1972

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RM 72-29

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1971 PROGRESS REPORT

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APRIL 1972

ABSTRACT

This study considers the diets, seasonal food preferences, habitat selection, seasonal activity cycles, and reproductive cycles of *Perognathus amplus*, *P. penicillatus*, *P. baileyi*, *Dipodomys merriami*, and *Peromyscus eremicus*.

The diets and food preferences were examined by a microscopic technique yielding relative frequencies of the dietary constituents. Cheek pouch contents of the heteromyids and stomach contents of all rodents indicate seasonal shifts in food usage. The rodents feed mainly on seeds, but some feed on insects during certain seasons.

Analysis of the plant communities involving line transects, permanent 1 sq. meter plots and soil samples (for seeds) were taken at the animal capture sites.

The activity (percent trapping success) of the rodents was determined, as well as the age structure of the populations and their reproductive condition. The parameters will indicate much about the population dynamics of the rodents as well as how they divide their resources.

The foods used frequently by the rodents, the availability of the food, relative density of seeds in the soil, phenology of major plants, activity of rodents, and age structure and reproductive condition of rodent populations are summarized and presented in graphic form.

INTRODUCTION

Knowledge of the diets and food preferences of a rodent community is essential to an understanding of the ecological and energetic relationships of that community. The purpose of this study was to identify the diets of five desert rodent species and relate the diets to reproduction of the rodents and to food resources in the desert. Many of the dynamic aspects of the desert are dependent on the timing of seed production by annuals. The seeds provide a major portion of the diets of the rodents, as well as much of the new seasonal, above ground, vegetational biomass. It is hoped to establish the relationships between the phenology of desert plants, seed production, rodent reproduction, and rodent diets and preferences. This should provide a base from which to move into the study of other aspects of desert ecology, such as the use of seeds by birds and insects, and the impact of rodents on seasonal production of vegetation.

OBJECTIVES

1. To measure reproductive cycles of five species of desert rodents (*Perognathus amplus, P. penicillatus, P. baileyi, Dipodomys merriami,* and *Peromyscus eremicus*) as functions of weather and of phenology and productivity of vegetation at the Silverbell Site.

2. To measure phenology, standing crop, seed utilization, and composition of the vegetation at regular intervals throughout the year.

3. To measure the species composition of the diets of the five rodent species.

4. To relate dietary composition to the available food base and to determine the degree to which availability and preference determine foods consumed.

5. To calculate preference indices for the dietary components of each of the five mammalian species.

METHODS

Since June 1970, the principal investigators and the research assistants have spent a total of 639 man-days in the field. From June through August, semi-monthly samples of mammals were taken; monthly samples were taken during the winter and spring. When possible, a minimum of 50 individuals of each species of rodent under study are being taken during each sampling period.

Collection of Phenological Data

Phenological data can be valuable in studying seasonal relationships between producers and consumers in any given biome. The bimodal pattern of rainfall in the Sonoran Desert (as defined by Shreve, 1951) is accompanied by a bimodal response of annuals present in this desert.

Early in the process study, it was determined that the rodents under investigation were primarily utilizing seeds collected from annual plants in the study area. Accordingly, phenological data were kept on all vegetation in the area to determine at what time(s) of the year peak production of fruits and seeds occurred, and when certain key plants set seed. Since green material was detected in some of the rodent stomachs, the dates that perennial species began to leaf out were also recorded.

The scheme used in gathering and organizing phenological data was adapted from Leith (1970). The vegetation was divided into four groups; herbs, shrubs, cacti, and trees. The observations made for each plant were: (1) vegetative stage; (2) production of culms; (3) flower and inflorescence buds; (4) flowering; (5) unripe seeds and fruits; (6) ripe seeds and dispersal; (7) yellowing of leaves; (8) leaves present; (9) plant not observed. The last two categories were added to Leith's scheme to include an important phenological event in the lives of perennial plants (8) and to include plants present in the study area but not always observed on a monthly basis (9).

Semi-monthly observations were made during the summers of 1970 and 1971 and monthly observations for the remainder of 1970-1971. Between 44-56 permanent vegetation plots were observed for each of the above time intervals, at which time field notes were made on the phenological conditions of the plant species observed. A number of "marker" plants were used to determine the status of that species' population in the study area. Also, the person recording vegetation at capture sites for the mammals noted significant phenological events for the plants present (e.g. *Larrea* flowering).

Data were then transferred from field notes and vegetation sheets to tables listing all the species present in the study area. Plants in flower were collected and preserved for the purpose of double checking the field data.

Collection of Seed Data

A major reason for collecting seed samples is that rodents under study are using seeds as main sources of food. They appear to be picking seeds from the soil long after the parent plants are dead. Ten random soil samples were collected semi-monthly during the summers of 1970 and 1971 and ten samples were collected monthly throughout the rest of 1970 and 1971. Beginning in June of 1971, ten samples of soil were collected at capture sites for each of the five species of rodents being studied. This technique will yield data on the quantity and quality of seeds available to the rodents.

Collection of Soil Samples

One-tenth meter soil samples were collected to depths of 0-2, 2-4, 4-6 cm. The method consisted of randomly tossing a 1/10 meter ring and collecting the soil enclosed by the ring.. Each layer of soil was removed with a trowel and stored in a cloth bag for transportation to the laboratory. The date of collection, location of sample and name of collector were recorded for each sample. Data were also recorded on annuals present inside the sampling ring and the four nearest shrubs and/or trees to the sample site.

Cain (1938) considers the number of samples (or plots) is adequate when a 10% increase in sample area, or in number of samples, yields an increase in number of species equal to 10% of the total. By calculating this percent increase it was determined that seven samples would be adequate. Ten samples per rodent species, per sampling period are now being taken.

Extracting Seeds From Soil

Each soil sample was poured through a Tyler Soil Sieve with 0.495 mm openings and with 32 mesh to the inch. This size sieve was small enough to capture all of the smallest seeds except those of the Orchidaceae and the Solanaceae (personal communication, R. Hevly). The soil and seeds not passing through the sieve were returned to the original sample bags.

The soil-seed extracts were then put separately into a 2000 ml beaker and tap water was added until the material was thoroughly wetted. Ten ml of hydrochloric acid (10%) was added to this mixture in order to: (1) break up the caliche soil particles so that the seeds were released from the soil, and (2) bubble the seeds to the surface of the solution.

After bubbling had stopped, the remaining solution was poured through a 150 mm Buchner funnel fitted with Whatman filter paper (#1) on top of a 2000 ml suction flask. Air was pulled from the flask at a pressure of 20 psi with a vacuum pump. The water was then removed from the sample leaving a mixture of seeds and very fine soil on top of the filter paper. The filter paper was then air dried and placed in the original sample bag. The rocks and large soil particle mixture which was not dissolved by the acid was discarded, because examination of ten samples (Tables 1 and 2) showed that less than 15% of the seeds remained in this sediment. Table 2 also shows that 77% of the total seeds in the samples are removed by using the technique on only the 0-2 cm layer. Because of the time and effort necessary to extract the remaining seeds, efforts are now concentrating on the upper (0-2 cm) layer.

Each sample was then re-sieved to remove the remaining fine soil. The seeds were then placed on a piece of graph paper and examined at magnification X10 with a binocular microscope. The seeds were separated into groups by genera, counted, and the number of each genus recorded on separate data sheets. Both known and unknown seeds were glued to a paper reference slide for identification or verification.

Table 1. Total number of seeds recovered from 10 soil samples at three depths (July, 1970).

	1		2		3		4		5	
Depth	Rec.*	Rem.*	Rec.	Rem.	Rec.	Rem.	Rec.	Rem.	Rec.	Rem.
0-2 cm	310	0	466	225	175	0	175	0'	249	17
3-4 cm	30	0	8	0	0	0	11	0	18	0
5-6 cm	8	0	0	0	27	2	3	0	5	0
Totals	348	0	474	225	202	2	189	1	262	17
	6		7		8		9		10	
0-2 cm	233	0	64	5	37	0	437	97	145	73
3-4 cm	12	2	11	0	9	1	76	0	16	0
5-6 cm	2	0	7	0	2	0	4	0	3	0
Totals	257	2	82	5	48	1	513	97	162	73

*Rec. = Recovered, Rem. = Remained

Table 2. Seed distribution and recovery methods for seeds recovered from 10 soil samples (July, 1970).

1. Total Number of Seeds Recovered = 2960
2. Number of Seeds Recovered by Flotation = 2537
3. Percent of Seeds Recovered by Flotation = 85.7%
4. Total Number of Seeds in Top 0-2 cm Layer = 2708
5. Percent of Seeds in Top 0-2 cm Layer = 91%
6. Number of Seeds Recovered from Top 0-2 cm by Flotation = 2291
7. Percent of All Seeds Recovered by Flotation in Top 0-2 cm Layer = 77.3%

Methods of Sampling Vegetation at Capture Sites

At most of the rodent capture sites, the vegetation was sampled using the line-intercept method. A twenty-foot steel tape was placed on the ground with the ten foot mark directly over the capture site. Alternate one-foot areas were considered a sample area. Within that one-foot area, all of the plants that touched the line or were within 1 cm of the line were recorded. These data are being used to calculate the relative frequency, relative density and relative dominance for each species. In addition, all cacti, shrubs and trees that intercepted the line were recorded. These data will be converted into a % cover value for each species of plant.

A series of 44 permanent plots have been established in the study area. These include 20 plots in the creosote-bush (*Larrea divaricata*) flats, 12 plots along washes, and 12 in the rocky hills. Each plot is circular and is one meter in area. Monthly sampling of vegetation in these plots provides information from which absolute frequency and absolute density values can be calculated.

Diets of Mammals

The diets of the rodents are being studied by microscopically examining the stomach contents of specimens. The contents of each stomach are washed and mixed thoroughly in warm water. One microscope slide is made of material from each stomach using Hertwig's clearing solution (Baumgartner and Martin, 1939), and preparations are partially dried in a drying oven at 60°C. Twenty systematically located fields under 100-power magnification are studied on each slide. Food items are identified on the basis of distinctive epidermal features, using, for comparison, series of reference slides of known plant material (Davis 1959; Croker, 1959; Storr, 1961). Each plant species present in each microscopic field is recorded and frequency percentages (the number of fields in which a plant species occurred out of 100 fields) are recorded for each specimen. Frequency percentages are then converted to particle density per field (using a table by Fraker and Brischle, 1944). Relative dry weights of the food items are then accurately estimated by using the relative densities of the species (Sparks and Malechek, 1968). Similar procedures have been used in recent studies by Ward and Keith (1962).

