REPRODUCTIVE BIOLOGY OF ORD'S KANGAROO RAT (*DIPODOMYS ORDII*) IN OKLAHOMA

BARBARA HODITSCHEK AND TROY L. BEST

ABSTRACT.—Ord's kangaroo rat (*Dipodomys ordii*) was studied to determine age and seasonal variation in reproduction and the relationship between reproduction and environmental parameters. The 423 specimens collected in central Oklahoma during the 13-month study were classified into three age groups based upon cranial characters. Testes 6.8 mm or longer and weighing 0.07 g or more had mature spermatozoa. Adult males were reproductively capable throughout the year. Peak breeding periods in adult females occurred in January through March and in September. The average number of embryos per pregnant female was 2.8. There was a significant correlation ($r = 0.681$) between the number of corpora lutea and the greatest daily precipitation during the month.

Ord's kangaroo rat (*Dipodomys ordii*) is one of the most widely distributed species of kangaroo rats (Hall, 1981), and its reproductive biology has been studied by several investigators (e.g., Duke, 1940, 1944; Alcorn, 1941; Day et al., 1956; Johnston, 1956; Pfeiffer, 1956, 1960; McCulloch and Inglis, 1961; Flake, 1974; Garner, 1974). Their findings indicate that seasonality of reproduction varies considerably within the geographic range of this species. The only previous investigation of its reproductive biology in Oklahoma was that of McCulloch and Inglis (1961) who studied *D. o. richardsoni*. We studied *D. o. oklahomae*, which is confined to the floodplain of the South Canadian River in central Oklahoma (Trowbridge and Whitaker, 1940; Hall, 1981). Our purposes were to examine: 1) differences in reproductive capabilities among age groups; 2) the seasonality of reproduction; and 3) possible relationships between changes in reproductive intensity and environmental parameters.

MATERIALS AND METHODS

From July 1970 through July 1971, 423 *D. o. oklahomae* (211 males, 212 females) were kill-trapped at monthly intervals near Norman, Oklahoma. Museum study skins and skulls were prepared and reproductive organs were preserved in 10% neutral formalin. Specimens were classified as adults, subadults, or juveniles according to the cranial criteria of Best and Schnell (1974).

One preserved testis of each male was trimmed of excess tissue, weighed, and measured for length and width to the nearest 0.1 mm with dial calipers. The remaining testis was embedded in paraffin, sectioned serially at 6 microns, stained with Harris' hematoxylin and eosin Y, and mounted in Permount. Reproductive condition was based on presence or absence of sperm in 20 randomly selected seminiferous tubules. The number of tubules with sperm was divided by 20 to yield a numerical value referred to as "sperm production."

For each pregnant female, embryos were counted and the crown-rump length of the largest was measured to the nearest 0.1 mm. This length measurement was multiplied by the number of embryos of each animal to give an estimate of embryonic development (referred to as "embryonic size" hereafter). The entire female reproductive tract was then preserved. The length and width of both preserved ovaries were measured to the nearest 0.1 mm using dial calipers, and these four measurements were then added together and divided by four, yielding an average ovarian size. All ovaries were embedded, sectioned, stained, and mounted using the techniques described for testes. Corpora lutea were counted in every tenth serial section of both ovaries. The remainder of the reproductive tract was cleared in methyl salicylate for 2 h to facilitate counting recent placental scars.

Monthly means, sample sizes, and standard deviations for each age group of males and females were determined. A single classification analysis of variance was used to compare age groups as well as months within each age group. The sums-of-squares simultaneous test procedures (SS-STP: Gabriel, 1964; Gabriel and Sokal, 1969) was used to determine which months and ages composed statistically nonsignificant subsets for each character.

TABLE 1.—*Reproductive characters for adult male and female* Dipodomys ordii *from Oklahoma assessed over 13 months. Measurements presented are* $\bar{X}$ *(n; SD).*

