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Reproduction and Weights of Giant Kangaroo Rats Over 24 Years of Trapping in the San Joaquin Desert

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***Abstract*.—Because of its endangered status, recovery of the Giant Kangaroo Rat (*Dipodomys ingens*) will benefit from increased information about its basic biology. During a 24-y study of a rodent community in the Lokern area of Kern County, California, we collected data on the reproductive status and weights of male and female *D. ingens* during twice yearly 6-d censuses (48 sessions) on a 12 × 12 trap plot. We found that females occasionally were reproductive during our April or May sessions but were not in reproductive condition in our late summer/fall sessions. Finding females in reproductive condition in the spring varied greatly depending on the year. We found similar variability in male reproductive condition, although some males showed signs of being reproductive in late summer/fall censuses. We caught young-of-the year in most spring sessions, and occasionally in late summer and fall sessions. Adult weights varied markedly across the 24-y study, and with one exception, the average weight of adult males in a year always was greater than the average weight of adult females. Yearly average weights of adult males varied from 113.6 g to 138.8 g, and for adult females the average weight varied from 108.6 g to 130.1 g. The average weight of adult males across all years (124.7 g, n = 657) was significantly higher than the average weight (117.9 g, n = 610) of all adult females.**

Key Words.—*Dipodomys ingens*; females; males; offspring; young-of-the-year.

Introduction

The Giant Kangaroo Rat (*Dipodomys ingens*; Fig. 1) is state and federally listed as Endangered (U.S. Fish and Wildlife Service 1998). It occupies a portion of the San Joaquin Desert along the bajada of the western edge of the San Joaquin Valley from Panoche south to Maricopa and west into the Carrizo and Elkhorn plains and the Cuyama Valley (Williams and Kilburn 1992). Conservation of this species relies, in part, on understanding its biology so that management actions are based on reliable information. In 1993, we initiated a 24-y study of a rodent community in the Lokern area of Kern County, California (Germano and Saslaw 2017). The rodent community at the site was dominated by *D. ingens*. Besides the information we published on population numbers, sex ratios, age classes, longevity, and survivorship (Germano and Saslaw 2017), we also recorded information on reproduction and weights of male and female *D. ingens* across the 24-y study. We report this information here.

Methods

***Study site*.—We trapped *D. ingens* on the west side of the San Joaquin Valley in Kern County. The site (35°25’43” N, 119°37’06” W; 100 m elevation) was a 40-ha (99-acre) federal parcel of land managed by the U.S. Bureau of Land Management. The site was surrounded on three sides by irrigated agriculture and bordered on the east by the California Aqueduct (see Germano and Saslaw 2017 for site map). The study site was a remnant saltbush (*Atriplex* spp.) scrubland typical of the San Joaquin Desert (Germano et al. 2011). Depending on the year, the soil surface was either covered by a moderate to dense growth of native and non-native forbs and grasses or was bare between the perennial shrubs.

***Field methods*.—In August 1993, we established a 144-trap plot (12 × 12 lines) at the study site. We placed wooden stakes at 10-m intervals and placed an extra-large Sherman live trap (Model XLF, H.B. Sherman Traps, Tallahassee, Florida) at each stake. For 24 y, from August 1993 to May 2016, we trapped rodents during six consecutive nights, twice each year during spring (March-May) and fall (August-October). We baited the traps with Parakeet Mix bird seed, which is a mixture of several different small seeds, and we included one or two sheets of brown paper towels that we wadded tightly as bedding material. We opened the

Figure 1. Giant Kangaroo Rat (*Dipodomys ingens*) from the North Lokern study site, Kern County, California. (Photographed by David J. Germano).

Sherman traps in late afternoon, and we checked them at dawn the next morning.

For each *D. ingens* we captured, we recorded its trap location on the grid, its sex and weight (using a spring scale), and its reproductive condition, and we permanently marked kangaroo rats with passive integrated transponder (PIT) tags (Model TX1400 series, Biomark, Boise, Idaho) inserted subcutaneously on the back with a hypodermic needle (Schooley et al. 1993; Williams et al. 1997). We judged reproductive condition of males as non-reproductive (scrotal sac not enlarged), questionable (scrotal sac partially enlarged), or reproductive (scrotal sac enlarged and presumed capable of insemination). For females, we scored them as non-reproductive, estrous (swollen vagina with or without a vaginal plug), lactating (nipples enlarged and pink or red), or pregnant (enlarged nipples, distended abdomen, and of a heavy weight). For all kangaroo rats, we determined age classes of individuals as adult or young. We determined young kangaroo rats by their low body mass, lack of guard hairs, grayish color of pelage, and relatively large head and feet for their body size. In practice, however, some animals that had these juvenile characteristics had attained adult weights and sometimes were reproductive, so for all analyses we classified *D. ingens* that were > 90 g as adults. Over the 24 y, the number of *D. ingens* that were > 90 g yet exhibited some juvenile characteristics added either no or just a few additional young in most years and up to 4–5 times more possible young in a few years.

