THE SOUTHWESTERN NATURALIST 38(3):224–235 SEPTEMBER 1993

FOOD HABITS OF SYMPATRIC RODENTS IN THE SHINNERY OAK-MESQUITE GRASSLANDS OF SOUTHEASTERN NEW MEXICO

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ABSTRACT—There was relatively little overlap in diet among *Dipodomys ordii*, *Onychomys leucogaster*, *Neotoma micropus*, and *Spermophilus spilosoma* in the shinnery oak-mesquite (*Quercus havardii-Prosopis glandulosa*) grassland of southeastern New Mexico. *D. ordii* primarily consumed *Triplasis purpurea*, *P. glandulosa*, *Euphorbia*, and arthropods; *O. leucogaster* predominantly consumed arthropods; *N. micropus* consumed plant fibers, new growth of dicots, *Q. havardii*, and *P. glandulosa*; and *S. spilosoma* primarily consumed arthropods, new growth of dicots, and grasses. Sexual differences in diet were virtually absent for *D. ordii* and *O. leucogaster*, but there was statistically significant variation in diets among seasons, years, and months ($P \leq 0.05$). A sample of approximately 60 specimens would be required to obtain a reasonable estimate of the variety of food items consumed by *D. ordii* and *O. leucogaster*.

Hypotheses attempting to explain ecological relationships within communities of desert rodents have concentrated on heteromyids, with little attention to cricetid and sciurid components, despite their typically high densities and close association with species of heteromyids. Because interfamilial interactions may play an important role in determining species composition, studies that include all species common to an area are necessary to understand the structure of desert-rodent assemblages (Rebar and Conley, 1983).

Dipodomys ordii (Heteromyidae), *Onychomys leucogaster* (Cricetidae), *Neotoma micropus* (Cricetidae), and *Spermophilus spilosoma* (Sciuridae) are among the most common species of rodents inhabiting stabilized-sanddune habitats on the plains of western Texas and eastern New Mexico. Here the sandy soils have a mixed-grass and shinnery oak-mesquite (*Quercus havardii-Prosopis glandulosa*) vegetation association. Several investigators have studied food habits of these species individually (e.g., Bailey and Sperry, 1929; Best and Hoditschek, 1982), but only Flake (1973) has examined relationships among diets for more than one of these four species in the same area. Considering that these species occupy the same habitat in southeastern New Mexico, their abundance in this habitat, and the extent of the geographic area where this habitat occurs, it seems important to elucidate the degree of interspecific overlap in diet, and thus, the potential for competition for food resources among these species. Thus, the primary purposes of this study were to ascertain what food items were consumed and to evaluate the extent of overlap in diet among *D. ordii*, *O. leucogaster*, *N. micropus*, and *S. spilosoma* in the shinnery oak-mesquite grassland of southeastern New Mexico. For *D. ordii* and *O. leucogaster* we also evaluated the extent of seasonal, monthly, and sexual variation in diet and the influence of sample size on determining the kinds of food items consumed.