Month	Testis characters for males				Characters for females				
	Length (mm)	Width (mm)	Weight (g)	Sperm prod.	No. embryos	Embryo size	Ovary size	Corpora lutea	No. scars
July 1970	10.0 (10; 0.5)	6.0 (10; 0.3)	0.20 (10; 0.02)	0.4 (10; 0.1)	0.1 (8; 0.9)	13.8 (8; 26.1)	2.2 (7; 0.2)	1.0 (7; 1.5)	0.5 (6; 1.2)
Aug. 1970	9.7 (8; 0.8)	5.9 (8; 0.3)	0.21 (8; 0.02)	0.4 (8; 0.1)	0.0 (2; 0.0)	0.0 (2; 0.0)	2.5 (2; 0.1)	3.5 (2; 5.0)	2.0 (1; —)
Sep. 1970	10.1 (6; 0.4)	6.1 (6; 0.5)	0.20 (5; 0.02)	0.4 (4; 0.1)	1.8 (5; 2.5)	28.4 (5; 41.1)	3.0 (5; 0.2)	6.2 (5; 1.5)	3.5 (4; 0.6)
Oct. 1970	9.0 (7; 1.3)	5.5 (7; 0.7)	0.16 (7; 0.05)	0.3 (6; 0.2)	0.0 (6; 0.0)	0.0 (6; 0.0)	1.9 (6; 0.3)	1.8 (6; 2.0)	1.4 (5; 2.0)
Nov. 1970	9.9 (6; 0.5)	6.0 (6; 0.3)	0.21 (6; 0.04)	0.5 (6; 0.2)	0.0 (12; 0.0)	0.0 (12; 0.0)	2.7 (12; 0.2)	0.6 (12; 1.5)	0.5 (12; 1.2)
Dec. 1970	9.3 (10; 0.7)	5.7 (10; 0.6)	0.18 (10; 0.03)	0.3 (10; 0.2)	0.0 (9; 0.0)	0.0 (9; 0.0)	2.0 (9; 0.2)	0.4 (8; 0.7)	0.0 (6; 0.0)
Jan. 1971	10.0 (9; 0.4)	5.8 (9; 0.4)	0.19 (9; 0.02)	0.5 (7; 0.1)	0.9 (7; 1.5)	7.7 (7; 14.2)	2.1 (7; 0.3)	2.9 (7; 0.4)	2.6 (5; 0.6)
Feb. 1971	10.0 (11; 0.7)	6.0 (11; 0.5)	0.21 (11; 0.03)	0.5 (9; 0.1)	1.2 (10; 1.6)	17.1 (10; 26.0)	2.2 (10; 0.2)	2.4 (9; 1.2)	2.2 (9; 1.7)
Mar. 1971	9.6 (19; 0.6)	6.0 (19; 0.5)	0.19 (19; 0.03)	0.4 (16; 0.1)	1.2 (13; 1.4)	14.5 (13; 18.6)	2.2 (13; 0.4)	1.9 (13; 1.3)	1.9 (10; 1.2)
Apr. 1971	9.1 (13; 0.8)	5.5 (13; 0.7)	0.17 (13; 0.04)	0.5 (11; 0.3)	0.0 (16; 0.0)	0.0 (16; 0.0)	1.9 (16; 0.2)	0.1 (16; 0.3)	0.1 (16; 0.3)
May 1971	10.3 (13; 0.8)	6.0 (13; 0.5)	0.22 (13; 0.04)	0.6 (11; 0.1)	0.2 (13; 0.6)	0.9 (13; 3.3)	2.0 (13; 0.2)	0.5 (13; 0.9)	0.4 (12; 0.8)
June 1971	9.4 (19; 1.2)	5.9 (19; 0.8)	0.20 (19; 0.05)	0.4 (16; 0.2)	0.0 (17; 0.0)	0.0 (17; 0.0)	2.0 (17; 0.2)	0.0 (17; 0.0)	0.4 (16; 0.7)
July 1971	10.1 (23; 0.9)	6.0 (23; 0.4)	0.23 (23; 0.04)	0.5 (22; 0.1)	0.1 (16; 0.5)	1.6 (16; 6.5)	2.2 (16; 0.2)	0.7 (16; 1.3)	0.7 (13; 1.3)
Combined	9.7(154; 0.9)	5.9(154; 0.6)	0.20(153; 0.04)	0.5(136; 0.2)	0.4(134; 1.0)	5.3(134; 15.4)	2.1(134; 0.3)	1.2(132; 1.8)	0.9(115; 1.4)

TABLE 2.—*Results of single classification analyses of variance for four male and five female reproductive characters in* Dipodomys ordii. *Comparisons are between three age groups and between 13 monthly samples of adults. Characters are described in the text.*

Character	Between age groups		Between months for adults	
	d.f.	*F*-ratio	d.f.	*F*-ratio
Males				
Testis length	2,207	197.348**	12,141	2.889**
Testis width	2,207	193.490**	12,141	1.500
Testis weight	2,204	170.623**	12,140	3.627**
Sperm production	2,189	63.582**	12,123	2.831**
Females				
No. embryos	2,209	3.463*	12,121	3.865**
Embryo size	2,209	3.836*	12,121	3.394**
Ovary size	2,207	2.094	12,121	2.693**
No. corpora lutea	2,206	12.194**	12,119	14.733**
No. scars	2,187	12.167**	12,103	7.357**

* $P \leq 0.05$; ** $P \leq 0.01$.