Reproductive Cycles

Body weights, lengths, pelage coloration, and tooth wear were used as criteria for distinguishing between adult, subadult, or juvenile animals. Counts of embryos and of placental scars were used to determine litter size; the timing of litter, the presence of recent placental scars, and the conditions of the mammary gland provided indications of the number of litters per year. Careful measurements were made of the horn and body of the uterus and length and width of ovaries in the females. Females were determined to be reproductively active if they were pregnant, lactating, or in estrous, as determined by the condition of the vaginal orifice. The standard measurements of the male include the length and width of the testis and the length of the caudal epididymis and seminal vesicle. The caudal epididymis and seminal vesicle were also periodically checked for the presence of sperm. Animals with sperm in the caudal epididymis or seminal vesicle were considered reproductively active. Scrotal testes, elongated seminal vesicle, and general coloration of the reproductive organs were also good indicators of reproductive condition.

FINDINGS & PROGRESS

Since field work began in June 1970, 78,141 trap nights (a trap night equals one trap set for one night) have been logged and 4,103 rodents representing 10 species have been taken. The five most abundant rodents in the study area and the numbers of each that have been taken are as follows:

Perognathus amplus	1192
P. penicillatus	1022
P. baileyi	364
Dipodomys merriami	1182
Peromyscus eremicus	325

The research has been concentrated on these species. Although most of the trapping is done in the desert flats dominated by creosote-bush (*Larrea divaricata*), traps are also set in the rocky hills during each sampling period. The hills form an important and widespread habitat in the study area. Of the rodents listed above, only *P. amplus, P. penicillatus,* and *D. merriami* are common in the creosote-bush flats.

Sampling of Vegetation

Vegetative data from 3740 capture sites (91% of the total capture sites) and seed content data from 414 soil samples have been recorded. To facilitate analyses, the data are being transferred to coding sheets and placed on file at the computer center. Although relatively little vegetative data has been analyzed to date (one computer program is in operation), certain points merit comment.

Vegetation. The results for a year and a half of phenological data are shown in Table 3. The percentages were calculated by dividing the total number of plants with ripe seeds and dispersing seeds, by the total number of plants in the study area. Note that there is a different "n" number for each set of plants.

There is a definite seasonal response to the usual bimodal rain pattern of the Sonoran Desert, with a burst of plant growth in October, November and December, and another in April, May and June. Note that in 1971, however, there was no rainfall in April, May or June. The winter of 1970 and the following spring were exceptionally dry. No measurable precipitation was recorded in four rain gauges at the study site from December 18, 1970, until July 27, 1971. The phenological data in Table 3 clearly reflect this lack of precipitation; no herbaceous species produced seeds from February, 1971, until September, 1971. The small mammals were forced to survive on seeds produced the previous year. Of central interest is the extent of utilization of the standing crop of seeds by the rodents.

Table 3. Percent of herb species (n=66), shrub species (n=23), cacti (n=11), and tree species (n=5) with ripe and dispersing seeds over an 18-month period.

Month	Herbs (% of plants)	Shrubs (% of plants)	Cacti (% of plants)	Tree (% of plants)
	% of plants with ripe and dispersing seeds			
June 1970	20	20	50	60
July 1970	20	22	50	60
August 1970	20	22	30	20
September 1970	10	10	40	20
October 1970	30	10	30	20
November 1970	30	10	20	20
December 1970	12	0	20	20
January 1971	4	0	20	0
February 1971	0	0	20	0
March 1971	0	0	0	0
April 1971	0	0	0	0
May 1971	0	0	0	0
June 1971	0	5	10	0
July 1971	0	10	20	20
August 1971	0	10	0	20
September 1971	20	20	10	20
October 1971	30	40	30	20
November 1971	30	30	30	40
December 1971	20	10	30	40

Change in Seed Density

Tables 4, 5, and 6 show the seeds present in the upper 2 cm of soil. The number of seeds per square meter varies dramatically from July, 1970, through March, 1971. A total of 2291 seeds were recovered in July, 1970, which were obviously produced from plants that bloomed prior to this time. The majority of these seeds were probably produced during the previous winter growing season. At the time of sampling, most herbaceous species were dead and seeds were already dispersed.

In November, 1970, only 219 seeds were recovered from the soil samples, which is a decrease of 90.44 % from the previous July. During the interim period, many herbs had bloomed in response to the summer rains (see Table 3). The low recovery of seeds may be due to at least two factors: (1) the herbs still retained the seeds, and (2) the rodents were selecting and harvesting the fresh seeds in preference to the old seeds present in the soil. Tevis (1957) reports harvester ants (*Vermessor* spp.) select new, fresh seeds over old seeds. Thus, ants may also account for the low number of seeds in the soil at this time.

The interval from November, 1970, to March, 1971, was extremely dry and no new herbaceous plant growth occurred. The number of seeds declined to a low of 125, a decrease of 42.94%. This decrease probably occurred as a direct result of the harvesting activities of ants, birds and small mammals. The period from November through March, when few seeds were present, corresponds roughly to the period of lowest activity for the five species of mammals under study.

Table 4. Absolute and relative densities of seeds for 1 m^2 in July, 1970.

Genera	Total Seeds Recovered	Relative Density (% of total number per sq. m.)
Pectocarya	1087	47.43
Larrea	279	12.17
Festuca	253	11.04
Plantago	184	8.03
Allionia	111	4.84
Franseria	89	3.88
Erodium	57	2.49
Euphorbia	36	1.57
Eriophyllum	54	2.35
Unk. #27	14	.61
Unk. #26	35	1.52
Unk. #25	30	1.31
Unk. #35	40	1.75
Unk. #36	4	.17
Carnegia	1	.04
Ephedra	1	.04
Unk. #43	2	.08
Thelypodium	3	.13
Lesquerella	4	.17
Lepidium	1	.04
Sphaeralcea	1	.04
Unk. #39	6	.26
Totals	2292	99.96

Table 5. Absolute and relative densities of seeds for 1 m^2 in November, 1970.

Genera	Total Seeds Recovered	Relative Density (% of total number per sq. m.)
Plantago	106	48.41
Pectocarya	50	22.83
Erodium	27	12.33
Larrea	21	9.59
Eriophyllum	7	3.20
Unk. #35	2	.91
Unk. #30	1	.45
Unk. #18	1	.45
Unk. #28	1	.45
Unk. #16	1	.45
Unk. #33	1	.45
Unk. #36	1	.45
Totals	219	99.97

Table 6. Absolute and relative densities of seeds for 1 m^2 in March, 1971.

Genera	Total Seeds Recovered	Relative Density (% of total number per sq. m.)
Plantago	59	47.2
Larrea	4	3.2
Eriophyllum	14	11.2
Pectocarya	9	7.2
Erodium	23	18.4
Franseria	1	.8
Euphorbia	2	1.6
Unk. #18	7	5.6
Unk. #16	1	.8
Unk. #36	1	.8
Unk. #28	1	.8
Unk. #27	2	1.6
Unk. #31	1	.8
Totals	125	100.0

Food Habits Studies

The most evident fact is that seeds of desert annuals are by far the most important rodent food. Excepting *Larrea*, perennials are of little importance. Of the annuals, *Plantago* is the most heavily utilized plant. *Plantago* plants, with seeds, were very common at the capture sites in July. The seeds recovered from the rodents' cheek pouches were fresh and clean. By November, the *Plantago* plants were still present but as they had dropped their seeds they were of little importance to the rodents. Seeds recovered from cheek pouches at this time were rough, dried, and coated with soil, indicating that the rodents pursued the seed into the soil surface. Even though *Plantago* plants were of little use after July, the standing crop of seeds produced in May and June continued to be the dietary staple.

The rodents were highly selective in their feeding. A common plant at the capture sites was a grass, *Festuca,* which was not selected by the rodents, while *Tridens,* another grass, was often eaten. Diets are illustrated in Tables 7-11.

Gross observations of stomach content have indicated that there is more greenery in the stomachs of the rodents than in their cheek pouches. It is speculated that the rodents use greenery, when available, as a "drinking fountain" while continuing to gather seeds at night. Differences between the stomach and cheek pouch contents suggest that the rodents are eating the soft, fibrous seeds immediately, and storing the hard seeds.

It would seem that during certain critical periods, the rodents would rely on high-carbohydrate seeds to provide metabolic water. At other times, however, they may be able to ingest high protein seeds provided there is enough moisture available from green plants and insects to allow for protein waste elimination.

Insects make up from 8 to 29% of the diets of the heteromyids. Some of the stomachs have been completely filled with ants, ruling out accidental ingestion. The insects provide a diet high in protein and moisture.

Tables 7-11. The diets of rodents under study for the representative months of July and November, 1970, and March, 1971, and yearly average. Numbers in parentheses are sample sizes. Sample sizes for yearly averages are greater than total for representative months as months other than the representative months were used. Cheek pouch contents and seeds in soil are reported as relative density:

$$\frac{\text{number of individuals of a species}}{\text{number of individuals for all species}}$$

Stomach contents are reported as relative frequency:

$$\frac{\text{number of points of occurence of a species}}{\text{number of points of occurence of all species}}$$

Table 7. *Perognathus amplus*.

July 1970 (29)	Nov. 1970	March 1971	Yearly Average (82)
		Cheek Pouch Contents	
Larrea 80.5			*Plantago* 48.2
Crucifer 10.2			*Larrea* 24.9
Pectocarya 7.2			*Pectocarya* 10.1
			Acacia constricta 6.4
		Stomach Contents	
Larrea 47.8			*Larrea* 28.2
Pectocarya 24.7			*Plantago* 23.8
Erodium 9.9			*Pectocarya* 22.1
			Acacia constricta 6.9
		Seeds in Soil	
Pectocarya 47.4	*Plantago* 48.4	*Plantago* 47.2	*Pectocarya* 42.2
Larrea 12.2	*Pectocarya* 22.8	*Erodium* 18.4	*Larrea* 13.3
Festuca 11.0	*Erodium* 12.3	*Eriophyllum* 11.2	*Plantago* 12.8
			Festuca 12.4

Table 8. *Perognathus penicillatus*

July 1970 (44)	Nov. 1970 (6)	March 1970 (8)	Yearly Average (101)
		Cheek Pouch Contents	
Larrea 54.7	*Acacia const.* 87.5	Unknown #5 55.0	*Larrea* 37.0
Ocotillo 18.7	*Larrea* 12.5	*Plantago* 25.0	*Plantago* 21.7
Plantago 18.4		*Eriochloa* 20.0	*Fouquieria* 12.0
			Acacia const. 13.1
		Stomach Contents	
Larrea 46.0	*Opuntia* 62.5	*Tridens* 47.5	*Larrea* 24.2
Pectocarya 16.7	Insects 17.0	*Acacia const.* 18.9	*Pectocarya* 17.6
Opuntia 16.0	*Acacia const.* 13.6	*Pectocarya* 13.9	*Opuntia* 15.2
			Insects 13.1