MATERIALS AND METHODS—*Dipodomys ordii* ($n = 384$), *O. leucogaster* ($n = 190$), *N. micropus* ($n = 66$), and *S. spilosoma* ($n = 70$) were kill-trapped at monthly intervals from March 1978 through December 1979, approximately 40 km east of Carlsbad, Eddy and Lea counties, New Mexico (within an 8-km radius of the Los Medaños Waste Isolation Pilot Plant, SE corner, T22S, R31E, Sec. 20). The habitat where specimens were collected was a shinnery oak-mesquite association (*Q. havardii-P. glandulosa*). Extensive vegetational analyses of this area also were conducted (Best and Jackson, 1982); the 29 most common plant species during 1979 were: *Aristida,* mean number of plants/ha = 7,815; *Artemisia filifolia,* 986; *Bouteloua eriopoda,* 3,644; *Cenchrus insertus,* 1,384; *Croton dioicus,* 1,718; *Dithyrea wislizenii,* 1,240; *Eriogonum,* 4,068; *Euphorbia,* 2,757; *Gutierrezia sarothrae,* 25,016; *Helianthus petiolaris,* 2,363; *Heliotropium convolulaceum,* 506; *Heterotheca psammophila,* 1,859; *Hoffmanseggia,* 20; *Houstonia humifus,* 38,897; *Larrea tridentata,* 396; *Lesquerella fendleri,* 2,954; *Monarda punctata,* 2,097; *Muhlenbergia porteri,* 566; *Munroa squarrosa,* 41; *Panicum capillare,* 4,101; *Paspalum setaceum,* 1,615; *Pectis angustifolium,* 568; *Perezia nana,* 103; *Prosopis glandulosa,* 104; *Quercus havardii,* 10,522; *Senecio multicapitatus,* 3,279; *Sporobolus,* 5,724; *Tridens pulchellus,* 2,154; and *Yucca campestris,* 512.

Stomach contents were washed, dried, and thoroughly mixed. Subsamples were permanently mounted on microscope slides using the techniques of Baumgartner and Martin (1939) as revised by Dusi (1949) and Hansson (1970). Slides were analyzed at 25×, and six fields were examined on each slide. An ocular grid divided each field into 100 square units. Average percent cover of each food item based on six 100-unit grids was calculated for each individual. Higher magnification was used as necessary to identify individual food items. Both seeds and vegetation that were identified as being from a particular species were merged under that species for further analysis. A collection of green tissues and seeds of plants on the study area was made using the same techniques employed for making slides of stomach contents to provide a reference for identifying stomach contents. Green leaves from grasses that could not be classified to genus are listed as Graminae. Green-dicotyledonous vegetation that could not be identified further is listed as new dicot growth, and unidentified fibrous plant material was classified as plant fibers. Unidentified plants were assigned a number and listed as unknowns. No attempt was made to classify arthropods beyond phylum because of the small size of body parts that were recovered in stomach contents.

Mean, standard deviation, and range were calculated for food items recovered from each species of rodent; for *D. ordii* and *O. leucogaster* these statistics also were calculated for each sex, season, year by season, and month. Because of small samples, *N. micropus* and *S. spilosoma* were not similarly analyzed for sexual, seasonal, annual, and monthly variation. Seasons were: winter, December through February; spring, March through May; summer, June through August; autumn, September through November. One-way analysis of variance was used to assess differences between sexes for *D. ordii* and *O. leucogaster.* Relationships among species, seasons, years, and months were assessed using a multivariate analysis of variance. Discriminant function analysis also was used to assess the degree of differentiation in diet among species. All statistical computations were performed using SAS (SAS Institute, 1985).

To obtain a measure of the variety of food items in the diet and the number of different food items consumed by each species, as well as by each sex, month, and season for *D. ordii* and *O. leucogaster,* we counted the number of different types of food items consumed. To determine the relationship between the number of different types of items recovered in food-habit studies in relation to sample size, random samples were selected from the data for *D. ordii* and *O. leucogaster.* The number of items recovered from a random sample of 10, 20, 30, etc., stomachs was plotted to ascertain a minimum number of samples that may be necessary to obtain similar results.