Product-moment correlation coefficients were calculated between each of the reproductive characters and several environmental variables obtained from the nearest weather station located 4.8 km S Norman (NOAA, 1970–1971). Three groups of environmental data were used: 1) 30-yr. monthly means for temperature, precipitation, heating degree days, and cooling degree days (NOAA, 1973); 2) eight monthly temperature characters, i.e., average maximum, average minimum, monthly average, departure from the normal, highest, lowest, degree days above 32°C, and degree days below 0°C (NOAA, 1970–1971); and 3) five monthly precipitation characters, i.e., monthly total, greatest daily, days with 0.3 cm or more, days with 1.3 cm or more, and days with 2.5 cm or more (NOAA, 1970–1971).

Comparisons were also made between each reproductive character and eight temperature and five precipitation characters for the previous month (e.g., May 1971 reproductive data were compared to April 1971 environmental data, etc.). The rationale behind these comparisons was that reproductive characters observed during one month would be related to an environmental event of the previous month.

RESULTS AND DISCUSSION

Data were meager for several monthly samples of subadults and juveniles. The results of the SS-STP test between ages showed that adults were different from the nonadult groups in most cases, thus prohibiting grouping of nonadult data with adult data. The samples, however, were composed primarily of adults throughout the year.

Intrasexual Variation

Males.—The presence of mature spermatozoa indicated that most adult male *D. ordii* were capable of reproduction during all months, even though testes length, weight, and sperm counts fluctuated (Table 1). Testes 6.8 mm or longer and weighing 0.07 g or more usually contained mature spermatozoa. Only five of the 155 adult males examined (testes weight range = 0.06 to 0.14) had no spermatozoa. Some subadult males had mature sperm during July, August, and November of 1970, and every month in 1971 except April. Juvenile males usually had the lowest means for each character each month, and only two collected in July 1970 had mature sperm.

The results of the analysis of variance (Table 2) indicate highly significant intergroup heterogeneity. With the exception of testicular width, *F*-ratios for all characters were highly significant. SS-STP analyses for the four male characters (Table 3) showed that testes lengths in October and April were different from those in May and September, and those in July 1971 differed from the October sample. Variation in testes width was not significant between months, indicating that mean width was relatively stable. Testes weights in October, December, and April were different from those in July 1971, and the means in October and April were different from that in May. Sperm production in October and December was different from that in May.

Females.—When the three age groups of females were compared for each character to

TABLE 3.—*Variation in four adult male and five adult female reproductive characters in* Dipodomys ordii *from central Oklahoma. Statistically homogeneous subsets derived from SS-STP analyses are shown by lines below the months and ranked means.*