Table 9. *Perognathus baileyi.*

July 1970 (11)	Nov. 1970 (23)	March 1970 (2)	Yearly Average (86)
		Cheek Pouch Contents	
Fouqueria 65.1	*Pectocarya* 60.8	*Pectocarya* 100.0	*Pectocarya* 54.9
Pectocarya 30.2	*Allionia* 14.4		*Acacia const.* 17.0
Franceria 4.7	*Acacia const.* 14.0		*Allionia* 7.0
			Fouqueria 6.1
		Stomach Contents	
Opuntia 59.4	*Pectocarya* 29.9	*Acacia const.* 25.0	*Pectocarya* 33.6
Larrea 13.9	*Tridens* 16.9	*Tridens* 25.0	*Acacia const.* 21.8
Pectocarya 10.8	*Opuntia* 13.8	*Eriochloa* 21.1	Insects 14.3
			Tridens 4.8

Table 10. *Dipodomys merriami*

July 1970 (31)	Nov. 1970 (42)	March 1971 (39)	Yearly Average (242)
		Cheek Pouch Contents	
Larrea 67.6	*Plantago* 76.5	*Larrea* 51.4	*Plantago* 47.2
Crucifer 12.7	*Pectocarya* 16.0	*Pectocarya* 25.4	*Larrea* 27.9
Plantago 11.0	*Tridens* 3.5	*Plantago* 18.5	*Pectocarya* 17.7
			Allionia 7.0
		Stomach Contents	
Pectocarya 40.9	*Plantago* 33.1	*Pectocarya* 42.7	*Pectocarya* 28.5
Insects 28.9	*Erodium* 26.7	*Plantago* 12.9	*Plantago* 23.8
Larrea 11.5	*Pectocarya* 17.4	*Larrea* 12.0	Insects 11.2
			Larrea 8.6
		Seeds in Soil	
Pectocarya 47.4	*Plantago* 48.4	*Plantago* 47.2	*Pectocarya* 42.2
Larrea 12.2	*Pectocarya* 22.8	*Erodium* 18.4	*Larrea* 13.3
Festuca 11.0	*Erodium* 12.3	*Eriophyllum* 11.2	*Plantago* 12.8
			Festuca 12.4

Table 11. *Peromyscus eremicus.*

July 1970 (31)	Nov. 1970 (20)	March 1971 (15)	Yearly Average (66)
		Stomach Contents	
Insects 37.9	Insect 72.0	Insects 89.6	Insects 95.3
Opuntia 27.3	*Opuntia* 11.6	*Opuntia* 3.2	Crucifer 18.3
Fouqueria 16.9	*Tridens* 10.0	*Cercidium* 2.8	*Opuntia* 16.4
			Fouqueria 7.7

Trapping and Activity Patterns

From June 1, 1970, through December, 1971, 78,141 trap nights have yielded 4,103 animals. Tables (12-16) show the number of trap nights, animals trapped, and percent success.

It is believed that the percent trapping success for each species is an adequate indication of activity patterns, especially from June, 1970, through August, 1971, when there was little or no growth of annuals to attract the rodents away from the traps. Figures 1 through 5 indicate these patterns and Figures 6 and 7 indicate the temperatures encountered by the rodents and temperature averages for the 10 years preceding our study.

On the creosote flats in late June, 1970, both the kangaroo rats and pocket mice responded to temperature extremes by aestivating. Both became more active in late summer with *P. amplus* then hibernating from December, 1970, through March, 1971. A Spearman rank correlation co-efficient indicated a correlation at the .05 level between average body weight and surface inactivity for the winter months.

Table 12. Monthly trapping success for *Perognathus amplus*.

Month	Trap nights	Animals taken	% Success*
June 1970	5740	397	6.9
July 1970	5424	107	2.0
August 1970	4590	165	3.6
September 1970	2200	83	3.8
October 1970	1900	18	.9
November 1970	1100	2	.2
December 1970	1100	0	0
January 1971	2145	0	0
February 1971	2125	0	0
March 1971	1000	0	0
April & May 1971	2225	16	.7
June 1971	3670	106	3.2
July 1971	4044	115	2.8
August 1971	4325	113	2.6
September 1971	1880	16	.9
October 1971	1950	33	1.7
November 1971	1000	19	1.9
December 1971	990	2	.2

* Trapping success equals $\frac{\text{number of animals trapped}}{\text{number of trap nights}}$

Table 13. Monthly trapping success for *Perognathus baileyi*.

Month	Trap nights	Animals taken	% Success*
June 1970	2766	50	1.8
July 1970	2327	37	1.6
August 1970	2230	36	1.6
September 1970	1200	69	5.8
October 1970	1300	54	4.1
November 1970	2400	30	1.3
December 1970	700	14	2.0
January 1971	1045	2	.2
February 1971	1100	4	.4
March 1971	800	3	.4
April & May 1971	800	5	.6
June 1971	3720	14	.5
July 1971	2710	17	.6
August 1971	2634	17	.6
September 1971	1050	2	.2
October 1971	800	7	.9
November 1971	750	0	0
December 1971	800	3	.4

* Trapping success equals $\frac{\text{number of animals trapped}}{\text{number of trap nights}}$

Table 14. Monthly trapping success for *Perognathus penicillatus*.

Month	Trap nights	Animals taken	% Success*
June 1970	2766	219	7.9
July 1970	2327	121	5.2
August 1970	2230	144	6.5
September 1970	1200	70	5.8
October 1970	1300	35	2.7
November 1970	2400	6	.3
December 1970	1300	0	0
January 1971	1045	1	.1
February 1971	1100	1	.1
March 1971	800	12	1.5
April & May 1971	800	14	1.8
June 1971	3720	58	2.9
July 1971	2710	159	5.9
August	2634	66	2.5
September 1971	1050	40	3.8
October 1971	800	22	2.8
November 1971	750	26	3.5
December 1971	800	28	3.5

* Trapping success equals $\frac{\text{number of animals trapped}}{\text{number of trap nights}}$

Table 15. Monthly trapping success for *Dipodomys merriami*.

Month	Trap nights	Animals taken	% Success*
June 1970	5741	147	2.6
July 1970	5424	65	1.2
August 1970	4590	48	1.0
September 1970	2200	49	2.2
October 1970	1900	98	5.2
November 1970	1100	81	7.3
December 1970	2400	76	3.2
January 1971	2145	65	3.0
February 1971	2125	80	3.8
March 1970	1000	41	4.1
April & May 1971	2225	62	2.8
June 1971	3670	62	3.1
July 1971	4044	104	2.6
August 1971	4325	90	2.1
September 1971	1880	24	1.3
October 1971 **	1950	13	.7
November 1971	1000	29	2.9
December 1971	990	46	4.6

* Trapping success equals $\frac{\text{number of animals trapped}}{\text{number of trap nights}}$

** Rained all one night.

Table 16. Monthly trapping success for *Peromyscus eremicus*.

Month	Trap nights	Animals taken	% Success*
June 1970	2766	69	2.5
July 1970	2327	30	1.3
August 1970	2230	27	1.2
September 1970 **			
October 1970	1300	24	1.8
November 1970	2400	21	.9
December 1970	700	3	.4
January 1971	1045	5	.5
February 1971	1100	20	1.8
March 1971	800	13	1.6
April & May 1971	500	5	1.0
June 1971	3720	8	.2
July 1971	2710	24	.9
August 1971	2634	10	.4
September 1971	1050	0	0
October 1971	800	2	.3
November 1971	750	29	3.9
December 1971	800	35	4.4

*Trapping success equals $\frac{\text{number of animals trapped}}{\text{number of trap nights}}$

** No traps were set in appropriate habitat.

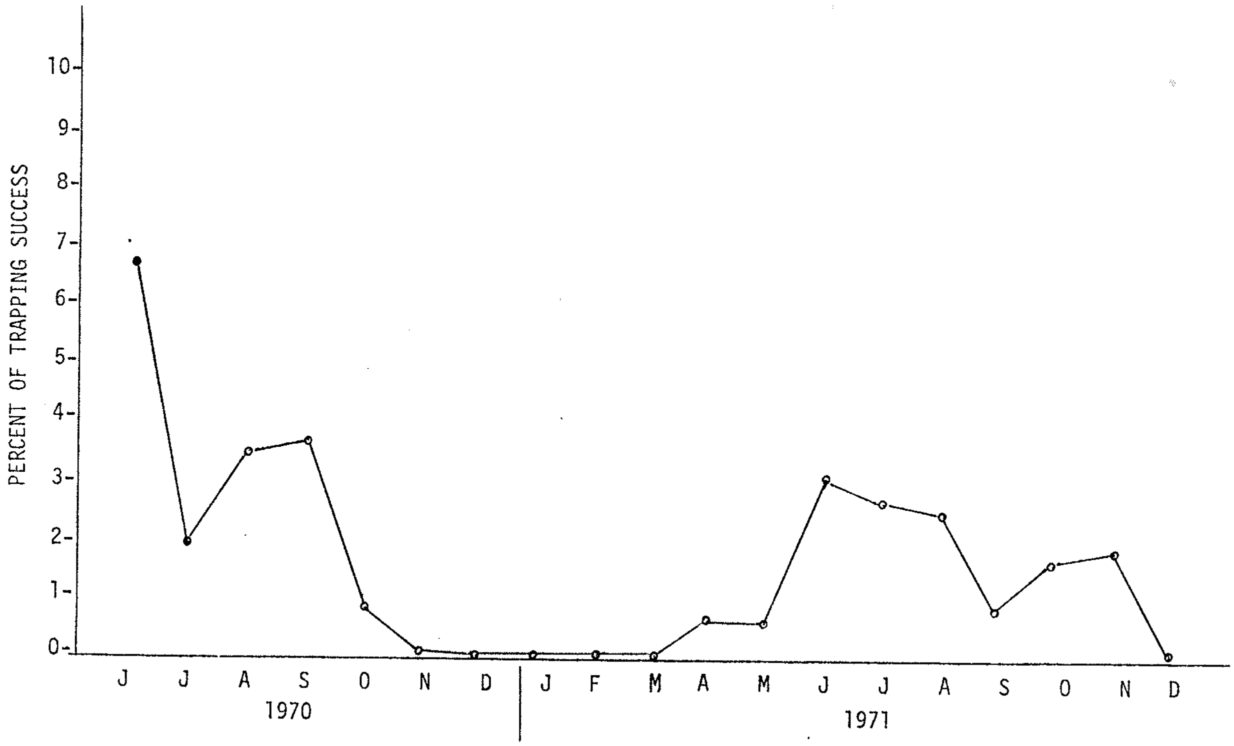

Figure 1. Percent trapping success of *Perognathus amplus*.