Analyses.—We used Pearson's Product Moment Correlation to determine if there was an association between the number of young (only those < 90 g) caught in a year to the total number of *D. ingens* caught the previous fall and the total number of all kangaroo rats (including Heermann's Kangaroo Rats, *D. heermanni*, and Tipton Kangaroo Rats, *D. n. nitratoides*) caught the previous fall. We made the same correlation comparisons for total number of young caught in year but including those judged to be young even if they weighed > 90 g. We used t-tests to compare average weights between sexes and the upper decile (10%) weights between sexes. We also used Pearson's Product Moment Correlation to determine if there was an association between the average weight of males and the average weight of females to the average number of *D. ingens* caught in that year, to yearly (July-June) rainfall, to the amount of residual dry matter (RDM) measured in that year, and to RDM measured in the previous year. The method of collecting RDM is in Germano and Saslaw (2017). For all tests $\alpha = 0.05$.

Results

Because our aim was to track population sizes and not specifically reproduction, we did not trap during the main reproductive period of *D. ingens* in January-March (Williams et al. 1993). Our spring trapping, however, was effective to note the ending of reproduction and when young of the year were being added to the population. From 1993 to 1997 (before the 1998 total population crash; Germano and Saslaw 2017), a high percentage of males were either scrotal or their scrotal sacs were partially inflated, in both spring and fall sessions (Table 1). After the crash, the proportion of males exhibiting active reproductive status when we trapped was much lower, even in years of high *D. ingens* abundance (Germano and Saslaw 2017). Our trapping in spring and late summer/fall did not often show females in a reproductive state, although there were exceptions, especially if trapping occurred in April or May (Table 1). In some spring trapping sessions, we found females in estrous, pregnant, and lactating, often all in the same session. Also, in August 1997 and 1999 (just before and after the population crash), we caught several females who were lactating (Table 1). We did not see any other signs of reproduction in females in late summer or fall in any other year.

We caught young-of-the year in most spring sessions, and occasionally in late summer and fall sessions (Table 1). The number of young of the year (< 90 g) was significantly negatively correlated with the total number of *D. ingens* caught the previous fall ($r = -0.482$, $t = 2.33$, df = 18, $P = 0.032$), and the total number of all kangaroo rats caught the previous fall ($r = -0.466$, $t = 2.23$, df = 18, $P = 0.038$). The total number of young of the year, including those judged young but > 90 g, was not significantly correlated with the total number of *D. ingens* caught the previous fall ($t = 1.81$, df = 18, $P = 0.087$), but was significantly negatively correlated with the total number of all kangaroo rats caught the previous fall ($r = -0.453$, $t = 2.16$, df = 18, $P = 0.045$).

Adult weights of *D. ingens* varied across years, but, except for 2008, males always weighed more on average than adult females (Fig. 2). In 2008, males weighed an average of 125.9 g and females weighed 125.6 g. Yearly average weights of males varied from 113.6 g in 2016 to 138.8 g in 1994. Yearly average weights of females varied from 108.6 g in 2015 to 130.1 g in 1994. The average weight of adult males across all years (124.7 g, n = 657) was significantly higher than the average weight (117.9 g, n = 610) of all adult females ($t = 8.88$, df = 1,262, $P < 0.001$). The heaviest 10% of adult males (upper decile weight) was 149.4 g (n = 66) was significantly greater than that of females (140.3 g, n = 61; $t = 8.02$, df = 124, $P < 0.001$). The same relationship was true of weight comparisons when comparing only non-reproductive *D. ingens*. Average weight of all non-reproductive males (123.9 g, n = 612) was significantly greater than that of non-reproductive females (117.6 g, n = 598; $t = 8.13$, df = 1,197, $P < 0.001$) as was upper decile weight of males (148.2 g, n = 62) to that of females (139.3 g, n = 60; $t = 8.17$, df = 117, $P < 0.001$). The heaviest male we caught weighed 176 g (non-reproductive) from 2013

Table 1. The reproductive condition of female (E =estrous, P = pregnant, L = lactating, NR = non-reproductive) and male (S = scrotal, Q = partially scrotal, NR = non-reproductive) Giant Kangaroo Rats (*Dipodomys ingens*) and the number of offspring captured during spring and fall trapping sessions from 1993 to 2016 at the North Lokern study site in the San Joaquin Desert of California. The reproductive condition is for both adult and young individuals. The number of young captured is given as individuals ≤ 90 g (a conservative designation of young) and all young, which includes any individual up to 120 g that we assessed were young in the field based on pelage characteristics and head to body proportions (see text). The number of reproductive kangaroo rats is sometimes fewer than the total number caught because reproductive condition was occasionally not recorded. No information is presented for the spring and fall trapping sessions in 1998 because we caught no rodents either time (Germano and Saslaw 2017).

