it appeared that soft-released individuals had a higher survival rate. By 2009, a small (n = 15) but consistent population was persisting on the translocation site (Germano et al., unpubl. report).

We wanted to replicate this experiment to further test the effectiveness of soft-release methods for translocating kangaroo rats. We translocated a group of *D. heermanni* using the same methods as the 2006 *D. n. nitratoides* study. While we recognize that *D. heermanni* is different biologically and behaviorally than *D. n. nitratoides*, using a similar but non-endangered surrogate species to further test translocation methods has been suggested in previous studies (Bright and Morris 1994) and, we believe, is appropriate for kangaroo rats. Furthermore, surrogate species releases have been used in other translocation or reintroduction efforts, such as with the California Condor (*Gymnogyps californianus)* using Andean Condors (*Vultur gryphus)* surrogates (Wallace and Temple 1987) and black-footed ferret (*Mustela nigripes*) using the Siberian polecat (*Mustela eversmanii*) as a surrogate (Miller et al. 1990a; Miller et al. 1990b; Biggins et al. 1999). Based on previous unsuccessful hard-releases of *D. n. nitratoides* (Germano 2001; Germano 2010) and the apparent improved survival of this species using soft-releases (Germano et al., unpubl. report), we predicted that our study would further support that soft-release of kangaroo rats is an effective way to improve survival of translocated individuals.

MATERIALS AND METHODS

Study Area

We translocated kangaroo rats from a northern parcel of the Allensworth Ecological Reserve to a southern portion of the reserve. Allensworth Ecological Reserve is located in southern Tulare County, approximately 60 km north of the city of Bakersfield, California. The reserve consists of a patchwork of parcels that total 2,142 ha. The parcels, which are owned and managed by the California Department of Fish and Game, consist of some continuous large parcels (> 500 ha) as well as some non-continuous smaller parcels that are intermixed with conservation, agricultural, and grazing lands in private ownership (California Department of Fish and Game, unpublished draft management plan). Parcels on the reserve are both fenced and unfenced; thus, trespass grazing by adjacent landowners' cattle occurs on some parcels within the reserve.

Vegetation communities are classified as Valley Sink Scrub, Valley Saltbush Scrub, and Non-native Grassland (Holland 1986). These communities consist of non-native grasses and forbs mixed with common and spiny desert saltbush (*Atriplex polycarpa* and *A. spinifera*, respectively), iodine bush (*Allenrolfea occidentalis)*, and bush seepweed (*Suaeda moquinii*). Soils at Allensworth are primarily sandy to fine-loamy and typically are highly alkali with moderate to poor drainage (Natural Resource Conservation Service, http://www.ca.nrcs.usda.gov/mlra02/wtulare/ index.html).

The San Joaquin Valley has a Mediterranean climate with hot, dry summers and cool, wet winters (NOAA 2005). Weather data recorded at nearby Wasco show annual mean maximum and minimum temperatures in July are 37º C to 17º C, respectively (NOAA 2005). In December, the mean maximum is 19º C and mean minimum is 1º C (NOAA 2005). Virtually all rainfall occurs in the winter months from November to April and averages 18.6 cm per year (NOAA 2005).

Field Methods

The *D. heermanni* that we translocated in this study came from a donor site in the northern portion of the reserve. On the donor site, we built an exclusion area to study competitive effects between *D. heermanni and D. n. nitratoides* (Tennant and Germano, *manuscript in this thesis - Ch. 2*). We removed *D. heermanni* from the exclusion area and surrounding habitat using Sherman live traps that were baited with birdseed consisting mostly of millet seed. We added waded paper towels to traps as bedding material. We opened baited traps in late afternoon and checked traps at first light the following morning unless temperatures were predicted to be lower than 10º C, in which case we checked traps approximately four hours after opening them. If conditions were predicted to be very cold (< 10º C), we used a small palm-sized ball of polyester batting in traps instead of paper towel. We marked all individuals to be translocated with Passive Integrated Transponder (PIT) tags under the skin dorsally towards the neck (Williams et al. 1997).

In early October 2009, we captured *D. heermanni* from the donor site (n = 43). We held individuals for several days before moving them to the translocation site in 19 L plastic buckets with wire mesh tops. Buckets contained approximately 3 cm of sand and approximately 120 cm^3 of millet seed. To determine the fate of hard and soft-released individuals, we fitted 11 soft-release candidates and 10 hard-release candidates with radio transmitters. We custom fitted 2-g radio-transmitters (Model BD-2, Holohil Systems, Ltd., Carp, Ontario, Canada) to individuals using aluminum beaded chain that was attached around the neck of individuals (Harker et al. 1999). To ensure proper fit and habituation of individuals to radio-collars, we monitored individuals in 19 L plastic buckets for 24–36 hours. We released all *D. heermanni* on the translocation site 16 October 2009.

The translocation site was located in the southern portion of the reserve and was chosen based on habitat structure, proximity to donor site (ca. 4.8 km), absence of large numbers of kangaroo rats currently occupying the site, and high number of available burrows. To assess the current rodent population on the site before we translocated kangaroo rats, we trapped for two nights during the first week of October 2009 and caught no small mammals. After this, we began preparing the site for hard and soft-release of *D. heermanni*. Preparation of hard-release burrows consisted of using a soil or hand auger to drill artificial burrows into the ground at a 30º angle to approximately 60 cm in depth. We used this angle and depth to emulate the structure of actual kangaroo rat burrows in the San Joaquin Valley (Germano and Rhodehamel 1995). We placed approximately 0.1 L of seed inside of each artificial burrow as well as one paper towel for use in thermoregulation and bedding. To avoid any potential aggressive interactions among kangaroo rats, we spaced burrows at least 15 m apart. *Dipodomys heermanni* that were hard-released were placed inside of an artificial burrow approximately one hour before sunset. The entrance to the burrow was blocked with a small paper bag filled with soil until after sunset. Upon darkness, we unplugged the burrow allowing individuals to exit on their own accord.

For soft-releases we used a cage constructed of 6.4 mm (1/4 inch) hardware cloth. Each cage was approximately 90 x 60 cm and was closed on the top, but open on the bottom. For each cage, we augured an artificial burrow in the center, using the same method for the hard release burrows, and then dug trenches approximately 20 cm deep around the dimension of the cage. We then buried the edges of the cage to discourage individuals from digging out. Cages were placed on the translocation site at random, but were spaced at least 15 m apart. We provisioned cages with approximately 0.5 L of seed and one paper towel for the initial release.