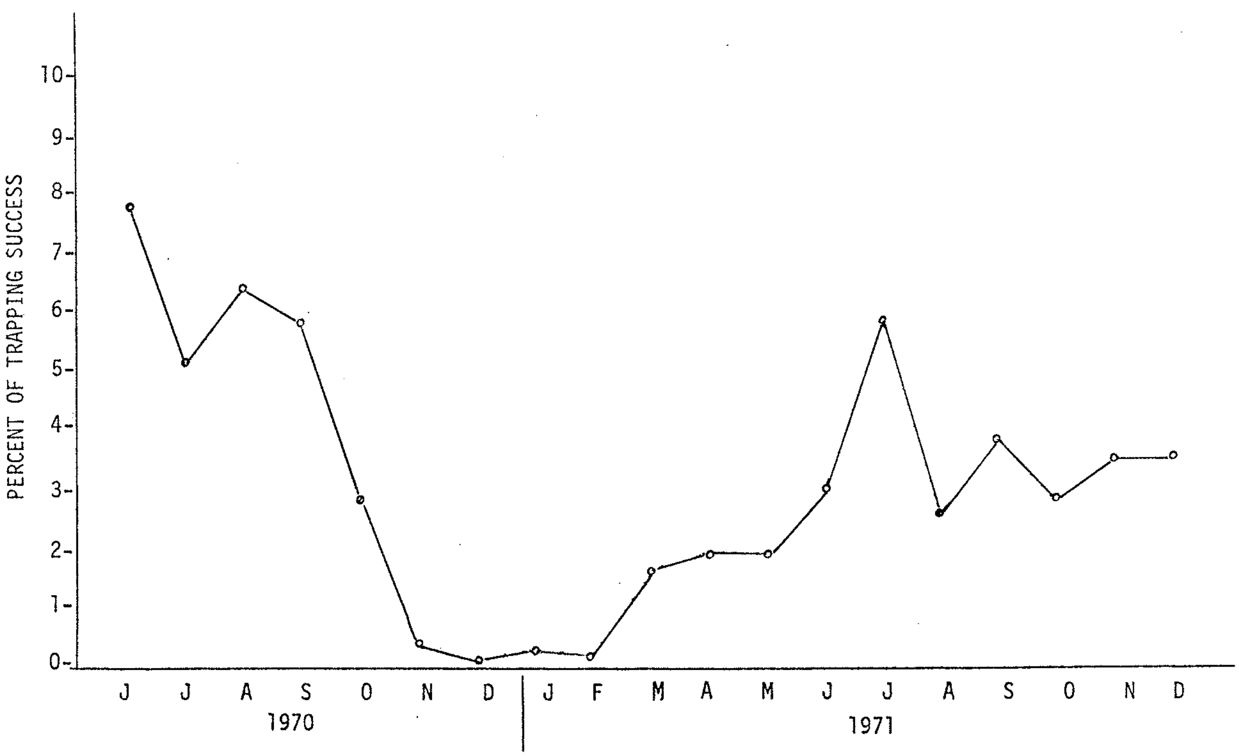

Figure 2. Percent trapping success of *Perognathus penicillatus*.

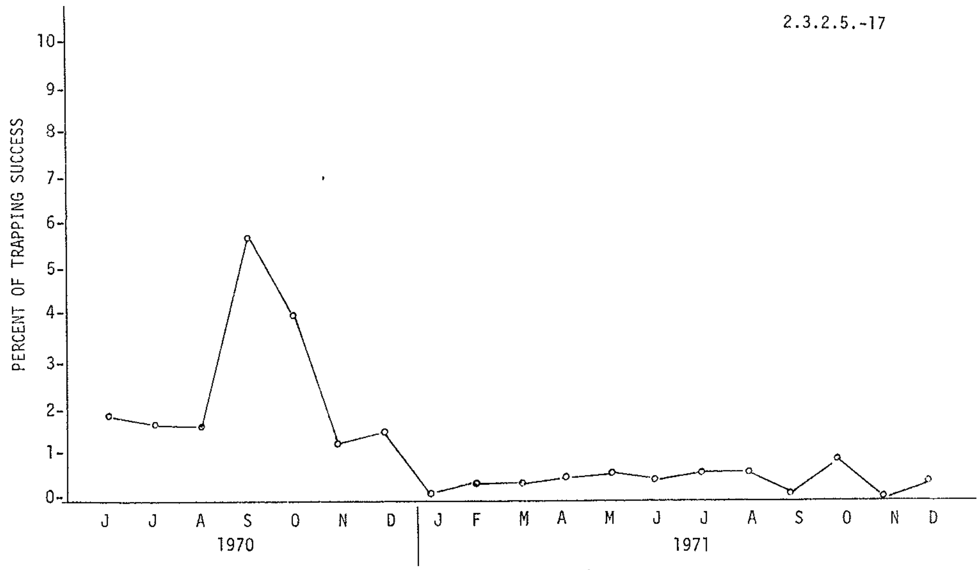

Figure 3. Percent trapping success of *Perognathus baileyi*.

Figure 4. Percent trapping success of *Dipodomys merriami*.

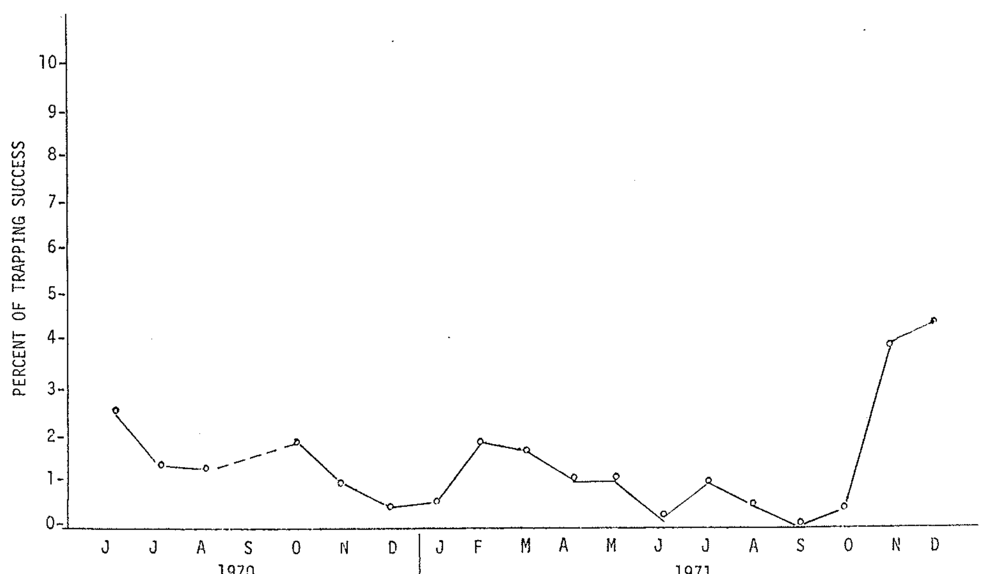

Figure 5. Percent trapping success of *Peromyscus eremicus*.

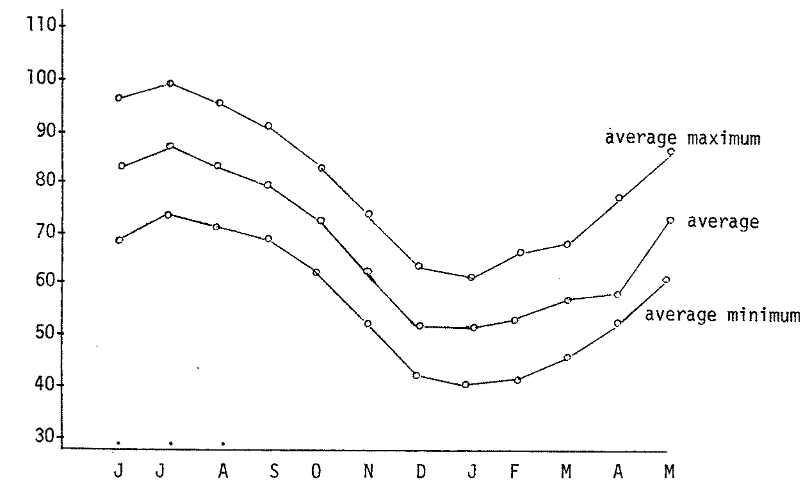

Figure 6a. Yearly average temperature pattern for Silverbell, Arizona, based on data averaged over a ten-year period, 1960 to 1970.

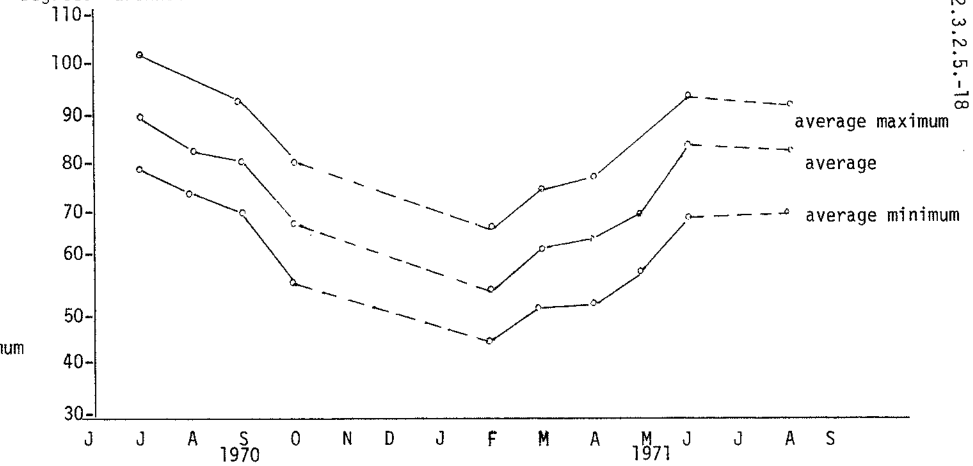

Figure 7a. Monthly temperature means recorded from Silverbell, Arizona, elevation 2700 ft., representing temperatures from hill habitat. Dotted lines indicate when no data were available.

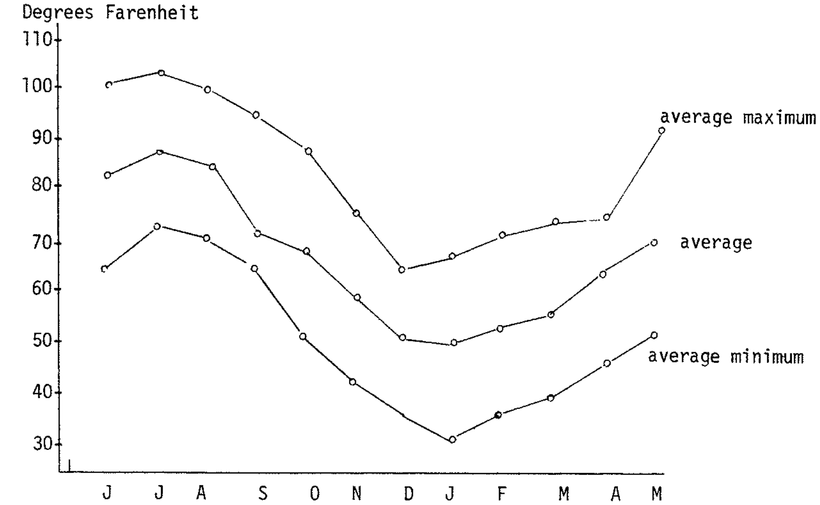

Figure 6b. Yearly average temperature pattern for Cortero, Arizona, based on data averaged over a ten-year pattern, 1960 to 1970.