RESULTS AND DISCUSSION—*Intraspecific Relationships*—Food items most frequently consumed by *D. ordii* were *Triplasis purpurea, P. glandulosa,* Arthropoda, *Euphorbia,* and Unknown 3 (Table 1). Plant food items recovered from our sample differ considerably from previous studies (Bailey, 1931; Johnson, 1961; Wood, 1969; Alcoze and Zimmerman, 1973; Flake, 1973; Schmidly, 1977; Bee et al., 1981). Even fairly close geographic areas showed considerable differences in diet. For example, in west-central Texas, Alcoze and Zimmerman (1973) found the most common food items to be dry stems, *Paspalum stramineum,* seeds and leaves of *Prosopis juliflora, Croton glandulosus, Sorghum halapense, Ambrosia artemisifolia, Helianthus annuus,* insects, and the fungus *Endogone.* In Trans-Pecos Texas, 90% of the diet consisted of seeds of *Larrea, Bouteloua,* and *Sporobolus* (Schmidly, 1977). Two studies performed in New Mexico also showed differences. Bailey (1931) reported that *D. ordii* consumed *P. glandulosa, Helianthus, Atriplex, Portulaca oleracea,* and *Larrea tridentata,* and in southern New Mexico, seeds and green vegetation formed the major portion of the diet with insects being next most common (Wood, 1969). Because of differences in geographic distribution of plants over western North America, the annual and seasonal phenology of plants, and the effect of climatic fluctuations on plant populations, it is not surprising that there is such a degree of variation among studies of food habits of this species. However, even with the large variation in diet, the attraction of *D. ordii* to seeds of grasses,

TABLE 1—Food items consumed by four species of rodents in southeastern New Mexico. Data are presented as the number of animals that consumed the food item (average percent of all food consumed by each species; *SD*). In addition, the *F*-ratios resulting from single-classification analysis of variance among the four species are presented (* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$).

		Rodent species				
No.	Food item	*D. ordii* (*n* = 384)	*O. leucogaster* (*n* = 190)	*N. micropus* (*n* = 66)	*S. spilosoma* (*n* = 70)	*F*-ratio
1	*Ephedra* sp.	0	0	0	3 (31.7; 20.2)	7.40***
2	*Yucca campestris*	1 (5.0; —)	0	3 (30.0; 17.3)	1 (10.0; —)	7.75***
3	*Amaranthus alba*	24 (38.3; 37.3)	0	0	0	3.66**
4	*Froelichia floridana*	5 (6.0; 2.2)	0	0	0	1.28
5	*Cryptantha angustifolium*	8 (15.8; 15.7)	0	0	0	1.24
6	*Lithospermum multiflorum*	1 (9.0; —)	0	0	0	0.28
7	*Opuntia phaeacantha*	8 (15.0; 9.9)	0	3 (34.0; 38.9)	0	3.36*
8	*Chenopodium* sp.	30 (29.4; 28.7)	0	1 (10.0; —)	0	4.46**
9	*Cyclaloma atriplicifolia*	11 (21.5; 14.2)	0	0	0	2.26
10	*Gaillardia* sp.	2 (5.0; 0.0)	0	0	0	0.57
11	*Helianthus petiolaris*	18 (20.7; 20.7)	2 (16.0; 19.8)	2 (17.0; 18.4)	3 (21.7; 18.2)	0.41
12	*Palafoxia sphacelata*	10 (12.9; 8.0)	1 (20.0; —)	1 (5.0; —)	1 (10.0; —)	0.70
13	*Gutierrezia sarothrae*	12 (25.3; 28.2)	1 (10.0; —)	0	0	1.48
14	*Descurania pinnata*	31 (11.1; 13.6)	1 (100; —)	0	3 (18.3; 12.6)	0.58
15	*Croton* sp.	86 (17.5; 12.0)	2 (4.5; 0.7)	2 (25.0; 21.2)	22 (18.0; 0.2)	13.36***
16	*Euphorbia* sp.	137 (24.7; 18.9)	18 (24.6; 22.8)	8 (23.8; 29.7)	5 (3.2; 3.4)	9.70***
17	*Phyllanthus abnormis*	1 (68.0; —)	0	0	0	0.28
18	*Quercus havardii*	8 (17.5; 14.7)	2 (10.0; 7.1)	8 (31.9; 20.5)	6 (15.0; 6.3)	9.96***
19	Gramineae	60 (23.4; 18.9)	7 (16.4; 13.6)	20 (53.0; 28.3)	23 (33.3; 22.6)	25.94***
20	*Aristida* sp.	59 (17.8; 17.1)	0	1 (5.0; —)	0	9.92***
21	*Bouteloua* sp.	40 (31.6; 23.9)	1 (80.0; —)	0	0	5.29***
22	*Cenchrus insertus*	47 (11.3; 9.9)	0	0	0	8.10***
23	*Munroa squarrosa*	3 (37.3; 33.0)	0	0	0	0.56
24	*Panicum obtusum*	6 (9.2; 3.8)	0	0	0	1.50
25	*Paspalum setaceum*	38 (27.8; 16.2)	0	0	0	8.46***
26	*Sporobolus cryptandrus*	16 (12.1; 10.4)	1 (4.0; —)	2 (62.5; 53.0)	1 (6.0; —)	2.95*
27	*Triplasis purpurea*	169 (37.7; 25.6)	8 (18.5; 11.3)	1 (5.0; —)	7 (17.1; 20.0)	37.36***
28	*Phacelia corrugata*	13 (26.5; 24.6)	2 (33.5; 36.1)	1 (9.0; —)	3 (4.3; 2.1)	0.58
29	*Monarda punctata*	6 (15.3; 17.8)	0	0	0	0.80
30	*Astragalus* sp.	30 (19.5; 17.1)	1 (10.0; —)	0	3 (26.7; 20.8)	3.45*