We placed soft-released individuals in the artificial burrow inside the cage approximately 1–2 hours before sunset. While we did try to place individuals inside the burrow, no effort was made to keep individuals in the burrow. Our goal was to keep soft-released individuals inside of the cage for 30 days. However, nearly all of our kangaroo rats dug out within the first 10 days of release; thus, we considered these individuals that dug out before the 30-day period to have a semi soft-release. For kangaroo rats that remained in their cage for the 30-day period, we added seed to cages 4–6 times based on need.

We tracked kangaroo rats following release with a three-element Yagi antenna and Communications Specialist R-1000 receiver (Communications Specialists, Orange, CA, USA). We recorded locations for kangaroo rats during the day when they were in burrows. We tracked translocated kangaroo rats daily for seven consecutive days post-release. Following the seven consecutive days of monitoring, we located individuals every third day for 30 days or until they were found dead. We assumed owl predation as the cause of death of kangaroo rats if we found a radio-collar fully intact on the ground, sometimes with pieces of intestine beside it, based on evidence that at least some owls decapitate their prey before consuming them (Olmsted 1950). We tracked kangaroo rats that received a soft or semi soft-release for an additional 30 days after they dug out of the cages themselves or after we removed cages at the 30-day mark. We determined that kangaroo rats had successfully established themselves on the site if they survived for 30 days post-release or 30 days post-cage.

We assessed survivorship at 30 days post-release or post-cage by trapping for target individuals and removing radio-transmitters. At the same time, we also set a wide trapping grid across the translocation site consisting of 119 traps. Using this trapping grid, we attempted to determine survival of translocated individuals without radio transmitters and find missing radio-transmittered individuals. We trapped the grid for four nights (476 trap nights) and determined overall survivorship of translocated individuals at 30 days and again at approximately six months.

We estimated distance traveled by individuals from their respective release site using GIS location data from radiotracking in ArcMap 9.3 (Environmental Systems Research Institute, Redlands, CA, USA). We used this information to assess distance traveled on the first day after release, number of different locations found after release, and total distance moved in the 30-day tracking period. We assessed survival probabilities of releases that were hard releases and soft and semi soft-releases combined using the program MICROMORT (Heisey and Fuller 1985). MICROMORT produces a maximum likelihood estimate of the probability of surviving for a specified interval of time (in our case 30 days post-release or post-cage) based on the number of days radio transmittered *D. heermanni* survived. In this analysis, we calculated the probability of surviving to 30 days two ways to report a range of values. First, we included data on individuals of unknown fate (e.g., radio-collar became unlatched, individual disappeared), but unless we were certain a mortality had occurred, we did not count individuals of unknown fate as mortalities. In this case, *D. heemanni* of unknown fate were entered into the program using only the number of days they were known to be alive. Second, we included data on individuals of unknown fate, but considered these individuals as mortalities. We report values for both tests. All statistical comparisons used $\alpha = 0.05$.

RESULTS

We translocated 43 individuals: 10 were hard-released (all 10 of which had radio transmitters), 32 were soft-released (11 of which had radio transmitters), and one individual escaped before being released into an artificial burrow. Although we initially soft-released 11 radio-transmittered kangaroo rats, two died within their cage by the fourth day (Table 1). One appeared to have died trying to dig out of the cage, pinning itself under the cage and perhaps suffocating. Another was likely killed by a hard-released *D. heermanni* with a radio-collar that entered the cage, apparently attacked the soft-released individual, and began using the artificial burrow inside the cage. The original soft-released individual (166.168) was found dead above ground inside the cage with its nose and part of its head stuck in the hardware cloth of the cage and its tail chewed.

Of the remaining nine soft-released individuals, only two remained in their cage for the full 30 day soft-release period (22%) and we considered only these to be true soft releases (Table 1). After cages were removed, and post-cage monitoring began, one individual survived for 30 days (166.082) and one did not (164.421 Table 1; Fig. 1). Individual 164.421 went missing on monitoring day 25 and was never relocated on the study area. For all individuals that went missing, we concluded that their fate was unknown. Individuals whose fate is unknown were likely either predated, moved off the study area, or had a radio-transmitter that failed.

Seven of the nine remaining *D. heermanni* that we initially soft released dug out of their cages within the first 10 days (78%). Because they did not remain in the cages for the full 30-day habituation period, we considered these individuals as having a semi soft-release. Two of these seven semi soft-released individuals survived to the 30-day post-cage mark (28.5%; Fig. 1). The remaining individuals were either predated or their fate is unknown.

Mean distance moved on day one after escape/cage removal for both soft and semi soft-releases was 55.4 ± 18.9 m (Table 1). The mean number of different locations we found soft and semi soft-released individuals during the first 30 days post-release was

2.1 ± 0.5 and the mean total distance moved was 103.3 ± 27.4 m (Table 1). Two *D. heermanni* dug out of their cage within the first three days and made long initial movements upon escape. Individual 166.665 and 164.658 moved 162 m and 138 m, respectively. Individual 166.665 had the greatest overall total movement (232 m) and was also one of the few semi soft-released individuals to survive. If we consider only *D. heermanni* 166.082 and 164.421, which are the only two individuals that we considered having a true soft release, mean movement on day one after cages were removed and mean total distance moved was 29.5 and 33.5 m, respectively.

TABLE 1. Identification (ID), the number of days post release that an animal dug out of its cage (DDO), fate (D = died, S = survived, ? = unknown), the number of days an individual survived post-caging (DSPC), mortality cause, distance moved (m) on day one (DMD1), the number of different locations after release (NDL), and the total distance (m) moved (TDM) for soft and semi soft-released *Dipodomys heermanni* (n = 11) at a southern parcel of Allensworth Ecological Reserve, Tulare County, California in 2009.