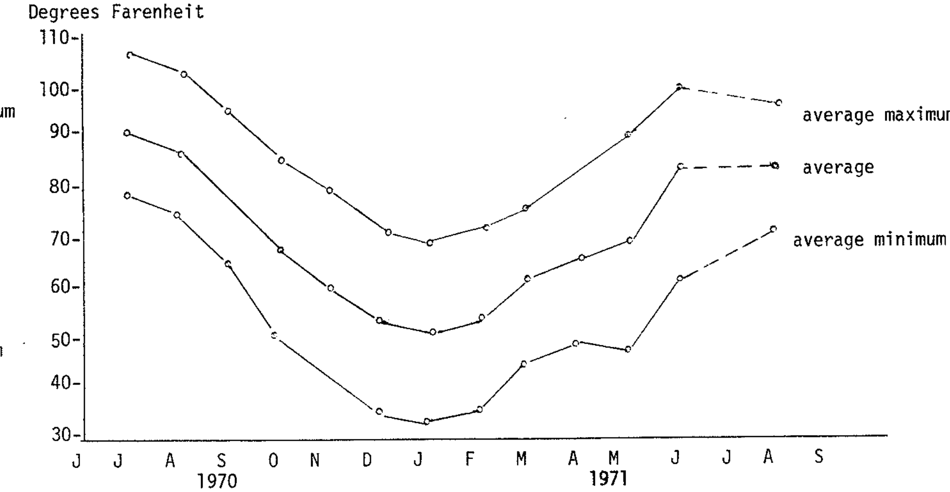

Figure 7b. Monthly temperature means recorded from Cortero, Arizona, representing temperatures from creosote flat habitat. Dotted lines indicate when no data were available.

Reproductive Cycles

Reproductive data have been obtained from dissections of 2744 individuals of the five species (Table 17) taken from June, 1970, to June, 1971. Males having scrotal testicles, enlarged caudal epididymes, and expanded, turgid, seminal vesicles were considered reproductively active. Females were considered reproductively active when they were in estrous, lactating, or carried embryos. For convenient graphing, females in post-partum condition with placental scars were also considered reproductively active.

Table 17. Total numbers of animals dissected for a one-year period. June 1970-June 1971 and the relative sex ratios within five species.

Species		Female
Dipodomys merriami	430	382
Perognathus amplus	385	403
Perognathus penicillatus	288	335
Perognathus baileyi	128	175
Peromyscus eremicus	116	101
TOTAL	1348	1396
Total Animals = 2744		

The breeding cycle of Dipodomys merriami. The reproductive period in *D. merriami* was continuous from early spring through late fall with two obvious peaks. A decline in reproduction occurred in July when fewer pregnant females were trapped, probably in response to stressful conditions brought on by high temperatures and extreme aridity. The reproductive peaks apparently correspond to the bi-annual rainfall pattern and may be responses to increased availability of green vegetation. There were no embryos recorded during March, April, and May, 1971, when rainfall was below normal. Reproductive data are presented in Fig. 8 and in Table 18.

Table 18. Litter sizes, as indicated by numbers of fetuses and placental scars, in five species. The mean number is given, followed by the size of the sample (in parentheses), and the range.

Species	Fetuses	Placental Scars
Dipodomys merriami	1.98, (70), 1-3	1.99, (274), 1-3
Perognathus amplus	4.05, (26), 3-5	4.55, (79), 2-6
Perognathus penicillatus	3.50, (40), 2-4	3.57, (175), 2-6
Perognathus baileyi	3.30, (8), 2-4	3.52, (76), 2-6
Peromyscus eremicus	2.65, (26), 2-4	2.78, (34), 1-4

Of a sample of 31 adult males taken in April, 55% were in breeding condition (Fig. 8). The non-breeding males taken at this time were individuals that would presumably become reproductively active later in the season. The two reproductive peaks were during late June - early July, and September, when 86% and 92% of the adult males had scrotal testes with copious amounts of sperm. Reproduction virtually ceased in November as there were no males with scrotal testes in a sample of 46 individuals. In October, 42% of the males were determined to be reproductively active. Most of the young males born in early spring became reproductively active during the second reproductive peak in September.

Pregnant females were trapped in 6 of the 12 months (Fig. 8). Eighteen percent of the females examined in February were pregnant, denoting the onset of the breeding season. The peak reproductive period was during June when 63% of adult females were pregnant. Breeding ceased in October when only 4% of the adult females had embryos. There were no pregnant females during March, April, or May, 1971, following initiation of the breeding season in February. This interrupted reproductive period was presumably due to extreme drought conditions.

Each month sampled had a very high percentage of adult females with placental scars, the fewest occurring in January (Fig. 8) when 64% had scars. Placental scars in *D. merriami* probably persist for a year or more following parturition. These data also suggest that there is a good carry-over of individuals from the previous year, concurring with the findings of Chew and Butterworth (1964).

A high percentage of females born in spring are reproductively active by autumn (Fig. 8). Those from the autum litters are the majority of the breeding individuals in the following spring. Compared to the other four species, however, the percentage of young adult animals breeding in the spring is lowest in *D. merriami*.

D. merriami was remarkably consistent in the number of young per litter (Table 18). Nearly all of the pregnant females had two embryos. *D. merriami* is the largest rodent under study and had the smallest litter size as well as the longest reproductive period.

Lidicker (1960) and Chew and Butterworth (1964) have suggested the possibility of second litters among *D. merriami* during the reproductive season. Our findings concur with their's; several pregnant females with recent placental scars, or lactating, were captured during June and September, 1970.

There is a definite correlation between the level of body weight (Fig. 9) and the incidence of reproductivity (Fig. 8). During the period of stress (July and August), average body weight and reproduction show a drastic decline. Males are consistently heavier than females except during this stressful period. When rainfall is lacking, body weights gradually decline as shown during the dry spring months in 1971.

Of the 802 *D. merriami* taken in the first year's catch, 53% were males. Young animals were trapped in every month except September, January, March, April, and May (Fig. 8). The largest number of young animals trapped (22%) was in June. Adult animals dominated the population each month, suggesting a high carry-over of adults.

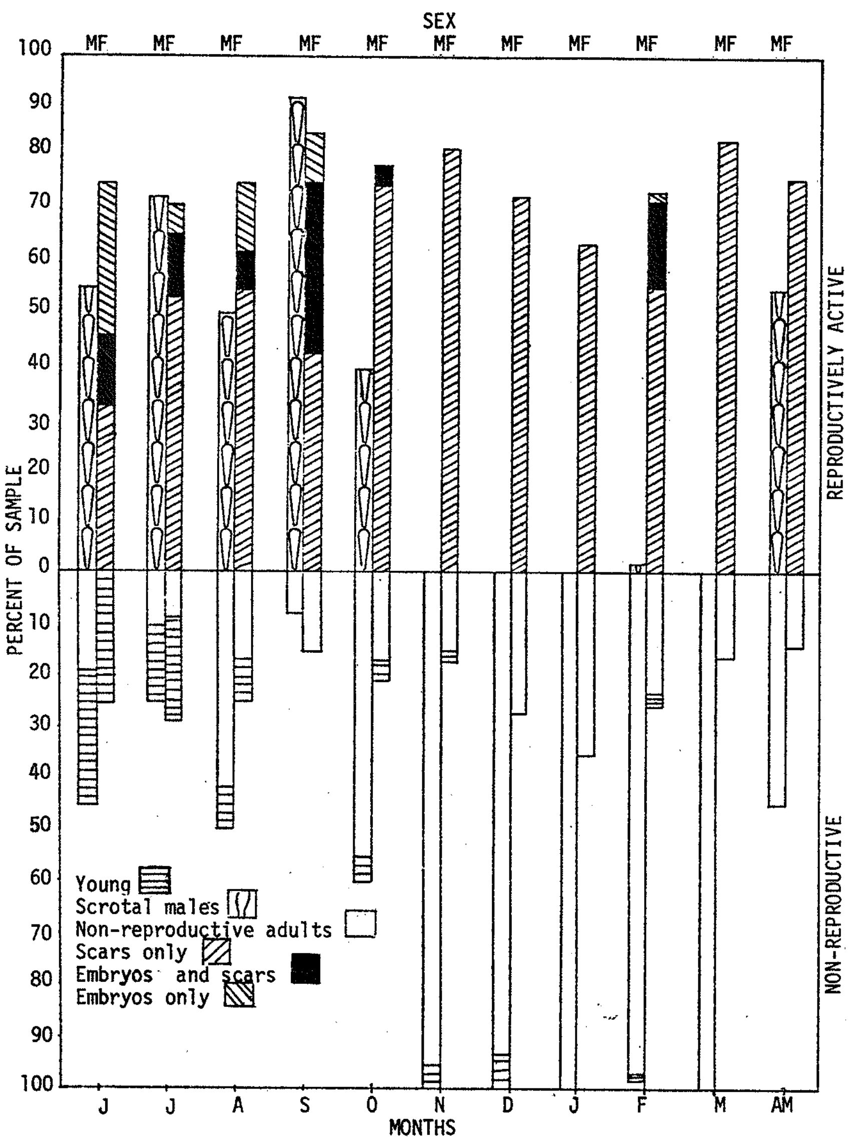

Figure 8. Summary of the reproductive cycle of *Dipodomys merriami* based on samples of 430 males and 382 females.

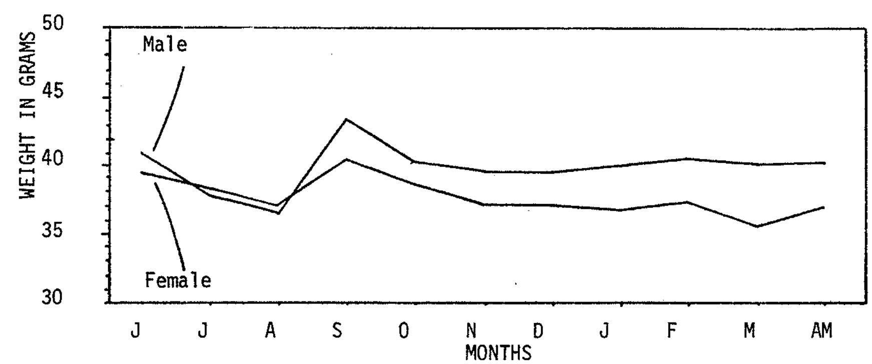

Figure 9. Monthly weight changes of 394 adult males and 385 adult females of *Dipodomys merriami*.

The breeding cycle of Perognathus amplus. Perognathus amplus has only one, relatively short breeding period. Males in scrotal condition were observed during April, May, June, and July, while embryos were found in females only in June and July.