TABLE 1—Continued.

No.	Food item	Rodent species				F-ratio
		D. ordii (*n* = 384)	*O. leucogaster* (*n* = 190)	*N. micropus* (*n* = 66)	*S. spilosoma* (*n* = 70)	
31	*Caesalpina jamesii*	1 (10.0; —)	0	0	0	0.28
32	*Krameria* sp.	2 (10.5; 2.1)	0	0	0	0.55
33	*Prosopis glandulosa*	160 (25.6; 20.1)	11 (18.3; 26.2)	18 (22.4; 16.5)	22 (22.5; 11.1)	13.08***
34	*Linum aristatum*	24 (27.2; 19.2)	2 (50.0; 49.5)	0	3 (38.3; 12.6)	1.85
35	*Mentzelia* sp.	7 (6.4; 2.4)	0	0	1 (7.0; —)	1.38
36	*Spharalcea* sp.	32 (12.3; 9.3)	1 (2.0; —)	5 (20.6; 10.6)	12 (20.4; 16.3)	8.44***
37	*Boerhaavia intermedia*	7 (14.3; 10.6)	0	0	1 (10.0; —)	1.13
38	*Oenothera* sp.	72 (24.5; 14.0)	3 (21.3; 14.6)	1 (4.0; —)	9 (22.7; 12.9)	11.43***
39	*Eriogonum* sp.	31 (18.8; 16.8)	0	0	0	5.16**
40	*Maurandya wislizenii*	7 (9.3; 7.3)	0	0	0	1.30
41	*Penstemon fendleri*	5 (16.8; 18.6)	0	0	0	0.71
42	*Larrea tridentata*	16 (12.0; 7.3)	0	0	0	3.22
43	U3	114 (12.0; 9.0)	9 (17.3; 22.6)	5 (9.0; 4.2)	6 (10.0; 5.5)	8.04***
44	U6	23 (27.0; 14.1)	0	0	1 (15.0; —)	3.88**
45	U29	3 (8.3; 2.9)	0	0	0	0.79
46	U59	41 (18.3; 16.7)	0	2 (8.5; 3.5)	11 (14.5; 12.7)	5.42***
47	U64	0	1 (5.0; —)	1 (30.0; —)	2 (12.5; 10.6)	2.60
48	U78	18 (20.3; 11.0)	2 (32.5; 24.8)	0	6 (38.3; 23.0)	5.34***
49	U80	13 (27.7; 17.5)	2 (15.0; 7.1)	0	4 (21.3; 2.5)	1.93
50	U81	1 (100; —)	0	0	0	0.28
51	U92	0	1 (100; —)	0	0	1.65
52	U211	4 (20.5; 14.2)	0	0	0	0.83
53	U212	1 (25.0; —)	0	0	0	0.28
54	U213	1 (100; —)	0	0	0	0.28
55	New dicot growth	28 (19.2; 12.7)	8 (58.1; 42.1)	25 (51.2; 29.3)	29 (31.1; 23.9)	32.43***
56	Plant fibers	27 (19.2; 11.9)	7 (30.7; 31.1)	40 (63.8; 32.6)	9 (17.4; 12.7)	145.86***
57	Fungi	16 (18.4; 15.2)	2 (42.0; 29.7)	0	0	1.10
58	Arthropoda	140 (24.9; 19.2)	108 (86.6; 22.7)	13 (21.4; 21.8)	64 (37.9; 23.4)	417.19***