ID	DDO	Fate	DSPC	Mortality cause	DMD1	NDL	TDM
166.168	--	D	0	Killed by conspecific	--	--	--
166.213	--	D	0	Pinned under cage trying to dig out	--	--	--
164.461	1	S	30+	None	65	2	78
166.665	2	S	30+	None/survived?	162	3	232
164.658	3	D	2	Predation - owl	138	1	138
164.119	2	D	3	Predation - owl	40	1	40
166.824	4	D	17	Predation - owl	18	6	196
164.290	10	?	3	Unknown – missing	9	1	9
166.144	10	?	3	Unknown – collar found on ground unlatched	8	2	170
166.082	--	S	30+	None/survived?	28	2	36
164.421	--	?	25	Unknown - missing	31	1	31
mean			13.0		55.4	2.1	103.3

Of the 10 radio-tranmittered hard-released *D. heermanni*, six survived 30 days post release (60%; Table 2; Fig. 1). The remaining four hard-released individuals went missing after 7, 13, 16, and 27 days (Table 1; Fig. 1). All four of the missing individuals were never relocated and their fate was unknown. Mean distance moved on the first day after release was 24.2 ± 6.3 m (Table 2). Hard-released individuals were found in a mean of 2.5 ± 0.2 different locations during the tracking period, and mean total distance moved was 95.9 ± 26.1 m. Individuals that made the greatest movements on day one (62 m, 46 m, 42 m, and 28 m) all survived. Individual 166.576, which moved the greatest total distance (222 m) also survived (Table 2). Distance moved on day one by soft or semi soft-released individuals that survived was not significantly different than distance moved day one by hard-released individuals that survived ($t = 1.80$, $df = 7$, $P = 0.113$). Total distance moved by soft or semi soft-released individuals that survived also was not significantly different than total distance moved by hard-released individuals ($t = 0.19$, $df = 7$, $P = 0.854$).

TABLE 2. Identification (ID), fate (D = died, S = survived, ? = unknown), mortality cause, distance moved (m) on day one (DMD1), the number of different locations after release (NDL), and total distance (m) moved (TDM) for hard-released *Dipodomys heermanni* (n = 10) at a southern parcel of Allensworth Ecological Reserve, Tulare County, California in 2009.

ID	Fate	Days survived	Mortality cause	DMD1	NDL	TDM
166.980	S	30+	--	62	2	95
164.477	S	30+	--	6	2	15
166.504	?	13	Unknown - missing	17	3	63
164.319	S	30+	--	46	2	56
167.069	?	7	Unknown - missing	15	2	33
166.381	?	27	Unknown - missing	0	4	207
166.576	S	30+	--	42	2	222
166.781	S	30+	--	28	3	204
166.423	S	30+	--	8	3	24
164.245	S	16	Unknown - missing	18	2	40
mean		24.3		24.2	2.5	95.9

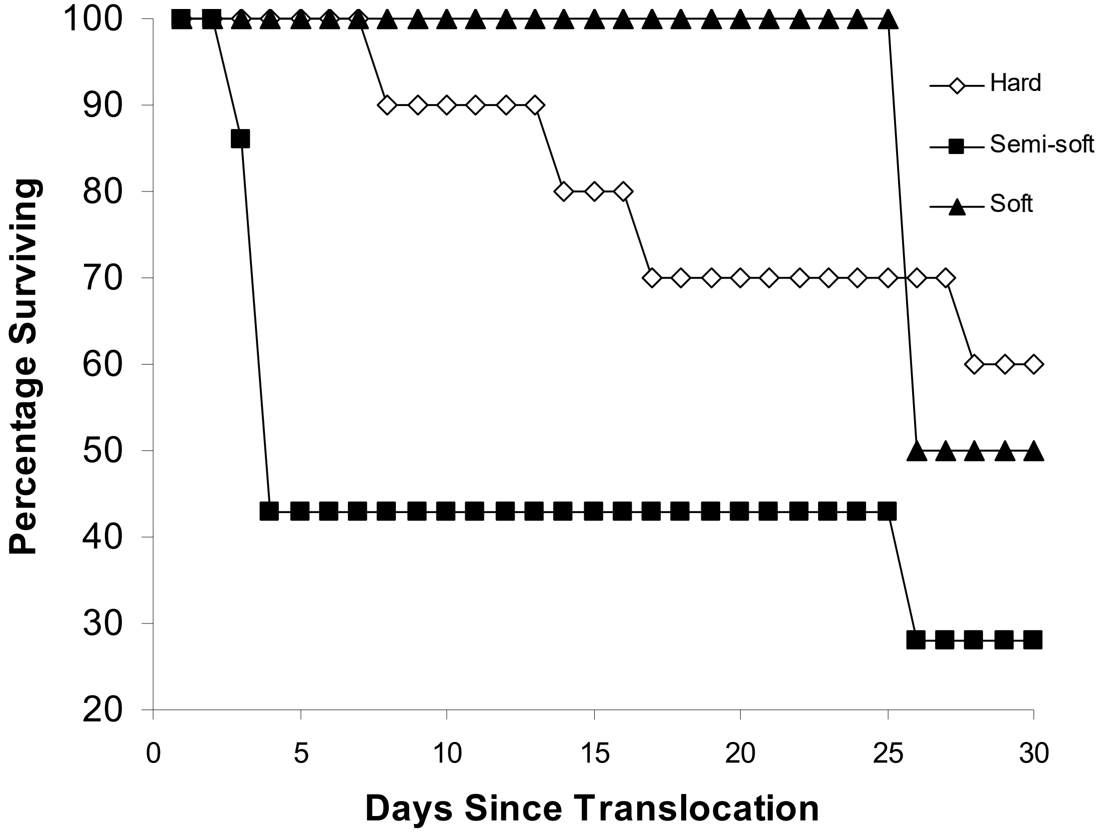

FIGURE 1. Survivorship plot for soft (n = 2), hard (n = 10), and semi-soft (n = 7) released, radio-transmittered *Dipodomys heermanni*, excluding two individuals that died inside of their cages before soft or semi soft-release could be assessed at a southern parcel of Allensworth Ecological Reserve, Tulare County, California in 2009.

We soft-released an additional 21 *D. heermanni* without radio-transmitters and observed their status for 30 days. Based on inactivity in the cages, by day 15 it appeared that the majority of individuals had dug out of the cages. Sometimes there were burrows leading in and out of the cage, indicating that perhaps the original resident or other neighbors visited the cage. On day 19, one individual was found dead in its cage and its cause of death was unknown.

We calculated the probability of surviving to 30 days for hard-released individuals (n = 10) and soft and semi soft-released individuals (n = 11). For hard-released individuals we had no known mortalities and four individuals of unknown fate.

The probability of surviving 30 days post-cage for hard-releases ranged from 0.61 (if we considered unknowns mortalities) to 1.00 (if we consider unknowns as survivors). For soft and semi soft-released individuals we had five known mortalities and three individuals of unknown fate. The probability of surviving to 30 days post-cage ranged from 0.18 (if we considered unknowns mortalities) to 0.34 (if we consider unknowns as survivors). If we considered unknowns as mortalities, the survival probability for soft and semi soft-releases (0.18) was not significantly different than the hard-release survival probability (0.61; $z = 1.34$, $P = 0.181$). If we consider unknowns as survivors, the survival probability for soft and semi soft-releases (0.34) was significantly different than the hard-release survival probability (1.00; $z = 4.00$, $P < 0.001$).