	Females				Males			Young		Total
Session	E	P	L	NR	S	Q	NR	≤ 90 g	All	Caught
17–22 August 1993	0	0	0	38	4	40	9	0	0	96
4–9 April 1994	0	0	6	48	12	30	13	8	12	113
25–30 August 1994	0	0	0	49	11	23	8	0	3	91
23–27 April 1995	1	7	15	17	21	8	10	5	20	81
23–28 August 1995	0	0	0	47	2	31	26	0	3	106
6–11 May 1996	0	0	0	33	1	22	11	2	15	67
27–31 August 1996	0	0	0	20	0	6	5	0	0	32
9–14 May 1997	0	1	0	11	5	10	1	1	7	28
18–23 August 1997	0	0	3	2	5	1	1	2	2	12
14–19 April 1999	2	2	0	0	3	2	1	2	2	11
18–22 August 1999	0	0	2	6	1	2	2	3	3	14
11–16 May 2000	1	1	0	14	3	1	9	11	12	29
6–11 September 2000	0	0	0	8	1	0	5	0	1	18
26–31 March 2001	1	0	2	4	1	2	2	2	3	14
8–13 August 2001	0	0	0	30	1	1	19	3	16	53
2–7 May 2002	0	0	0	45	0	0	35	0	2	81
9–14 August 2002	0	0	0	27	0	2	25	0	0	55
29 April-6 May 2003	0	0	0	18	1	1	22	12	12	48
5–10 August 2003	0	0	0	24	1	0	31	1	1	56
13–18 April 2004	0	0	3	33	0	2	28	4	4	67
30 July-4 August 2004	0	0	0	25	0	0	19	0	0	45
25 April-1 May 2005	1	0	10	7	6	5	9	6	11	41
7–12 September 2005	0	0	0	27	0	3	22	0	0	52
25 April-1 May 2006	0	0	2	38	0	0	39	9	13	80
17–22 September 2006	0	0	0	42	0	1	44	0	0	86
20–25 March 2007	0	0	0	32	0	1	44	0	0	79
9–14 October 2007	0	0	0	17	0	2	14	0	0	34
15–19 April 2008	0	0	0	30	0	1	28	11	14	60
1–6 September 2008	0	0	0	29	0	0	15	0	0	44
25–29 May 2009	1	0	14	34	6	5	31	24	45	97
24–29 August 2009	0	0	0	62	1	1	46	4	11	112
3–8 May 2010	0	0	2	69	0	0	70	6	13	148
4–10 October 2010	0	0	0	75	0	0	65	1	1	142
26 April-3 May 2011	0	2	4	90	0	0	74	9	19	172
26 Sept-1 October 2011	0	0	0	75	0	3	75	0	0	153
23–28 April 2012	0	0	0	64	0	3	78	0	0	145
17–22 September 2012	0	0	0	40	0	7	41	0	0	90
8–13 April 2013	0	1	0	51	0	1	50	10	12	103
30 Sept-5 October 2013	0	0	0	13	0	1	15	0	0	31
7–12 April 2014	0	0	0	6	0	0	7	1	1	13
22–27 September 2014	0	0	0	2	0	0	0	0	0	2
13–18 April 2015	2	4	4	6	0	5	7	1	1	29
31 Aug-5 Sept 2015	0	0	0	18	0	0	11	0	0	29
25–30 May 2016	0	0	0	24	0	0	25	15	22	49