Males with scrotal testes were considered reproductively active. When the testes are scrotal, there are large quantities of sperm, and when abdominal, there may be only traces or no sperm at all, depending upon size and vigor of the animal and season of the year.

In June, the period of greatest reproductive activity for *P. amplus*, 47% of the males were scrotal. The baculum, caudal epididymis, seminal vesicles, and the testes have been measured in 385 male *P. amplus* representing various ages and reproductive stages over a full year's period, but analysis and correlation of these data have not yet been completed.

In a sample of 70 adult females during June, 1970, 34% were pregnant (Fig. 10). The average number of fetuses was 4.05 with a range of 3-5 (Table 18). The heavier females, especially those with previous placental scars, had the larger litters. It is surmised that, because of the short breeding period in *P. amplus*, a full year is required for young animals to become reproductively active.

There was no evidence of multiple litters during the breeding season of *P. amplus*. Only during June, 1970, were there females taken that had both scars and embryos. Those scars observed were old and not easily detected. This evidence indicates that there is a high population turn-over each year. *P. amplus* had the largest litter size although it is the smallest of the five species studied (Table 18). Embryos were observed only during June and July.

Males were slightly, but consistently, heavier than females. Based on body weight, both males and females were in prime condition during June (Fig. 11), the month when they were most reproductive. In October, adult *P. amplus* responded to autumn rains with increased body weights just prior to above-ground inactivity in late November. Perhaps the increased body weight and stored fat observed in animals taken during October is in preparation for hibernation.

The breeding cycle of Perognathus penicillatus. The reproductive period of *P. penicillatus* was continuous from April through September. The period of greatest activity was June, during which 80% of the total adult population was considered reproductively active.

Male *P. penicillatus* become reproductively active earlier in the season than do females and remain fertile later in the year. This condition is more likely to insure insemination of the females. Stressful conditions imposed during August resulted in a decline of fertile adult males as compared to the preceeding or following month (Fig. 12).

Pregnant females were taken during June, July, August and September. During June, 37% of the adult females were pregnant and 42% were in estrous, lactating, or had recent placental scars.

Pregnant females with placental scars were trapped only during June and July (Fig. 12). This supports the idea that the females reproducing late in the season (August and September) were born early in spring litters. The first females to have embryos at onset of the breeding season are the older animals that have carried over from the previous year.

Forty pregnant females had an average litter of 3.4 within a range of 2-4 (Table 18). Several females that were in early pregnancy were trapped during June and appeared to be still lactating, suggesting the possibility of multiple litters. Individuals from litters early in the reproductive season mature rapidly and become reproductively active late in the breeding period. This rapid maturation could aid the population reproductive potential.

Adult male and female *P. penicillatus* are consistent in their comparative weight ratios and in their periodic weight fluctuations (Fig. 13). Both male and female are heaviest during June, when the average adult weight is 14.44 gm. Unlike *P. amplus*, whose weight increases prior to becoming inactive during the winter, the weight of *P. penicillatus* decreases.

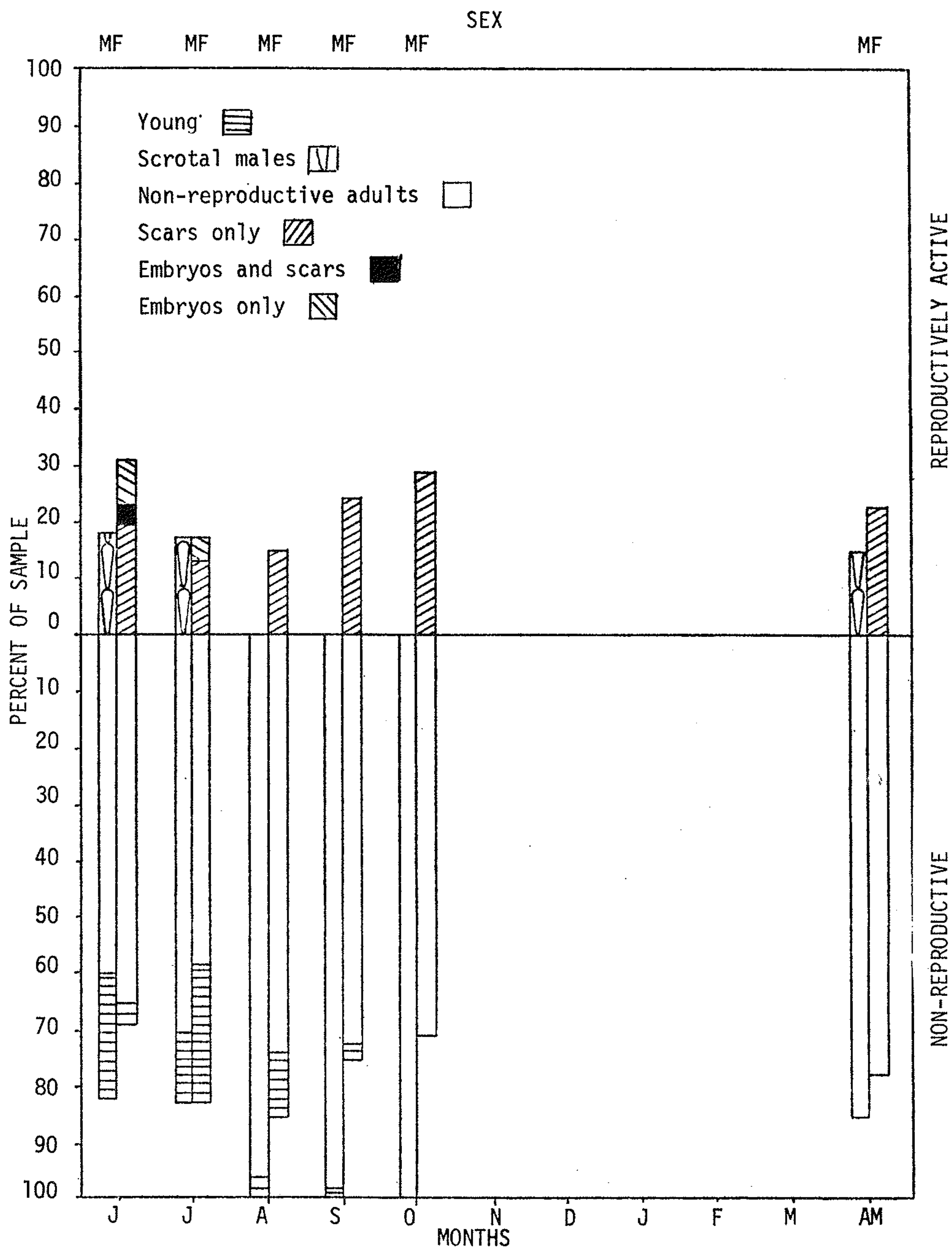

Figure 10. Summary of the reproductive cycle of *Perognathus amplus* based on samples of 403 females. Some months not plotted because of poor trapping success.

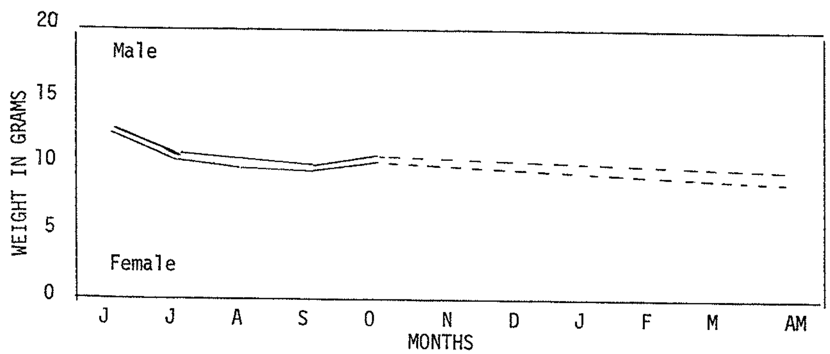

Figure 11. Monthly weight changes of 259 adult males and 242 adult females of *Perognathus amplus*. Dotted lines represent periods of poor trapping success.

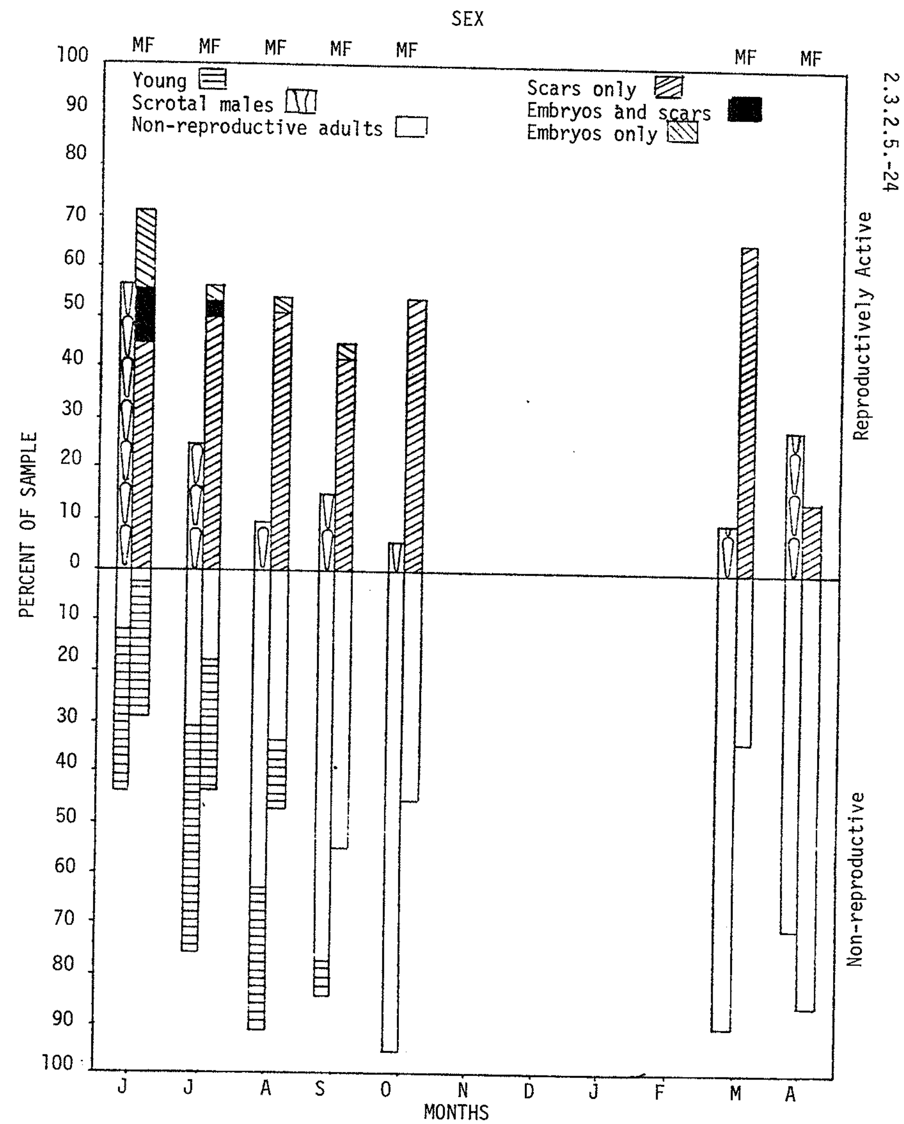

Figure 12. Summary of the reproductive cycle of *Perognathus penicillatus* based on samples of 288 males and 335 females. Some months not plotted because of poor trapping success.