We trapped for four nights (15–18 November 2009) to assess survivorship 30 days post-release and to remove radio-transmitters from individuals that had reached the 30 day post-release or post-cage mark. During the November trapping session, we captured three hard-released individuals, two semi soft-released individuals, and 10 of originally soft-released individuals that were not fitted with radio transmitters. We also captured nine resident *D. heermanni* that were undetected during pre-translocation trapping. On 15 December 2009, we set 12 traps for the two soft-released individuals that we followed for 30 days post-cage. During this trapping session we captured one more *D. heermanni* that was soft-released without a radio-transmitter that we had not caught in November. If we combine our capture data from our November and December trapping sessions with knowledge of who we knew was alive at the 30 day mark based on trapping and radio-telemetry (six hard-released individuals, two semi-soft, two soft, and 11 soft-released without radio-transmitters), our survivorship estimate was 48.8% (21/43) at the 30 day mark. By the end of December 2009, we could further refine our survivorship estimate. We estimated that by the end of December (~60 days) 39.5% (17/43) individuals remained alive. This is based on combined trapping data from November and December (16 individuals captured), knowledge that three of our six hard-released individuals died or went missing after 30-day mark, and that only one of the two soft-released radio-transmittered individuals survived.

At approximately six months post-translocation (early May 2010), we trapped our grid again for four nights to assess survivorship. We captured seven translocated individuals during this trapping session: one hard-released (1 of 10 released; 10%); one semi-soft (1 of 7 released; 14%); and five soft-released (5 of 23 released; 22%). Several of our translocated individuals showed sign of reproduction, including one female that had a copulatory plug. We also captured 13 unmarked *D. heermanni*, most of which were likely resident animals based on age class, although two were juveniles. We estimated survival for translocated individuals at six months, irrespective of type of release to be 16.3% (7/43).

Discussion

We expected that soft-released *D. heermanni* would have higher survivorship than hard-released individuals. However, in this study, survivorship was highest for hard-released individuals (60%; MICROMORT probability of survival 0.61–1.00). Hard-released individuals also, on average, moved less than soft or semi soft-released animals on the first day after release. Every hard-released *D. heermanni* survived to at least seven days, and on average survived 24.3 days. This is in marked contrast to the 2006 study of translocated *D. n. nitratoides,* where only three of eight (37.5%) hard-released individuals survived to 30 days (Germano et al., unpubl. report). All five mortalities occurred quickly (in ≤ 4 days), which is similar to a previous study where predation was the cause of mortality of all translocated *D. n. nitratoides* in ≤ 5 days (Germano 2010).

Although our sample size ended up being small (n = 2), survivorship also was high for individuals that remained in their cage for the full 30-day soft-release period (average days survived 27.5; survivorship 50%). The remaining nine individuals with radio-transmitters that were initially soft-released either died in their cage (n = 2) or dug out of their cage within the first 10 days (n = 7). In the 2006 study of translocated *D. n. nitratoides,* one individual died in its cage, and its cause of death was unknown, although it may have been due to a too tight fit of the radio-collar (D. Germano, pers. obs.). Of the remaining 12 *D. n. nitratoides,* seven dug out of their cage before the full 30 day acclimation period (58.3%; Germano et al., unpubl. report). We found an even higher rate of cage escape in our study (78%). This is likely because several of our cages were placed in soft alkaline soil, where it was easier for humans to dig cages into the ground, but subsequently also easier for kangaroo rats to dig out. Of the five *D. n. nitratoides* that remained in their cages for the entire 30-day acclimation period in the 2006 study, three survived for 30 days post-cage (60%; Germano et al., unpubl. report). Even though our sample size was low, we also found a similar survivorship (50%) of *D. heermanni* that stayed in their cages for 30 days (true soft-releases).

In this study, average days that animals survived and the probability of survival were lowest for semi soft-released individuals (12.6 days; survivorship 28.5%). In the 2006 *D. n. nitratoides* study, seven of 12 individuals dug out of their cages before 30 days (thus, were semi soft-releases), and subsequently four of seven of these semi soft-released individuals survived to 30 days post-cage (57%; Germano et al., unpubl. report). In this study, only two of seven *D. heermanni* that were semi soft-released survived (28.5%). If we consider soft and semi soft-released individuals together, their probability of survival in MICROMORT ranged from 0.18–0.34, which is much lower than the survival estimated for soft and semi soft-released individuals in the 2006 study.

Other reintroduction studies have shown success with some form of soft-release (length of soft-release period differs). For example, soft-releases have been successful for a range of avian species including mallards (*Anas platyrhynchos*; Gatti 1981), sandhill cranes (*Grus canadensis;* Ellis et al. 2000), Aldabra rails (*Dryolimnas [cuvieri] aldabranus;* Wanless et al. 2002) and burrowing owls (*Athene cunicularia;* Mitchell et al. 2011). Benefits of some form of soft-release for small mammals have been documented in studies of dormice (*Muscardinus avellanarius*; Bright and Morris 1994). For dormice, 87–100% of soft-releases survived to day 10 of the study period, versus 50–80% of early (May or June) or late (August or September) hard-releases (Bright and Morris 1994). Also, the successful reintroduction of Perdido Key beach mice used a temporary soft-release enclosure (Holler et al. 1989), and experiments with water voles (*Arvicola terrestris*) currently use only soft-releases because previous hard-release methods were deemed ineffective (Moorhouse et al. 2009). However other studies have demonstrated success using only hard-releases. For example, successful reintroduction of a marsupial rat-kangaroo called the burrowing bettong (*Bettongia lesueur*) in mainland Australia used primarily hard-releases (Short et al. 1992). Soft-releases were initially used; however, individuals injured themselves on fencing and this release method was terminated (Christensen and Burrows 1995). During reintroduction experiments for two species of hare-wallaby (*Lagorchestes* spp.) in Australia, soft-released animals showed no benefit to survival, site fidelity, or body condition compared to hard-releases (Hardman and Moro 2006). Another factor to consider with soft-releases is whether caging individuals adds physiological stress that may affect survival. In this study we had two individuals that died inside their cage, possibly of stress related causes. In the 2006 *D. n. nitratoides* study there was one individual that died in its cage (D. Germano and L. Saslaw, unpubl. report). It may be that cages represent another novel, captive environment that increases chronic-stress (Dickens et al. 2010) and some individuals simply cannot adjust.