Character	Results of SS-STP analyses												
Males													
Testis length	May 10.29	Sep. 10.10	Jul 71 10.07	Jan. 10.01	Jul 70 10.00	Feb. 9.96	Nov. 9.93	Aug. 9.65	Mar. 9.59	June 9.44	Dec. 9.26	Apr. 9.12	Oct. 9.00
Testis width	Sep. 6.12	Jul 70 6.03	Nov. 6.03	Feb. 5.99	Jul 71 5.99	May 5.98	Mar. 5.96	June 5.93	Aug. 5.89	Jan. 5.84	Dec. 5.71	Oct. 5.49	Apr. 5.45
Testis weight	Jul 71 .2287	May .2234	Feb. .2146	Aug. .2075	Nov. .2065	Sep. .1998	Jul 70 .1976	June .1946	Jan. .1937	Mar. .1869	Dec. .1790	Apr. .1653	Oct. .1627
Sperm production	May .6318	Nov. .4986	Feb. .4792	Jan. .4714	Apr. .4705	Jul 71 .4580	June .4417	Mar. .4391	Jul 70 .4300	Aug. .4219	Sep. .4188	Dec. .3330	Oct. .2694
Females													
No. embryos	Sep. 1.80	Feb. 1.20	Mar. 1.15	Jan. 0.86	Jul 70 0.50	May 0.15	Jul 71 0.13	Aug. 0.00	Oct. 0.00	Nov. 0.00	Dec. 0.00	Apr. 0.00	June 0.00
Embryo size	Sep. 28.40	Feb. 17.10	Mar. 14.54	Jul 70 13.75	Jan. 7.71	Jul 71 1.63	May 0.92	Aug. 0.00	Oct. 0.00	Nov. 0.00	Dec. 0.00	Apr. 0.00	June 0.00
Ovary size	Aug. 2.53	Sep. 2.29	Feb. 2.24	Mar. 2.21	Jul 70 2.19	Jul 71 2.16	Jan. 2.14	Nov. 2.05	Dec. 2.01	May 1.95	June 1.95	Oct. 1.92	Apr. 1.85
No. corpora lutea	Sep. 6.20	Aug. 3.50	Jan. 2.86	Feb. 2.44	Mar. 1.92	Oct. 1.83	Jul 70 1.00	Jul 71 0.69	Nov. 0.58	May 0.46	Dec. 0.38	Apr. 0.06	June 0.00
No. scars	Sep. 3.50	Jan. 2.60	Feb. 2.22	Mar. 1.90	Oct. 1.40	Aug. 1.00	Jul 71 0.69	Nov. 0.50	Jul 70 0.50	June 0.44	May 0.42	Apr. 0.06	Dec. 0.00

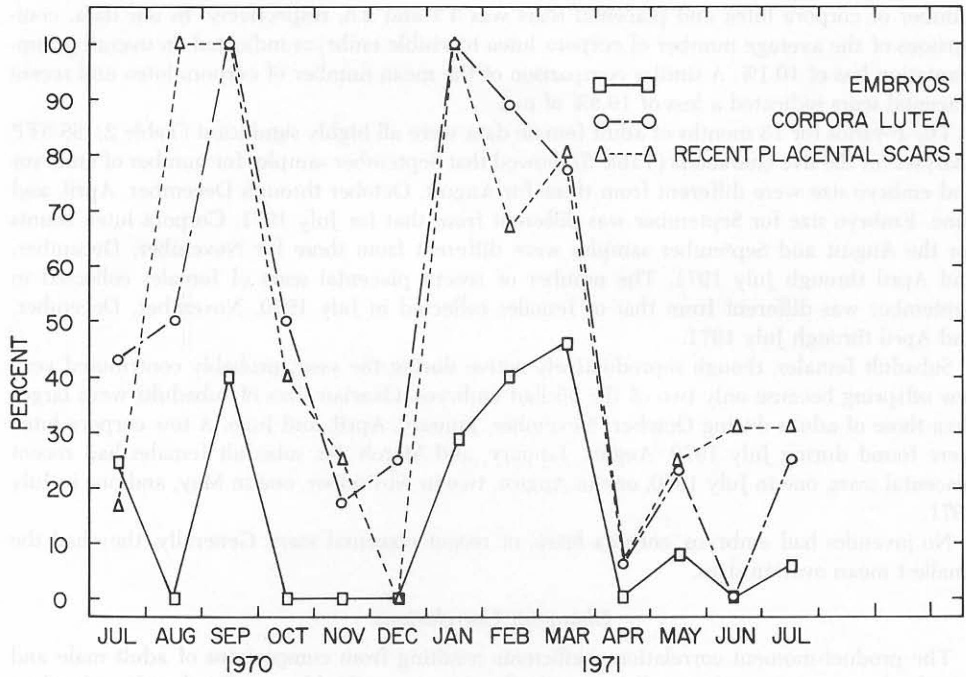

FIG. 1.—The percentage of adult female *Dipodomys ordii* from central Oklahoma with embryos, corpora lutea, and recent placental scars.

determine the degree of overlap between ages, the *F*-ratios were lower than those obtained for males (Table 2). Of the five female characters examined, all but ovarian size showed significant intergroup variation. The SS-STP analyses showed character overlap between age groups for number of embryos and embryo size in all except between adults and juveniles. In addition, differences between subadults and juveniles in the number of corpora lutea and recent placental scars were not significant, yet both nonadult groups were distinct from adults.