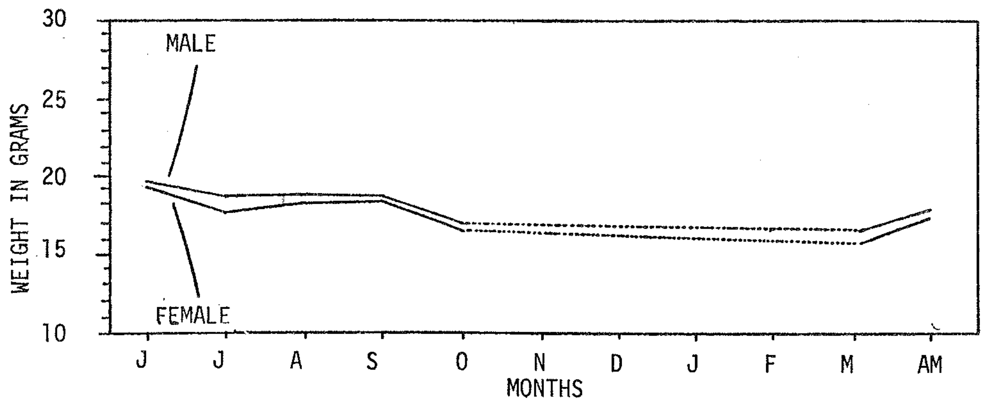

Figure 13. Monthly weight changes of 214 adult males and 272 adult females of *Perognathus penicillatus*. Dotted lines represent periods of poor trapping success.

Breeding cycle of Perognathus baileyi. The reproductive cycle in *P. baileyi* is similar to that of *D. merriami* as it has two peaks of reproductive activity; one in June and another, less prominent, in September (Fig. 14). Among the species observed in this study, only the two larger heteromyids have this type of pattern. These reproductive peaks also correspond to the bi-annual rainfall pattern and are probably a subsequent response to green vegetation. When rainfall was lacking in spring, 1971, there were not enough *P. baileyi* trapped to speculate on the reproductive status.

Males were reproductively active from June through October. Virtually all the adult males were fertile during June and 56% were fertile during the second reproductive peak in September. During the remainder of the summer months, most of the adult males were non-scrotal, but in most cases their reproductive organs contained moderate amounts of sperm so as to be potentially reproductive.

June, 1971, was the only month in which all the adult female *P. baileyi* were considered reproductively active (Fig. 14). The breeding population declined to 24% during August, following a similar pattern in the males. Embryos were recorded for only two months, June and September; but young animals were trapped during 5 months of the year. Examination of 8 pregnant females and 76 females with placental scars, revealed an average litter size of 3.41 with a range of 2-6. It is surmised that placental scars do not persist as long in *P. baileyi* as they do in *D. merriami*. Since 3% of the pregnant adult females captured in June had placental scars, multiple litters may occur.

Of the five species studied, *P. baileyi* shows the most erratic weight fluctuations (Fig. 15). There are obvious disparities in the male-to-female weight ratios from month to month even though the males are consistently heavier than the females. Weight fluctuations in this species could not be correlated with environmental factors.

Of the sample of 304 animals, 57% were females (Table 15). A large percentage of the animals trapped were adults, indicating a high survival.

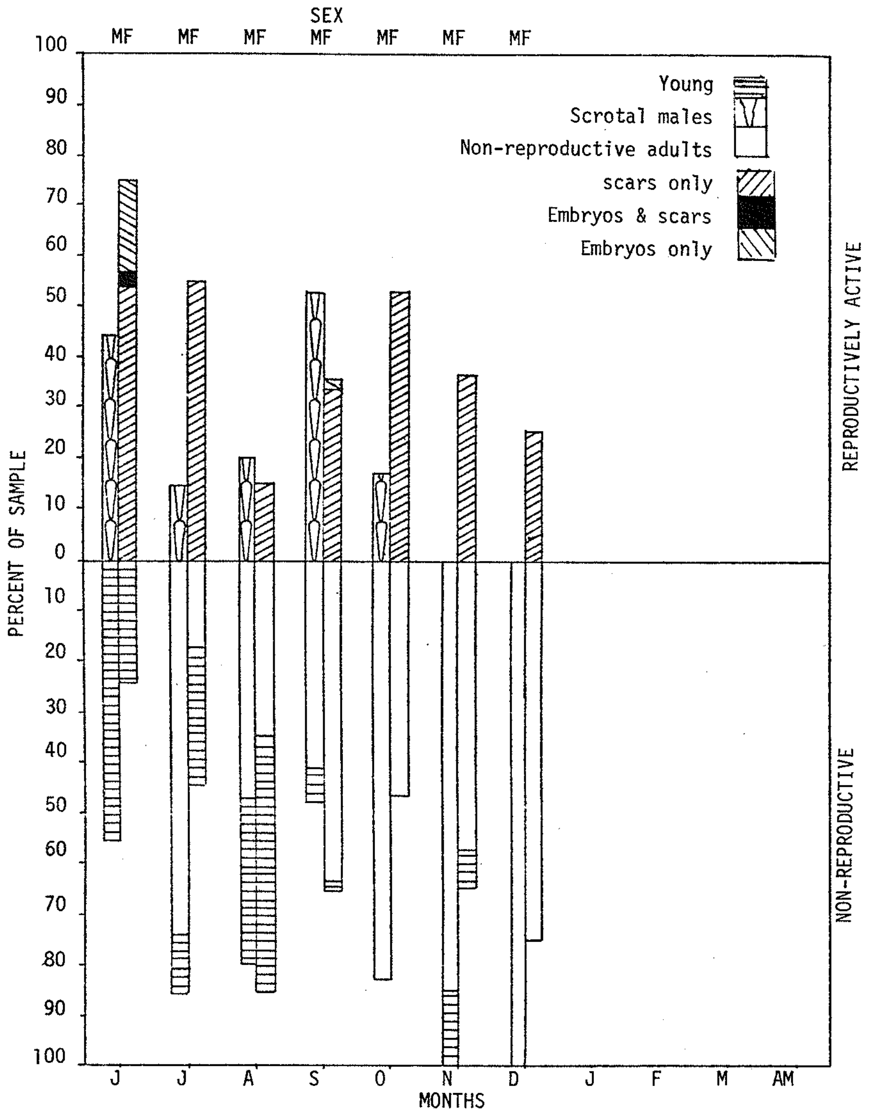

Figure 14. Summary of the reproductive cycle of *Perognathus baileyi* based on samples of 128 males and 175 females. Some months not plotted because of poor trapping success.

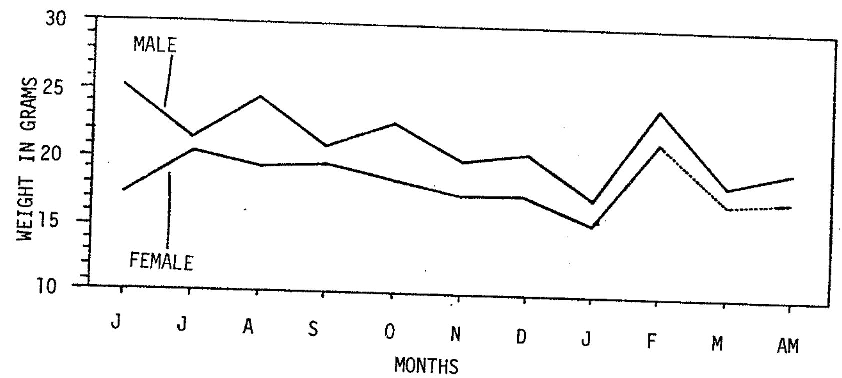

Figure 15. Monthly weight changes of 108 adult males and 148 adult females of *Perognathus baileyi*. Dotted lines represent periods of poor trapping success.

The breeding cycle of Peromyscus eremicus. MacMillen (1964) reported that male *P. eremicus* undergo a definite reproductive season whereas the females produce litters throughout the year. This reproductive phenomenon was explained by the occurrence of postparturient heat and prolongation of gestation in females which became pregnant while lactating. Examination of 217 animals over a year reveals a somewhat similar situation in our study area. During the peak reproductive months, many of the reproductively active *P. eremicus* still have subadult pelage.

A majority of the males became fertile in April (67%) following a winter's reproductive quiescence and a dry spring, whereas females did not (Fig. 16). During 3 months of 1970 (June, July, and August), all of the adult and some of the subadult males were scrotal. In June, 41% of the scrotal males were subadult.

Pregnant females were found during 5 months of the year (Fig. 16), and some individuals may be pregnant during most of the other months. This was not shown due to low trapping success of this species in September, December, January, February, and March. Dissection of pregnant females revealed that the fetuses were often located in one horn or the other, suggesting rotating ovulation by the ovaries.

Litter sizes of 26 pregnant females varied from 2-4 with an average of 2.65. MacMillen (1964) reports as many as three litters in a single year for *P. eremicus*. Examination of pregnant females which were lactating and/or had recent placental scars are evidence of multi-litters.

Seeds from annuals generally constitute the majority of the diet in heteromyids. It is suggested that reproductive cycles correspond with the availability of these seeds and the periodic succulent vegetation. Insects and fleshy portions of plants constitute the principal diet in *P. eremicus*. As *P. eremicus* does not depend on increased moisture content during certain periods of the year, it is conceivable that it is continuously reproductive.

P. eremicus was the only animal studied in which the females were generally heavier than the males (Fig. 17). The average weights of both males and females fluctuated around 20 gm.

Both males and females achieve sexual maturity during the first year of life. Reproductively active individuals with subadult pelage were fairly common, especially during late summer. The ratio of males to females was nearly 1:1 (See Table 17).