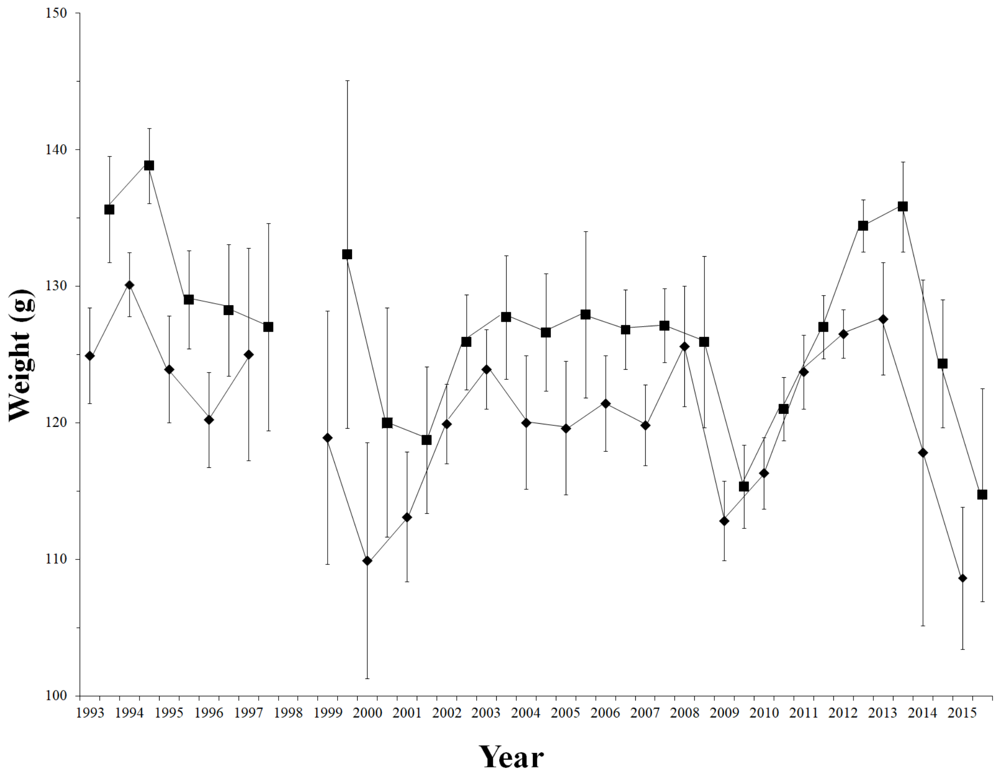

Figure 2. Average weights of female (diamonds) and male (squares) adult Giant Kangaroo Rats (*Dipodomys ingens*) from the North Lokern study site, Kern County, California, 1993 to 2015. No rodents of any species were caught in the two trapping sessions in 1998. The error bars are the 95% confidence intervals.

and the heaviest female caught was pregnant in 2011 and weighed 176 g. The heaviest non-reproductive female we caught was 166 g in 2004 trapping. There was no association between average weight of adult males (t = 0.970, df = 21, P = 0.343) or average weight of adult females (t = 1.55, df = 21, P = 0.136) and the average number of *D. ingens* caught in a year or between average weight of adult males (t = 0.891, df = 20, P = 0.385) or average weight of adult females (t = 0.803, df = 20, P = 0.432) and yearly rainfall. Levels of RDM in the same year also were not associated with male (t = 0.728, df = 19, P = 0.728) or female (t = 1.552, df = 19, P = 0.823) weight, nor was the level of RDM from the previous year with male (t = 1.756, df = 19, P = 0.094) or female (t = 0.672, df = 19, P = 0.510) weight.

Discussion

In some years, we found male and female *D. ingens* in reproductive condition in April and May. Female *D. ingens* have been reported to be in reproductive condition from January to May (Grinnell 1932; Williams et al. 1993). Grinnell (1932) caught three pregnant females in February and one pregnant female 18 May. Shaw (1934) caught a female lactating 3 March, and Williams and Kilburn (1992) reported a museum specimen that was caught 16 February contained three fetuses. By far, the most comprehensive data set of timing of female reproduction of *D. ingens* and the appearance of young-of-the year is from a report by Williams et al. (1993). They trapped *D. ingens* on the Elkhorn Plain in San Luis Obispo County from 1987 to 1991. Between July 1987 and April 1989, trapping for reproductive condition occurred bimonthly or monthly on two plots. From November 1988 through August 1991, trapping occurred monthly for two to three nights on a third plot (Williams et al. 1993). Based on this extensive trapping, females were found in estrous in February 1988, January to February 1989 and 1990, and in 1991, from February through August. Pregnant females were caught from January to March in 1988, in February 1989, March 1990, and March through August 1991. Lactating female *D. ingens* were found on the Elkhorn Plain from February to April 1988, March to April 1989, April 1990, and March to August 1991 (Williams et al. 1993). Young-of-the-year (< 90 g) followed a similar pattern with young caught from February to May in 1988, March to April 1989, April 1990, but from April to August in 1991 (Williams et al. 1993).

