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Survival of Translocated Heermann's Kangaroo Rats (*Dipodomys heermanni*) in the San Joaquin Desert of California Using Hard and Soft Release Methods

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***Abstract*.—Translocation of endangered kangaroo rats in the San Joaquin Desert, California, has often been proposed as a mitigation strategy for populations impacted by land development activities, but has largely been unsuccessful. In a 2006 translocation experiment, soft-released Tipton kangaroo rats (*Dipodomys nitratoides nitratoides*), an endangered species, had higher 30-d survival rates than hard-released individuals, although differences were not significant. In this experiment, we completed a translocation of *D. heermanni*, a non-protected species. To determine survivorship of *D. heermanni*, we placed radio-transmitters on 10 hard-released and 11 soft-released individuals. We predicted that our study would support soft-release as an effective way to improve survivorship. However, we found that hard-released individuals had the highest rate of survivorship to 30 d (60%), while survival was lowest for soft and semi soft-released individuals (27%). One factor that may have contributed to the success of hard-released individuals in our study was the unusually high number of available burrows of Botta's Pocket Gophers (*Thomomys bottae*) on the translocation site, which provided immediate refugia. We conclude that soft-release may not be necessary if translocation sites have both high quality habitat and ample refugia, but recommend more research on soft-release methods.**

Key Words.—hard-release; kangaroo rat; soft-release; survivorship; translocation

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), which define translocation as the human-mediated movement of wild animals from one part of their range to another, and reintroduction as the movement of individuals to areas within their historic range where they have been extirpated (International Union for Conservation of Nature/Species Survival Commission [IUCN/SSC] 2013).

The number of translocation or reintroductions completed annually has been growing in the last two decades (Griffith et al. 1989; Fischer and Lindenmayer 2000; Germano et al. 2015), 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 San Joaquin Desert of California (Germano et al. 2011) has been affected by anthropogenic driven change to natural communities beginning as early as the 1850s (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 currently persist on only 2–4% of their historic ranges (Williams and Germano 1992). The only kangaroo rat species in the San Joaquin Desert 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 Desert is classified as the subspecies *D. h. tularensis* (Tappe 1941). *Dipodomys heermanni tularensis* (Fig. 1) is a medium-sized species (about 70 g) that ranges widely throughout most of the San Joaquin Desert in all but the wetter habitats (Williams and Kilburn 1992).

Also in the Tulare Basin is the Tipton Kangaroo Rat (*D. n. nitratoides*), one of three recognized subspecies of *D. nitratoides*, and which has been the focus of transloca-

Figure 1. Heermann's Kangaroo Rat (*Dipodomys heermanni*). (Photographed by David Hunter).

tion efforts since the early 1990s because of its protected status. It is one of the smallest kangaroo rat species (about 35 g) and was listed as endangered in 1988 under the federal Endangered Species Act and in 1989 (US Fish and Wildlife Service [USFWS] 1988) under the California Endangered Species Act (California Department of Fish and Game [CDFG] 1989). The recent review by the USFWS (2010) suggests that *D. n. nitratoides* currently persists at 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. Numerous mitigation driven translocation efforts for this species have occurred at the request of biologists in both state and federal resource agencies (Germano 2001, 2010; David Germano, pers. obs.). In the 1990s, several small scale translocations of *D. n. nitratoides* were completed and, based on limited post-release field work, were considered unsuccessful in all but one instance (Germano 2001). 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. 2013). Assessment methods included an analysis of hard and soft-release methods using radiotelemetry, where a hard-release was a direct release onto the site and a soft-release was a 30-d acclimation period inside a wire-mesh cage, as well as long-term monitoring over a 3-y period and genetic analysis to assess relatedness of offspring to translocated individuals (Germano et al. 2013). 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. 2013). Also, although not statistically significant, it appeared that soft-released individuals had a higher survival rate. By 2009, a small (n = 15), but persistent, population occurred on the translocation site (Germano et al. 2013).

We wanted to replicate the 2006 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 *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, b; Biggins et al. 1999). We think that the type of release method used to translocate kangaroo rats affects their survival at the release site. Based on previous unsuccessful hard-releases of *D. n. nitratoides* (Germano 2001; Germano 2010) and the apparent improved survivorship of this species using soft-releases (Germano et al. 2013), we predict that survival of *D. heermanni* that are soft-released will be significantly greater than the survival of *D. heermanni* that are hard-released.