One of the factors that may have contributed to the success of hard-released individuals in our study was the high number of available burrows on the translocation site, which provided refugia for translocated individuals. Based on the burrow systems we found, the site likely once supported a large number of valley pocket gophers (*Thomomys bottae*) and kangaroo rats. We did not trap for gophers but most of the burrow systems seemed abandoned. When we trapped the site in October 2009, no small mammals of any kind were caught, although we caught a few resident *D. heermanni* when trapping during the duration of our study. We suspect that any kangaroo rats that might have previously been on site declined during wet years when high levels of grass and thatch accumulated (Single et al. 1996; Uptain et al. 1999; Germano et al. 2001). The site is not actively managed for vegetation structure by California Department of Fish and Game and this could have affected kangaroo rat populations. While tracking translocated *D. heermanni,* we found that they used all types and sizes of available natural burrows on the site. Studies on translocated prairie dogs (*Cynomys* spp.) in Utah also have shown that at sites where there are pre-existing burrow systems, prairie dogs disperse less far and have higher survival rates than areas without abandoned burrows (Robinette et al. 1995; Truett et al. 2001).

Intraspecific aggression may have been one factor that caused lower survival rates of soft and semi soft-released individuals. On the night of release, we observed individuals with a night vision scope and saw digging by conspecifics (either hard-released individuals or residents) around the cages of soft-released individuals. It is unknown whether individuals on the outside were trying to gain access inside the cage because there was a food source inside, whether this was a interference competition based aggressive interaction, or whether the presence of food incited aggression. We suspect that this may have been an intraspecific aggressive interaction because one of our soft-released individuals apparently was killed by a hard-released conspecific that entered its cage. Furthermore, intraspecific aggression among *D. heermanni* was the suspected cause of death of two kangaroo rats in a previous study (Germano 2010) and is known to be high among *D. heermanni* (Trappe 1941; Tennant and Germano, *manuscript in this thesis - Ch. 2*) and kangaroo rats in general (Randall 1993). Studies in Britain also reported two deaths of translocated male dormice due to intraspecific aggression (Bright and Morris 1994).

Some of the soft-released individuals dug out and moved long distances (~150 m) from the main release area of the translocation site, possibly to escape intraspecific aggression and competition from already established hard-released kangaroo rats. It may be possible to reduce aggressive interactions among kangaroo rats by spacing released individuals farther apart or by placing them in the same spatial relationship found on the donor site. Kangaroo rats have complex neighbor relationships that may help to reduce aggression among conspecifics because of familiarity and relatedness between neighbors (Randall 1993). Research on prairie dogs has shown that keeping familial relationships intact decreases stress and increases survivorship (Shier 2006). We did not account for spatial relatedness when we translocated kangaroo rats. Preliminary data on translocated *D. stephensi* suggests that keeping neighbor relationships intact improves survival and overall translocation success (D. Shier, pers. comm.).

High post-release mortality from predation is one of the main limiting factors in success of translocation efforts, and is often most pronounced in captive-reared populations (Wolf et al. 1996; Fischer and Lindenmayer 2000). Kangaroo rats are an important prey for a variety of species in the San Joaquin Valley and other arid areas of the west, including snakes, owls, hawks, weasels, foxes, and coyotes (Grinnell 1932, Culbertson 1946, Hawbecker 1951, Daly et al. 1990, Nelson et al. 2007). While we attempted to reduce post-release predation mortality by using a soft-release, we still observed a high rate of mortality from predation, similar to previous translocation efforts for kangaroo rats (Germano 2001; Germano 2010), brush rabbits (*Sylvilagus bachmani*; Hamilton et al. 2010), swamp rabbits (*S. aquaticus*; Watland et al. 2007), and voles (*Microtus* spp.; Banks et al. 2002). We think that three of our semi soft-released individuals were predated by owls. For all the individuals that went missing, we do not know if they died or survived; however, these individuals were likely either predated, moved off the study area, or their transmitters failed. Based on the fact that we know from other studies that translocated prey species typically have high rates of predation, and also that kangaroo rat populations naturally have high rates of predation, we suspect that many of our radio-transmittered individuals that went missing were likely predated.

Some studies have suggested that predator removal is important to translocation success of prey species (Short and Turner 2000; Banks et al. 2002; Watland et al. 2007). However, in the San Joaquin Valley this is likely impossible, due to protected status of several predator species. One possibility may be to enclose a release area with electrical wire and that can repel mammalian predators, similar to efforts with translocated prairie dogs (Truett et al. 2001), although aerial predators would not be deterred.

If we consider the overall survival and success of our translocated population of *D. heermanni* at six months, we found only 16.3% survivorship. However, this is higher than the population of *D. n. nitratoides* translocated nearby, which had 8.3% survivorship at six months and started with an even larger donor population of 144 individuals (D. Germano and L. Saslaw unpubl. report). Estimates of survivorship of translocated animals in other studies that were similar to our efforts are from 40–70% at one to three months post-release (our estimate at one month was 48.8% and at two months was 39.5%). For example, for hare-wallabies in Australia one month post-release, 68% of either hard (n = 19) or soft (n = 15) released individuals remained on the reintroduction site (< 1 km from release; Hardman and Moro 2006). In a translocation effort for the San Bernardino kangaroo rat (*Dipodomys meeriami parvus)* in San Bernardino County, California, 15 individuals were hard released without artificial burrows to a reclaimed mine site and six were retrapped (40%) on the site three months later (O'Farrell 1999).

We believe that several factors may have played a role in this translocation having a high level of initial survivorship. First of all, the donor and translocation site were in close proximity to each other and likely had very similar soil and microhabitat types. Furthermore, we consider the donor site as being within the core range of the target species, having high habitat quality, a high abundance of available burrows (presence of refugia), and low numbers of competitors, all of which have been identified as important factors for translocation success (Griffith et al. 1989). A high level of survivorship for *D. m. parvus* in San Bernardino may also be attributable to similar factors that played a role in our study. For example, the reclamation site was near the donor site (ca. 4 km), habitat was considered suitable, and there were existing, well-developed rodent burrows and shrubs (O'Farrell 1999). Interestingly, the 2006 *D. n. nitratoides* study included all of these factors except for two: (1) close proximity of the donor and translocation site and (2) high abundance of natural burrows. Because preferred habitat types of *D. n. nitratoides* are relatively similar throughout the San Joaquin Valley, we postulate that one important factor to consider when selecting appropriate translocation sites for kangaroo rats is a high abundance of natural burrows.