Although we did not trap at the most appropriate times to fully determine timing of reproduction, we did find females in reproductive condition in some spring trapping sessions, similar to the yearly variability found by Williams et al. (1993). We also captured young *D. ingens* in many spring trapping sessions across the 24-y study. Rainfall patterns varied widely during our 24 y of trapping with progressively higher rainfall from 1993 to 1998, dry conditions until higher rainfall started in 2009, and then dry conditions again in 2012 (Germano and Saslaw 2017). The number of young (< 90 g) was negatively associated with the number of *D. ingens* and the total number of all kangaroo rat species the preceding fall, suggesting that space and food levels over the winter may limit reproductive output of *D. ingens* (i.e., too many adults for the available food). On the Elkhorn Plain, rainfall was above average in 1987–1988, but was well below average in 1986–1987 and from 1988 through 1990, culminating in the almost total absence of herbaceous cover in 1990 (Williams et al. 1993; Germano et al. 1994; Germano and Williams 2005). This is reflected in the increasingly more restricted time when females were reproductive. The highly unusual extended period of reproduction (and young found) from February through August in 1991 appears to be due to the breaking of the drought when high amounts of rain fell in March 1991 (Williams et al. 1993; Germano et al. 1994; Germano and Williams 2005). This rain led to high levels of herbaceous plant material (Williams et al. 1993; Germano et al. 1994; Germano and Williams 2005) to which *D. ingens* immediately responded reproductively. On our Lokern study site, high amounts of rainfall and high levels of ground cover culminated in a population collapse in 1998, although an increase in rainfall and higher levels of herbaceous cover after a prolonged dry period increased numbers of *D. ingens* until a severe drought once again led to a crash in numbers (Germano and Saslaw 2017).

No data have been published on the timing of reproductive readiness in male *D. ingens*. We found that a high percentage of male *D. ingens* were either scrotal or partially scrotal during both spring and late summer/fall trapping sessions from August 1993 until March 2001. Thereafter, except for April 2005, we found no males or a low percentage of males that were in some level of reproductive condition. As with females, we did not trap in late fall or winter when most males in every year likely are reproductive to match female receptiveness. At least some male Merriam's Kangaroo Rats (*D. merriami*) have been found to be reproductive all year (Bradley and Mauer 1971; Kenagy and Bartholomew 1985) and Behrends et al. (1986) found 60% of males scrotal in November, 60–100% in December, and 100% from January through May. Some male Ord's Kangaroo Rats (*D. ordii*) also have found to be reproductive all year (Garner 1970; Hoditschek and Best 1983), and we suspect that *D. ingens* follow this same pattern.

Average weights of *D. ingens* on our study plot varied widely over the 24-y study period, similar to the 5-y study on the Elkhorn Plain (Williams et al. 1993). On the Elkhorn Plain, average weight of adult males varied from 121.0 g to 143.0 g and for females 116.0 g to 135.8 g (Williams et al. 1993), and we found average male weight varied from 113.6 g to 138.8 g and female weight from 108.6 g to 130.1 g. The earliest data on weights of *D. ingens* found much higher averages than more recent work, although sample sizes and length of study were much less than either our study or that by Williams et al. (1993). Grinnell (1932) reported an average weight of 15 males as 157.0 g with a range of 140.0 g to 174.2 g and for seven females, an average of 151.4 g (range, 130.8–180.0). For five adult *D. ingens* (two females, three males), average weights were 147.4 with a range of 125 g to 159 g (Shaw 1934). These higher average weights are similar to the upper decile weights we found: 149.4 g for males and 140.3 g for females. Perhaps the average weights of *D. ingens* have decreased in the past 60–70 y, although the much lower sample sizes of these early studies may have skewed these results. Our maximum weights of males (176 g) and of females (176 g pregnant, 166 g non-reproductive) are similar to that found by Grinnell (1932) but higher than that of Shaw (1934). The highest weights reported by Williams et al (1993) were 166 g for a male and 158.0 g for a female. Previously (Germano and Saslaw 2017), we found no association between average weights of *D. ingens* and the number of *D. ingens* on the plot, the amount of yearly rainfall, or levels of RDM. Here we analyzed the average weight of males and females separately but also found no association of these weights with *D. ingens* numbers, rainfall, or RDM.

The information we collected on reproduction and weights of *D. ingens* is similar to previous studies but was collected over a much longer time period than before. We show the first data for timing of reproduction for male *D. ingens* although a focused study of monthly or bimonthly trapping is needed to fully understand when males become reproductive and for how long. Long-term studies such as ours shed light on how environmental variability affects the basic biology of *D. ingens*. As a listed endangered species, the recovery of *D. ingens* will be advanced with a fuller understanding of its basic biology because this may allow for the prediction of changes to populations due to climate change that is happening across the planet.

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