Methods

Study area.—We translocated *D. heermanni* 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 Wildlife, 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. Parcels on the reserve are both fenced and unfenced; thus, trespass grazing by cattle of adjacent landowners occurs on some parcels within the reserve.

Vegetation communities are classified as *Atriplex spinifera* shrubland alliance, *Allenrolfea occidentalis* shrubland alliance, *Suaeda moquinii* shrubland alliance, and *Bromus rubens-Schismus* (*arabicus*, *barbatus*) herbaceous semi-natural alliance (Sawyer et al. 2009). 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. 2011. Web Soil Survey. United States Department of Agriculture. Available online at http://websoilsurvey.nrcs.usda.gov. [Accessed 11 October 2010]).

The San Joaquin Desert has a Mediterranean climate with hot, dry summers and cool, wet winters (National Oceanic and Atmospheric Administration [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.—*Dipodomys 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 2013). We removed *D. heermanni* from the exclusion area and surrounding habitat using Sherman live traps that were baited with birdseed. 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 43 *D. heermanni* from the donor site. 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 randomly selected 11 candidates for soft-release and 10 candidates for hard-release that were fitted with radio-collars. The candidates for radio-collars were adult *D. heermanni* equally proportioned of males and females and were in non-reproductive status at time of translocation. 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; Germano et al. 2013). To ensure proper fit and habituation of individuals to radio-collars, we monitored individuals in 19 L plastic buckets for 24–36 h before release. We released all *D. heermanni* (collared and un-collared) on the translocation site 16 October 2009.

The translocation site was located in the southern portion of the reserve and was chosen based on replicate habitat structure and plant community, proximity to donor site (about 4.8 km), absence of large numbers of kangaroo rats currently occupying the site, and high number of available burrows (Tennant et al. 2013). 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 Desert (Germano and Rhodehamel 1995). We placed approximately 0.1 L of seed inside of each artificial burrow. To avoid any potential aggressive interactions among kangaroo rats, we spaced burrows at least 15 m apart. *Dipodomys heermanni* that we hard-released were placed inside of an artificial burrow approximately 1 h 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 × 60 cm and was closed on the top, but open on the bottom (similar to cages used in Germano et al. 2013). 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 for initial release.

We placed soft-released individuals in the artificial burrow inside the cage approximately 1–2 h 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 d. However, nearly all of our kangaroo rats dug out within the first 10 d of release; thus, we considered these individuals that dug out before the 30-d period to have a semi soft-release. For kangaroo rats that remained in their cage for the 30-d period, we added seed to cages four to six 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, California, 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 d 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 d after they dug out of the cages themselves or after we removed cages at the 30-d mark. We determined that kangaroo rats had successfully established themselves on the site if they survived for 30 d post-release or 30 d post-cage.

We assessed survivorship at 30 d post-release or post-cage by trapping for target individuals and removing radio-transmitters. At this point, we confirmed the fate of all established individuals by removing radio-collars or otherwise determining their fate (some mortality occurred post-establishment). 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 d and again at 6 mo.

***Analyses*.**—We estimated distance traveled by individuals from their respective release site using GIS location data from radiotracking in ArcMap 9.3 (Esri, Redlands, California, 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-d tracking period. We assessed survival probabilities of all release types (hard, soft and semi-soft) 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 d 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 d 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. heermanni* 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. We also compared distances moved on day one by soft or semi soft-released individuals that survived to distances moved on day one by hard-released individuals that survived using a *t*-test. We used a *t*-test also to compare total distances moved by *D. heermanni* in the same groups. All statistical tests were completed in Minitab 17 (Minitab Inc., State College, Pennsylvania, USA) and 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. Another appeared to be killed by a hard-released *D. heermanni* with a radio-collar that entered the cage, attacked the soft-released individual, and began using the artificial burrow inside the cage. The original soft-released individual 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 with its tail chewed. Of the remaining nine soft-released individuals, only two remained in their cage for the full 30-d soft-release period (Table 1). After cages were removed, and post-cage monitoring began, one individual survived for an additional 30 d post-cage and one did not (Table 1; Fig. 2).