Females were considered reproductively active if they had embryos, corpora lutea, or recent placental scars. At least a few adult females were reproductively active each month (Table 1). Except for October through December, April, and June, embryos were present each month, and the pregnancy rate was greatest in July 1970, September, and January through March (Fig. 1). Adults had the largest embryos of the three age groups except during August, when those of subadults surpassed them. Adult ovaries were large from January through March, smaller from October through December, and smallest in April. In general, those months in which adults had higher numbers of corpora lutea or recent placental scars were the months of higher numbers of embryos. Corpora lutea or recent placental scars also occurred in August, October through December, April, and June, months in which embryos were absent.

Figure 1 depicts variation in the percent of adult females with embryos, corpora lutea, and recent placental scars for each month. The highest percent of pregnancies occurred twice during the year, i.e., January through March and in September. Our findings partially agree with those of McCulloch and Inglis (1961), who determined that *D. ordii* began breeding during August or September and ended in March. Similarly, Garner (1974) reported parturition from August through May.

Litter sizes reported for *D. ordii* vary from 2.4 to 3.6 (Bailey, 1931; Alcorn, 1941; Day et al., 1956; Johnston, 1956; McCulloch and Inglis, 1961; Flake, 1974; Garner, 1974). We found the average number of embryos, which represents the potential litter size, to be 2.8. The average number of corpora lutea and placental scars was 3.1 and 2.5, respectively. In our data, comparisons of the average number of corpora lutea to visible embryos indicated an overall preimplantation loss of 10.1%. A similar comparison of the mean number of corpora lutea and recent placental scars indicated a loss of 19.8% of ova.

The *F*-ratios for 13 months of adult female data were all highly significant (Table 2). SS-STP analyses for the five characters (Table 3) showed that September samples for number of embryos and embryo size were different from those for August, October through December, April, and June. Embryo size for September was different from that for July 1971. Corpora lutea counts for the August and September samples were different from those for November, December, and April through July 1971. The number of recent placental scars of females collected in September was different from that of females collected in July 1970, November, December, and April through July 1971.

Subadult females, though reproductively active during the year, probably contributed very few offspring because only two of the 56 had embryos. Ovarian sizes of subadults were larger than those of adults during October, November, January, April, and June. A few corpora lutea were found during July 1970, August, January, and March. Six subadult females had recent placental scars, one in July 1970, one in August, two in November, one in May, and one in July 1971.

No juveniles had embryos, corpora lutea, or recent placental scars. Generally, they had the smallest mean ovarian sizes.

Character Correlations

The product-moment correlation coefficients resulting from comparisons of adult male and female characters showed that all four male characters were highly correlated with each other. The highest correlation coefficients were between testes length and weight ($r = 0.843$, $P \leq 0.01$); the lowest values were between testes width and sperm production ($r = -0.381$, $P \leq 0.01$). The five female characters were also significantly correlated with each other, the highest being between number of embryos and embryo size ($r = 0.914$, $P \leq 0.01$), and the lowest between embryo size and number of corpora lutea ($r = 0.233$, $P \leq 0.05$). Comparisons of male with female characters yielded no significant correlations.

Environmental Relationships

The importance of environmental factors, especially rainfall, in affecting reproduction in *Dipodomys* has been indicated in several studies (Reynolds, 1958, 1960; McCulloch and Inglis, 1961; Chew and Butterworth, 1964; Beatley, 1969, 1976*a*, 1976*b*; Bradley and Mauer, 1971; Kenagy, 1973, 1976; Van De Graaff and Balda, 1973; Reichman and Van De Graaff, 1975; Soholt, 1977). Some have shown that the consumption of green vegetation made available by seasonal rainfall initiates or maintains reproduction.

Our 1970–1971 sampling period appeared to be "typical" for precipitation and temperature in central Oklahoma. There were no departures from the climatological standard normals for precipitation based upon the period 1931–1960, and only minor departures for temperature (NOAA, 1970–1971).

Differences in the percentage of pregnant kangaroo rats in July 1970 and July 1971 support our supposition that environmental conditions significantly affect their reproduction. When the relationship between environmental parameters and the 13 monthly means for four adult male and five adult female reproductive characters was examined, one character, the number of corpora lutea, was significantly correlated with the greatest amount of rainfall for a single day during the month ($r = 0.681$, $P \leq 0.05$). Thus, rainfall seems to be important in generating conditions suitable for maintaining the reproductive condition as well as initiating reproduction.

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Department of Biology and Museum of Southwestern Biology, University of New Mexico, Albuquerque, NM 87131. *Submitted 1 March 1982. Accepted 30 May 1982.*