Management recommendations

This study demonstrates that there may not be a benefit to soft-release methods for translocating kangaroo rats. We suspect this recommendation may differ depending on translocation site conditions. If conditions on the site include high quality habitat and ample refugia (in this case, natural burrows for kangaroo rats), soft-release may not be necessary to increase survival and site fidelity. Performing soft-releases requires significantly more effort of both time and resources, and it may not be worth spending limited budgets on these efforts if survival is not significantly improved (also see Hardman and Moro 2006). However, further research on soft-releases, including analysis of parameters such as caging time and cage size, is warranted to determine if survival can be improved. We further recommend that if sites do not include ample refugia, supplemental artificial burrows be added to a site; however, the extent to which kangaroo rats will habituate and use permanent artificial burrows if natural burrows are not available is unknown. We recommend that sites with refugia (but without an abundant population of kangaroo rats) be given higher priority for translocation than sites without refugia. In addition, dealing with territorial species, such as kangaroo rats, may require attention to spacing and neighbor relationships to reduce intraspecific aggression and death.

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4

Summary and Recommendations for Future Translocations or Reintroductions of Endangered Kangaroo Rats

Summary of Research

Competition

My research suggests that competitive depression of a population of translocated *Dipodomys nitratoides nitratoides* by the larger *D. heermanni* is occurring at Allensworth Ecological Reserve. If this type of interference competition is occurring in other areas of the San Joaquin Valley where *D. n. nitratoides* and *D. heermanni* occur sympatrically, recovery of the endangered *D. n. nitratoides* may be an even greater challenge than already occurs. A change in community structure due to competitive release was not unexpected because previous studies have demonstrated that competition is a strong force in heteromyid communities. For example, past experiments demonstrated that the removal of one or more species in different functional groups leads to an increase in the remaining species that utilize similar resources (Munger and Brown 1981; Heske et al. 1994; see review by Brown and Harney 1993). Furthermore, previous studies have also shown that larger heteromyids use aggressive interference to outcompete smaller species (Blaustein and Risser 1976; Frye 1983; Basset 1995; Perri and Randall 1999). An increase in the number of *Perognathus inornatus* in our exclusion area also was not surprising because past research in the San Joaquin Valley has demonstrated that during periods of kangaroo rat decline, *P. inornatus* also experience competitive release (Single et al. 1996; Cypher 2001)

I was surprised at how quickly the population of *D. n. nitratoides* increased in the exclusion area in response to the absence of *D. heermanni*, which indicated to me that competition with *D. heermanni* was a major factor influencing the success of the 2006 translocation effort for *D. n. nitratoides.* Even though I observed no direct agnostic behaviors during behavioral observations, *D. heermanni,* being the larger of the two species, still dominated interactions. However, avoidance behaviors predominated during interactions and likely allowed for some level of coexistence between species (also see Perri and Randall 1999).

One of the goals of the Recovery Plan for Upland Species of the San Joaquin Valley (USFWS 1998) is to determine the nature of competitive interactions between *D. n. nitratoides* and *D. heermanni*, and then determine whether certain habitat management prescriptions may give *D. n. nitratoides* a competitive advantage over *D. heermanni*. While it appears that *D. n. nitratoides* do well in areas with alkali playas, soft alkaline soils, and low levels of non-native grasses (D. Germano, unpubl. data), I recommend additional research on population dynamics of *D. n. nitratoides* and *D. heermanni*. Additional sites should differ in habitat types and/or management regimes to determine if *D. n. nitratoides* might have a competitive advantage in certain habitats. I suspect that because of the small size of *D. n. nitratoides*, large home ranges, and preference to scatter hoard under most conditions (see Murray et al. 2006), even small increases in ground cover affects their success and potential ability to compete with *D. heermanni* for resources and territory.

Translocation

My results on translocation methods, using *D. heermanni* as a surrogate species, indicated that there may not be a benefit to soft-release over hard-release methods on certain sites. Based on previous translocation efforts for kangaroo rats that have shown that mortality from predation for hard-released individuals occurs within the first 4–5 days (Germano 2001; Germano and Saslaw, unpubl. report; Germano 2010), I was surprised that hard-released *D. heermanni* had higher survivorship than soft-released animals at my translocation site. Based on a literature review of reintroduction studies, some form of soft-release has been successful for both avian species (Gatti 1981; Ellis et al. 2000; Wanless et al. 2002; Mitchell et al. 2011) and small mammals (Holler et al. 1989; Bright and Morris 1994). However, in other reintroduction experiments, soft-releases have not improved survival, site fidelity, or body condition (Hardman and Moro 2006). In one study with the marsupial rat-kangaroo the burrowing bettong (*Bettongia lesueur)* soft-released individuals injured themselves on fencing and this release method was terminated (Christensen and Burrows 1995). It may be that cages are another novel environment that increases chronic-stress of reintroduced individuals (Dickens et al. 2010) and affect acclimation to the reintroduction site and survival.

Two factors that may have contributed to the success of hard-released individuals in my study were the high quality habitat on the translocation site and the high number of available burrows. The site likely once supported a large number of valley pocket gophers (*Thomomys bottae*) and kangaroo rats, thus ample refugia (in the form of vacant burrows) were available for translocated individuals. In other translocation experiments involving prairie dogs (*Cynomys* spp.) in Utah, individuals dispersed less far and had higher survival rates on translocation sites where there were pre-existing burrow systems compared to areas without abandoned burrows (Robinette et al. 1995; Truett et al. 2001).

Recommendations for Translocations or Reintroductions

Translocation often has been proposed by resource agencies as a mitigation strategy for species that are impacted by land development activities (O'Farrell 1999; Germano 2001; Edgar et al. 2005; Ashton and Burke 2007; Germano 2010). In the San Joaquin Valley, translocation of individuals displaced by development activities has been used as a means of mitigating land development activities that affect threatened and endangered species. Based on work completed since the early 1990s, translocation research presented in this thesis (Tennant and Germano, *manuscript in this thesis - Ch.3)*, and published information on translocations and reintroductions, I provide some preliminary recommendations for future translocations or reintroductions of *D. n. nitratoides* or other similar kangaroo rat species.

I use standard definitions of the International Union for Conservation of Nature (IUCN) to define the terms translocation and reintroduction. Thus, translocation is the human-mediated movement of wild animals from one part of their range to another, and reintroduction is the movement of individuals to areas within their historic range where they have been extirpated (IUCN 1998). While I realize these two terms are different, I often use them interchangeably because I believe the recommendations I provide apply to either situation. I also use conventional criteria for considering a translocation a success, which is that a translocation or reintroduction is successful if the introduced population is self-sustaining (Griffith et al. 1989).