Seven of the remaining nine (78%) *D. heermanni* that we initially soft released dug out of their cages within the first 10 d. Because they did not remain in the cages for the full 30-d habituation period, we considered these individuals as having a semi soft-release. Two of these seven (28.5%) semi soft-released individuals survived to the 30-d post-cage mark (Fig. 2). The remaining individuals were either confirmed to be preyed upon or went missing. Individuals who went missing were likely either preyed upon, moved off the study area, or had a radio-transmitter that failed. If they were never recaptured on the study site, we considered their fate unknown. Mean distance moved on day one after escape/cage removal for soft and semi soft-released individuals was 55.4 ± 18.9 m (Table 1). The mean number of different burrow locations we found soft and semi soft-released individuals during the first 30 d post-release was 2.1 ± 0.5 and the mean total distance moved was 103.3 ± 27.4 m (Table 1).

Of the 10 radio-transmittered *D. heermanni* that we hard released, six (60%) survived 30 d post release (Table 2; Fig. 2). The remaining four hard-released individuals went missing after 7, 13, 16, and 27 d (Table 1; Fig. 2). 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 burrow locations during the tracking period, and the mean total distance moved was 95.9 ± 26.1 m. Individuals that made the greatest movements on day 1 (62 m, 46 m, 42 m, and 28 m) all survived. The individual that 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 on 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 that survived (t = 0.19, df = 7, P = 0.854).

In addition to our radio-collared individuals, we soft-released an additional 21 *D. heermanni* and observed their status for 30 d. 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 of unknown causes.

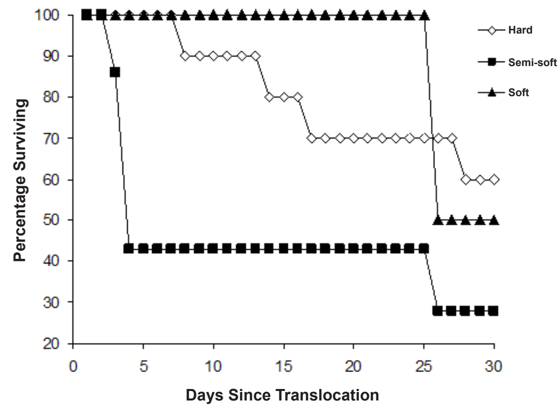

Figure 2. Survival plot for soft (black triangles; n = 2), hard (white diamonds; n = 10), and semi-soft (black squares; n = 7) released, radio-transmittered Heermann's Kangaroo Rats (*Dipodomys heermanni*), excluding two individuals that died inside of their cages before soft or semi soft-release could be assessed at a southern parcel of Allensworth Ecological Reserve, Tulare County, California in 2009.

We calculated the probability of surviving to 30 d 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 d 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

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 burrow locations after release (NDB), and the total distance (m) moved (TDM) for 11 soft and semi soft-released Heermann's Kangaroo Rats (*Dipodomys heermanni*) at a southern parcel of Allensworth Ecological Reserve, Tulare County, California in 2009.

ID	DDO	Fate	DSPC	Mortality cause	DMD1	NDB	TDM
1	—	D	0	Killed by conspecific	—	—	—
2	—	D	0	Pinned under cage trying to dig out	—	—	—
3	1	S	30+	—	65	2	78
4	2	S	30+	—	162	3	232
5	3	D	2	Predation – owl	138	1	138
6	2	D	3	Predation – owl	40	1	40
7	4	D	17	Predation – owl	18	6	196
8	10	?	3	Unknown – missing	9	1	9
9	10	?	3	Unknown – collar found on ground unlatched	8	2	170
10	—	S	30+	—	28	2	36
11	—	?	25	Unknown – missing	31	1	31
mean			13.0		55.4	2.1	103.3

we had five known mortalities and three individuals of unknown fate. The probability of surviving to 30 d 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 d post-release and to remove radio-transmitters from individuals that had reached the 30 d post-release or post-cage mark. During the November trapping session, we captured 10 of the originally soft-released individuals that were not fitted with radio-collars. 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 d 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 d mark (six hard-released individuals, two semi-soft, two soft, and 11 soft-released without radio-transmitters; total = 21), our survivorship estimate was 48.8% (21/43) at the 30 d mark. By the end of December 2009, we could further refine our survivorship estimate. We estimated that at the end of December 2009 (about 60 d post release) 39.5% (17/43) of individuals remained alive. This is based on combined trapping data from November and December and knowledge that three of our six hard-released individuals died or went missing after the 30-d mark, and that only one of the two soft-released individuals with radio-transmitters survived.