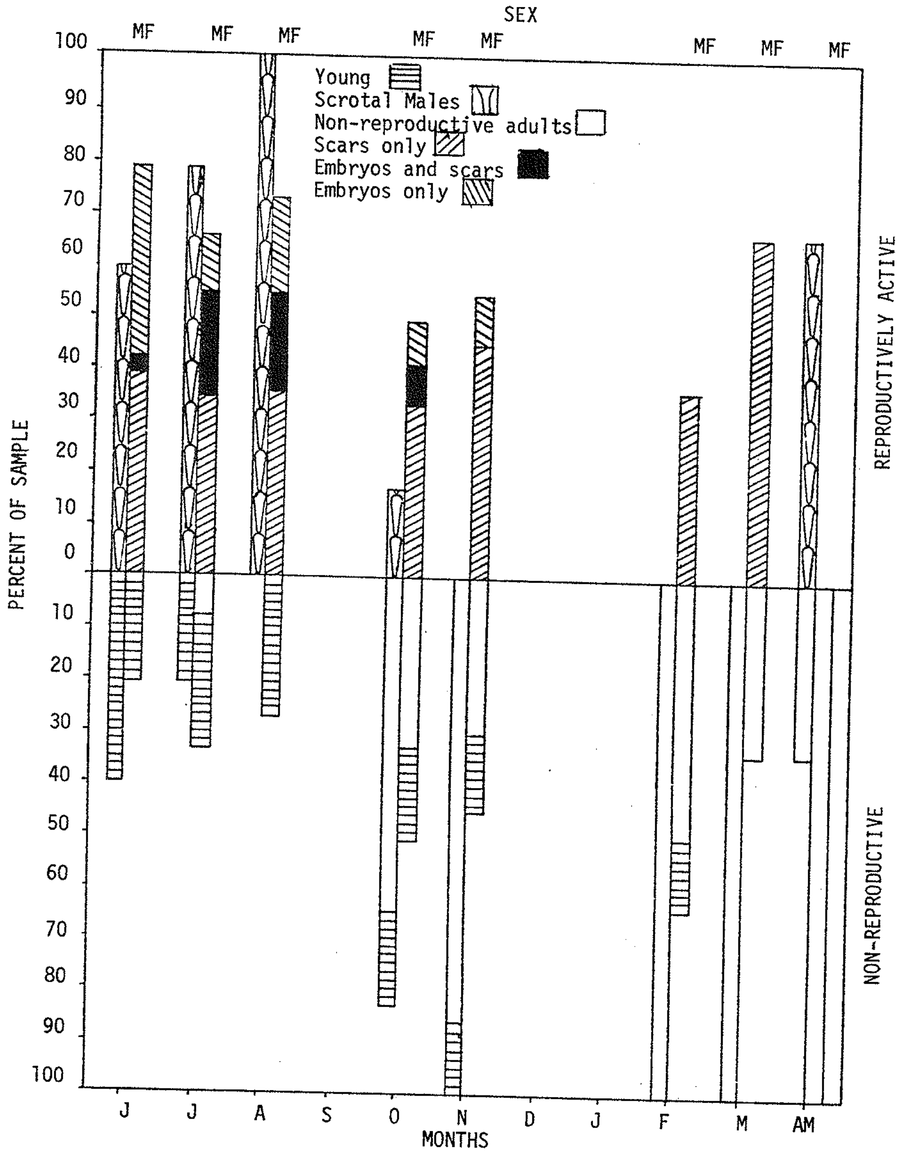

Figure 16. Summary of the reproductive cycle of *Peromyscus eremicus* based on samples of 116 males and 101 females. Some months not plotted because of poor trapping success

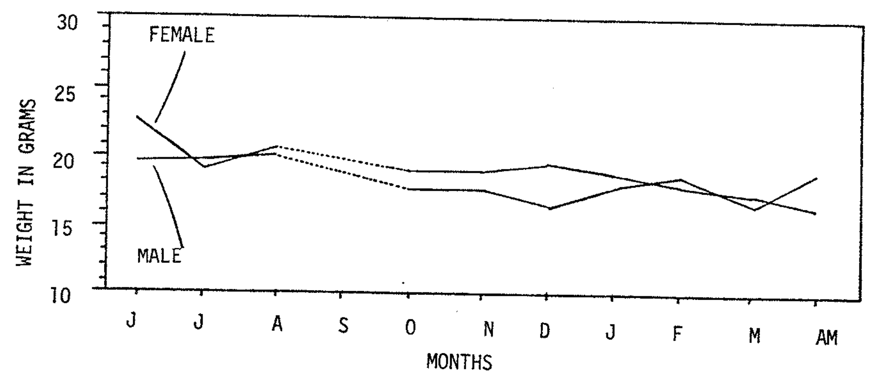

Figure 17. Monthly weight changes of 81 adult males and 78 adult females of *Peromyscus eremicus*. Dotted lines represent periods of poor trapping success.

Correlation Between Litter Size and Reproduction Period

There is a positive correlation between the size (N) of litters produced within each species and the length of the reproductive period. Categorizing the five species into those that have the shortest reproductive period to those with the longest we have: *P. amplus* (3 months), *P. penicillatus* (5 months), *P. baileyi* (5 months), *P. eremicus* (6 months), and *D. merriami* (7 months). By arranging the same from largest litter sizes to the least we have: *P. amplus* (4.05), *P. penicillatus* (3.50), *P. baileyi* (3.30), *P. eremicus* (2.65), and *D. merriami* (1.98). Ranking each of these two factors into two ordered series we have:

Species	Reproductive months	Litter size	di	di^2
P. amplus	1	1	0	0
P. penicillatus	2.5	2.5	0	0
P. baileyi	2.5	3	.5	.25
P. eremicus	4	4	0	0
D. merriami	5	5	0	0

Then by using the Spearman Rank Correlation Coefficient, "rs", and specifically the formula $\Sigma x^2 = \frac{N^3 - N}{5}$, we find that the results are significant at the 95% level.

The smaller the species (body weight), the shorter the breeding period and the greater the litter size. Multiple litters within a single breeding season are common among the larger species and their litter sizes are relatively small.

These correlations are only one facet in the complexities of population dynamics and species co-existence in a desert community.

DISCUSSION & CONCLUSIONS

From information now available, certain tentative conclusions seem justified:

1. The major source of food for the heteromyid rodents is seeds; other foods are of little importance, with insects being somewhat seasonal.

2. The seeds gathered most frequently are those of annual forbs, *Plantago, Pectocarya,* and *Erodium,* along with the seeds of *Opuntia* and *Larrea.*

3. The seeds are taken primarily from the surface, or just beneath the surface of the soil, rather than being harvested from the plants themselves.

4. Rodents appear to be storing the hard-coated seeds and immediately eating the soft ones, as well as eating greenery without storing it.

5. The entire seed production by the major food plants occurs during two fairly brief intervals, one in the spring after the winter precipitation, and one in the late summer after the summer thunderstorms.

6. Even after periods of little or no annual growth, there is a vast reservoir of seeds in the soil.

7. The majority of the seed populations available to the rodents are in the top 2 cm. of the soil. Over 77% of the total number of seeds recovered were in this layer of soil.

8. The seeds found in the remains of the soil after extraction were from samples in which the seeds were left in solution overnight. Absorption of water by the seeds may have affected their densities so that extraction from the soil was difficult.

9. In order to extract the remainder of seeds from the 2-4 cm. and 4-6 cm. levels, approximately 4000 cc of soil would have to be processed. It would seem unnecessary to process twice as much soil volume to obtain less than 15% of the total seed population.

10. By taking monthly soil samples from the study site, we should be able to accurately estimate what seed populations are available as a potential food source to the rodents being studied. We should also be able to accurately estimate seasonal changes in seed populations and with these data, correlated with cheek pouch and stomach content data, determine if there is a seasonal preference for seeds by the different species of rodents.

11. The seasonal activity cycles of the most abundant rodents are partially out of phase. The pocket mice are active throughout the warm part of the year but are below ground in the winter. The reverse is true of the kangaroo rat which is relatively inactive above ground in the hot part of the year but is active in the winter.

12. In the four species of heteromyids, the male is, on average, heavier than the female; with *P. eremicus* the reverse is true.

13. The body weight fluctuates seasonally, probably in response to the quality and quantity of food available and environmental stress factors.

14. There are two definite reproductive periods in *D. merriami* and, to a lesser extent, in *P. baileyi*. The other three species have one reproductive period of varying length which always occurs in spring and early summer.

15. The smaller species have shorter breeding periods and larger litters.

The picture that seems to be emerging is of considerable interest. The most important rodents, all highly specialized mammals able to maintain osmotic balance without drinking water, are eating seeds and insects. Knowledge of the dietary balance between insects, high carbohydrate seeds, and high protein seeds, may reveal how the rodents obtain metabolic water. The abundant seed crop of small (in some cases tiny) annual forbs provides the most important food; these seeds are produced only during two brief periods in the year. Soon after the seeds are set, the plants become dry and their seeds (and in many cases the entire plants) are swept away by the wind, leaving the surface of the ground remarkably barren. The wind-blown seeds either become lodged in small depressions in the soil or are shallowly buried, and are gathered by the rodents from these places. The large perennials provide a fairly minor share of the food of these rodents, but may be of critical importance at certain seasons. Because the pocket mice are most actively foraging during the season when the kangaroo rat is least active, and visa versa, competition between these animals, which seem to utilize roughly the same food resources, is lessened. Indeed, the apportionment of the food may partly depend on the offsetting of the activity cycles and different foraging techniques and strategies. Perhaps the late summer seed crop carries the kangaroo rat through its active times and provides energy for part of its reproduction, whereas the spring seed production is critical in carrying the pocket mice through their warm season activity and through their spring reproduction. Because both the pocket mice and the kangaroo rat probably breed in the spring, it may be that survival of young and therefore population levels during the summer are primarily dependent on the level of productivity of the spring forbs.

Competition between the rodents is reduced in several ways. Some species that utilize similar foods may occupy different habitats. A case in point is that of *D. merriami* and *P. penicillatus:* the former occupies creosote-bush flats, the latter, rocky hills and washes dissecting the creosote flats. Some species that occupy common ground utilize different foods. *P. eremicus* and *P. penicillatus* both inhabit the rocky hills, but the pocket mouse feeds entirely on seeds whereas the cactus mouse probably feeds heavily on insects (at least during the summer when these animals are both active). Perhaps of greatest importance in its effect on competition is the offsetting of activity cycles; those species that compete most directly for food, such as *D. merriami* and *P. amplus*, have their activity peaks at different seasons. The activity curves also indicate a direct relationship between the weight of the rodent species and its ability to cope with environmental extremes.

Reproduction is closely linked with seasonal rainfall and subsequent vegetation. The onset of the breeding season in all the species except *P. eremicus*, which does not utilize the annuals so exclusively, is apparently initiated by the crucial fall and winter rains.

P. amplus is the smallest species under study and produces the largest litters in the shortest reproductive season. Furthermore, of the five species, there appears to be in *P. amplus* the highest population turn-over from one reproductive season to the next. As there is an increase in the average body weights in the remaining four species, there is also a direct correlation between the length of the breeding season, the number of multiple litters, and the amount of adult carry-over. Conversely, the numbers of individuals per litter decreases with increased body weight. Only in *P. baileyi* and to a greater extent *D. merriami*, are there two reproductive periods within a single year: a major peak in spring in response to winter rains and a minor response in autumn initiated by summer rains.

In all species except *P. amplus* there is evidence of young animals maturing and becoming reproductively active within the season in which they are born. In *P. eremicus* reproductively active individuals having subadult pelage are very common, especially later in the breeding season.

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