Recommendations

1. Absence of a *Dipodomys nitratoides nitratoides* population

One of the first considerations when choosing a translocation site is to ensure that the site is not currently occupied by a population of *D. n. nitratoides*. Because so few sites in the San Joaquin Valley support this species, the first priority should be to protect any site that currently supports a resident population. Furthermore, kangaroo rats have intricate intraspecific social relationships and it would be difficult to introduce new individuals into a population without inciting agnostic behaviors from residents (see intraspecific interactions recommendations [No. 6] and Tennant and Germano, *manuscript in this thesis - Ch.3).* It is likely many individuals translocated to a site already occupied will not survive. Even when translocated animals survive, they may displace resident animals, resulting in losses equivalent to the addition of individuals, especially if the resident population is at or near the carrying capacity. In either case, no net benefit to the species is probable.

2. Absence of competitors

Because the larger *D. heermanni* can competitively depress populations of the smaller *D. n. nitratoides* (Tennant and Germano, *manuscript in this thesis - Ch. 2),* translocation and reintroduction efforts for *D. n. nitratoides* must consider the competitive effects of larger, coexisting species. In previous studies, translocations into areas with a congeneric competitor were less successful than translocations to sites without a resident competitor or even a potential competitor (Griffith et al. 1989). Since the early 1990s, site selection for translocation and reintroduction of *D. n. nitratoides* has been based on the presence or absence of competitors. However, as is often the case with small mammal communities, populations fluctuate temporally. Thus, despite choosing sites apparently devoid of competitors, competitors may indeed be present, as was the case in the 2006 translocaiton of *D. n. nitratoides* to the Allensworth Ecological Reserve (Germano et al., unpubl. report).

I recommend that trapping to assess species presence or abundance on a target translocation site occur within 2–3 weeks of the target translocation date. Trapping need not occur over the entirety of the site, but should at least be conducted in a portion of the target area, and especially in areas where burrows are located. Ideal translocation sites are those devoid of congeneric competitors. However, it is extremely difficult to find sites in the San Joaquin Valley that have both suitable habitat and are devoid of either the target species or competitors. If the number of competitors on a site is relatively low, a translocation still might be successful. One parameter is that I suggest is that sites should not be used if more than two competitor species per 50 traps are caught over a four night census period.

If translocation sites for *D. n. nitratoides* cannot be found that have both appropriate habitat and a low number of competitor individuals, I recommend that competitors be removed before translocating *D. n. nitratoides*. Even if a few competitors remain on site (it is unlikely that trapping will totally eliminate the competitor population), the translocated species will have a better chance of becoming established. Patterns of day burrow use suggest that kangaroo rats may prefer to avoid the home ranges of other species (Perri and Randall 1999). Thus, it may be possible that once a *D.*

n. nitratoides population is established on a site, their abundance and spacing mechanisms may allow them to better compete and coexist with congeneric competitors.

3. Time of year

Translocations of kangaroo rats generally are not conducted during any time of year that would cause excessive stress to individuals. For example, translocations typically are not conducted during times of year when temperatures are at high or low extremes. However, because many translocations occur under project development timelines, avoiding high or low temperature extremes often is not an option. For example, the 2006 translocaiton of *D. n. nitratoides* to Allensworth Ecological Reserve occurred at the beginning of December when low temperatures were barely above freezing because development at the donor site was slated to begin (Germano and Saslaw, unpubl. report). Conversely, mid summer temperatures in the San Joaquin Valley regularly exceed 40° C and high daytime temperatures may put undue stress on kangaroo rats that have not established a series of self-made burrow systems.

Other studies involving translocated dormice (*Muscardinus avellanarius)* found that animals released in early summer (May, June) lost more body mass than those released in late summer (August, September; Bright and Morris 1994). Bright and Morris (1994) also suggested that food scarcity for dormice in early summer may necessitate supplemental feeding. It is unknown to what extent seasonal food shortages affect kangaroo rat populations and how this should be factored into translocation efforts. Food availability may be highest in the late spring, just after annual herbaceous vegetation has matured. Food shortages and population pressure do impact kangaroo rat populations in extreme drought years (Williams et al. 1993), and perhaps this is not an optimal time for translocation efforts.

Another factor to consider when translocating kangaroo rats is the activity of predators. In 2010, a reintroduction effort for *D. n. nitratoides* was attempted in the month of August and three of the reintroduced individuals were predated by northern Pacific rattlesnakes (*Crotalus oreganus oreganus*; Endangered Species Recovery Program, unpubl. data). Several species of snakes are predators of kangaroo rats, and, like most reptiles, are active from late spring to early fall. Because high mortality rates are already common when translocating prey species, I recommend conducting translocations when reptile activity is low in order to reduce predation.

Given the factors above, I recommend that the best time of year to conduct translocations of kangaroo rats in the San Joaquin Valley is either in late fall (late September – November) or spring (March – May). During these times, temperatures are moderate and snake activity is low.

4. Habitat quality and refugia

In a review of translocations by Griffith et al. (1989), successful translocations occurred at sites with both high quality habitat and the presence of refugia (which, in the case of kangaroo rats, would be presence of available burrows). In fact, without high quality habitat and assurance that active management will occur on the translocation site, there is a low chance of success no matter how many individuals are released (Griffith et al. 1989; Wolf et al. 1996). In the San Joaquin Valley, sites with high quality habitat typically are those that lack dense non-native grass cover, or that are aggressively managed to reduce dense non-native grass cover that occurs during years when herbaceous growth is high (Germano et al. 2001). If sites are not managed for low herbaceous cover, the likelihood of continued survival of translocated kangaroo rats is low. Thus, I recommend that any potential translocation site should have a vegetation management and monitoring plan.

Translocated *D. heermanni* exhibited high survivorship on a site with high abundance of available natural burrows (Tennant and Germano, *manuscript in this thesis - Ch. 3)* indicating that presence of refugia may be an important factor for survival of translocated individuals. Studies of translocated prairie dogs (*Cynomys* spp.) in Utah also have shown that at sites where there are pre-existing burrow systems, prairie dogs disperse shorter distances and have higher survival rates than in areas without abandoned burrows (Robinette et al. 1995; Truett et al. 2001). Thus, I recommend that sites with high quality habitat and refugia be given higher priority than sites without refugia. If sites do not include ample refugia, supplemental artificial burrows should be added to a site, although the extent to which kangaroo rats will use permanent artificial burrows if natural burrows are not available is unknown. However, the presence and use of artificial burrows may provide enough time for translocated individuals to construct their own burrow systems.