At approximately 6 mo 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 (one of 10 released; 10%); one semi-soft (of seven released; 14%); and five soft-released (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, when considering survivorship of radio-collared kangaroo rats during the first 30 d period of translocation, survivorship was highest for hard-released individuals. Hard-released individuals also, on average, moved less than soft or semi soft-released animals on the first day after release. 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 d (Germano et al. 2013). All five mortalities occurred quickly (in ≤ 4 d), which is similar to a previous study where predation was the cause of mortality of all translocated *D. n. nitratoides* in ≤ 5 d (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-d soft-release period. The remaining nine individuals with radio-transmitters that were initially soft-released either died in their cage

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

ID	Fate	Days survived	Mortality cause	DMD1	NDB	TDM
1	S	30+	—	62	2	95
2	S	30+	—	6	2	15
3	?	13	Unknown – missing	17	3	63
4	S	30+	—	46	2	56
5	?	7	Unknown – missing	15	2	33
6	?	27	Unknown – missing	0	4	207
7	S	30+	—	42	2	222
8	S	30+	—	28	3	204
9	S	30+	—	8	3	24
10	S	16	Unknown – missing	18	2	40
mean		24.3		24.2	2.5	95.9

(n = 2) or dug out of their cage within the first 10 d (n = 7). In the 2006 study of translocated *D. n. nitratoides*, one individual died in its cage, although this may have been due to a too tight fit of the radio-collar (David Germano, pers. obs.). Twelve *D. n. nitratoides* remained and seven dug out of their cage before the full 30-d period (58.3%; Germano et al. 2013). 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-d acclimation period in the 2006 study, three survived for 30 d post-cage (60%; Germano et al. 2013). Even though our sample size was low, we also found a similar survivorship (50%) of *D. heermanni* that remained in their cages for 30 d.

In this study, average number of days that an individual survived and the probability of survival were lowest for semi soft-released individuals. In the 2006 *D. n. nitratoides* study, seven of 12 individuals dug out of their cages before 30 d (thus, were semi soft-releases), and subsequently four of seven of these semi soft-released individuals survived to 30 d post-cage (57%; Germano et al. 2013). 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 this study was 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). 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*) switched to using only soft-releases because previous hard-release methods were deemed ineffective (Moorhouse et al. 2009). Reintroduction work with Stephen's Kangaroo Rats (*Dipdomys stephensi*) has also used soft release methods (Shier and Swaisgood 2012).

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 (Germano et al. 2013). It may be that cages represent a 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 Botta's 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, 2012). The site is not actively managed for vegetation structure by the California Department of Fish and Wildlife 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 to the cage because there was a food source inside, whether this was an 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; Erin Tennant, pers. obs.) 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 (about 150 m) from the main release area of the translocation site, possibly to escape intraspecific competition from already established hard-released kangaroo rats. It may be possible to reduce aggressive interactions between kangaroo rats by placing them in the same spatial neighbor relationship found on the donor site. Reintroduction efforts with *D. stephensi* have demonstrated that keeping neighbor relationships intact increases survival, settlement (establishment of home range), and reproductive success (Shier and Swaisgood 2012).

High post-release mortality from predation is another factor that can limit translocation success (Wolf et al. 1996; Fischer and Lindenmayer 2000). Kangaroo rats are an important prey for a variety of species in the San Joaquin Desert 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). 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 Desert 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) and Stephen's Kangaroo Rats (Sheir and Swaisgood 2012), 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 16.3% survivorship. This is higher than the population of *D. n. nitratoides* translocated nearby, which had 9.6% survivorship at six months and started with an even larger donor population of 144 individuals (Germano et al. 2013). Estimates of survivorship of translocated animals in other studies that were similar to our efforts range were from 40–70% at one to three months post-release (our estimate was 48.8% at one month; 39.5% at two months). 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 had very similar soil and microhabitat types. Furthermore, the donor site is within core range of the target species, having high habitat quality, a high abundance of available burrows (presence of refugia), and a low abundance 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 (about 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: close proximity of the donor and translocation site and high abundance of natural burrows. Because preferred habitat types of *D. n. nitratoides* are relatively similar throughout the San Joaquin Desert, we postulate that one important factor to consider when selecting appropriate translocation sites for kangaroo rats is a high abundance of natural burrows.

Management implications.—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, territorial species, such as kangaroo rats, require attention to spacing and neighbor relationships to reduce intraspecific aggression and improve translocation success (Shier and Swaisgood 2012).

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