5. Number of individuals

Size of translocation and reintroduction efforts for endangered kangaroo rats have ranged from small efforts (15 individuals; Germano 2001; O’Farrell 1999) to large scale removals from an entire parcel of occupied habitat (144 individuals; Germano et al., unpubl. report). Also, all past translocation efforts for kangaroo rats have consisted of only one release effort. In an assessment of successful translocations by Griffith et al. (1989), a typical translocation effort consisted of six releases over a three year period. Of these releases, the majority consisted of < 75 animals but > 30 animals (Griffith et al. 1989). Griffith et al. (1989) and Fisher and Lindenmayer (2000) both found that success increases when a greater number of animals are initially released. Also, releasing > 100 individuals was associated with greater translocation success (Fisher and Lindenmayer 2000).

Often in the San Joaquin Valley, development projects occur on a small footprint (i.e. oil wells or pads, small developments < 4 ha) and the number of individuals requiring translocation is small (< 30 individuals). Predation rates on translocated prey species often is high (Germano 2001; Banks et al. 2002; Watland et al. 2007; Germano 2010; Hamilton et al. 2010) and therefore, overall survivorship is typically low (8.3% - Germano and Saslaw, unpubl. report; 16.3% - Tennant and Germano, *manuscript in this thesis - Ch. 3*). I suggest that translocation efforts should not be conducted for kangaroo rats if there are < 40 individuals to be translocated. Translocations or reintroductions should be conducted with a founder population of at least 40–60 individuals.

6. Intraspecific relationships and spacing

Kangaroo rats have complex neighbor relationships that may help to reduce aggression among conspecifics because of familiarity and relatedness between neighbors (Randall 1989, 1991, 1993). Thus, attention should be given to spacing and neighbor relationships in order to reduce intraspecific aggression and death during translocations.

Other translocation research has demonstrated that attention to familial relationships can increase survivorship. For example, research on prairie dogs has shown that keeping familial relationships intact decreases stress and increases survivorship (Shier 2006). Preliminary data on translocated *D. stephensi* also suggests that keeping neighbor relationships intact improves survival and overall translocation success (D. Shier, pers. comm.).

I recommend that translocations take into account neighbor relationships on donor sites. I have found that one way to do this is to group individuals on the recipient site in the same spatial arrangement that they were trapped at the donor site. Thus, kangaroo rats trapped in adjacent traps on the recipient site will be placed in adjacent burrows on the donor site. This requires advance planning using spatial maps of both the donor and recipient sites so that individuals can be grouped together.

In spacing kangaroo rats on the recipient site, I have generally tried to place kangaroo rats close enough so that they will come into contact and find mates, but also far enough apart so as to avoid aggressive interactions. In past translocation efforts, kangaroo rat burrows and cages have been spaced at least 15 m apart. However, *D. n. nitratoides* tend to have larger home ranges than other species (ca. 1000 – 3000 m^2; Tennant and Germano *manuscript in this thesis - Ch. 2*); thus, 15 m spacing may be too close and promote aggression. However, home ranges of smaller kangaroo rat species typically overlap and spacing is likely highly dynamic. More research is needed on kangaroo rat burrow spacing dynamics so that translocations can better incorporate proper spacing parameters. One possible option is to map the burrow locations of each individual on the donor site through trapping and night vision technology, and then emulate this spacing on the recipient site (D. Shier, pers. comm.).

7. Hard or soft releases

The assessment by Griffith et al. (1989) of translocations found no consistent association between successful translocations and either hard or soft-release methods. In the San Joaquin Valley, results from translocation efforts for *D. n. nitratoides* since the 1990s have shown that mortality from predation for hard-released individuals occurs within the first 4–5 days (Germano 2001; Germano and Saslaw, unpubl. report; Germano 2010). Thus, soft-release methods could help reduce initial high predation rates. In the previous translocation study for *D. n. nitratoides*, more soft or semi soft-released individuals survived than those that were hard-released, but the differences were not significant (Germano and Saslaw, unpubl. report). The reverse was true for my study of translocated *D. heermanni*. In this study, hard-released individuals had higher survivorship than soft-released individuals, but differences in survivorship also were not significant (Tennant and Germano, *manuscript in this thesis - Ch. 3)*. Also, many kangaroo rats in my study dug out of their cages in one to two days, which made it difficult to assess whether caging increased survivorship.

Many reintroduction studies have shown success with some form of soft-release, especially with avian species, which can easily disperse (Gatti 1981; Ellis et al. 2000; Wanless et al. 2002; Mitchell et al. 2011). Successful use of soft-release methods has also been beneficial for some small mammals (Holler et al. 1989; Bright and Morris 1994). However, other reintroduction experiments using soft-releases have not improved survival, site fidelity, or body condition (Hardman and Moro 2006). In fact, in may be that cages are another novel environment that increases chronic-stress of reintroduced individuals (Dickens et al. 2010) affecting adjustment to the reintroduction site and survival.

Pending further data on hard and soft-release methods, I recommend that the decision to hard or soft-release individuals be based largely on translocation site conditions. If conditions on the site include high quality habitat, ample refugia, and low levels of competitors, then soft-release may not be necessary to increase survival and site fidelity. Performing soft-releases requires significantly more effort and resources, and it may not be worth spending limited budgets on these efforts if survival is not significantly improved (also see Hardman and Moro 2006). However, additional testing of the benefits and different parameters that may affect survival of soft-releases, such as length of caging time, size of cage, and spacing of cages should continue until a definitive answer is determined.

Conclusion

The best option for conserving *D. n. nitratoides* is to protect all remaining parcels on which it occurs. Recovery of this species may also require that additional land be purchased and converted back into native habitat. However, I recognize that full protection of remaining lands that support *D. n. nitratoides* will be challenging, so translocating some individuals away from sites slated for development to unoccupied suitable habitat may be a necessary alternative strategy.

More research on effective methods for translocating kangaroo rats is needed. Many questions still exist, one of which is whether sites can be found readily in the southern San Joaquin Valley that 1) have high quality habitat, 2) can be actively managed, 3) contain a high abundance of refugia, but 4) lack a current population of endangered kangaroo rats, and 5) have no or few competitors. The lack of available sites has confounded translocation efforts in the past (D. Germano, pers. comm.). A current list of potential translocation sites for target species needs to be developed and maintained so that when potential translocation or reintroductions for rare kangaroo rats are considered, potential sites can be quickly identified. If potential translocation sites and a translocation plan can not follow these or similar recommendations, I think that translocations should not be attempted. As has been pointed out in the past, translocating species under less than optimal conditions raises ethical questions that should not be ignored. It would likely be better to place specimens into museums, use them in outreach programs, or use them for research, than conduct translocations with a low probability of success.

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