forbs, and shrubs is apparent throughout the areas where diet has been studied.

Of the studies of food habits of *D. ordii,* ours has shown the greatest frequency (140 of 384 animals) of consumption of arthropods. Our finding that the number of arthropods consumed during spring and summer is significantly higher than during autumn and winter indicates that *D. ordii* in our study area readily consumes arthropods when they are available.

There also are considerable differences between our findings and those from studies that examined cheekpouch contents. Cheekpouch contents generally indicate high consumption of seeds, and other things (e.g., sand and sticks) often are carried in cheekpouches (but not necessarily consumed; Trowbridge and Whitaker, 1940; Best and Hoditschek, 1982). Few arthropods have been found in cheekpouches. However, arthropods have a tendency to escape when placed in cheekpouches, so data from stomach contents are more reliable than data from cheekpouch contents for determining how frequently arthropods are consumed. In addition to differences between what may be found in stomachs and what may be found in cheekpouches (Reichman, 1975), it seems that cheekpouch contents do not reflect the large numbers of arthropods consumed by *D. ordii.* Because our data are not an estimate of biomass consumed, we can only state that arthropods were present in stomachs of 140 of 384 *D. ordii.* However, this frequency is similar to that observed for the three other most frequently encountered food items (*T. purpurea, P. glandulosa,* and *Euphorbia*), so arthropods are an important source of food for this species in southeastern New Mexico.

For *O. leucogaster,* arthropods were the most frequently consumed food item (Table 1). As with *D. ordii,* food items consumed by *O. leucogaster* in our study differ from those found in other studies. Food items found in previous studies mainly include insects and other invertebrates, but also some rodents and vegetable matter; mostly seeds of grasses and cultivated grain (Bailey, 1905, 1931; Bailey and Sperry, 1929; Johnson, 1961). The presence of vertebrate tissues has been recorded in many studies (e.g., Bailey, 1905, 1931; Bailey and Sperry, 1929; Johnson, 1961; Flake, 1973; Davis, 1978). We did not recover flesh or hair of mammals or evidence of consumption of other vertebrates from the stomachs we examined. However, we often found partially consumed bodies of *D. ordii* and *O. leucogaster* in our kill-traps that may have been eaten by *O. leucogaster.*

Plants of various species also were used as a source of food by *O. leucogaster* in southeastern New Mexico, especially during autumn, winter, and spring. The average percent volume of arthropods was lowest for *O. leucogaster* during winter, indicating that this species probably consumes more plant material as arthropods become less abundant. Percent volume of plant matter consumed by *O. leucogaster* ranged from 11–12% in previous studies (Bailey and Sperry, 1929; Hansen, 1975). However, Hansen (1975) concluded that the 12% occurrence of plant material in stomachs of 136 *O. leucogaster* he examined was from material contained in digestive tracts of arthropods. Considering the low frequency of plant items in the diet of *O. leucogaster,* it is possible that some of the plant material we observed was from digestive tracts of arthropods; however, we found only plant matter in some stomachs, so these individuals must have consumed some plant material.

The primary food items in the diet of *N. micropus* were plant fibers, new dicot growth, Graminae, and *P. glandulosa.* Other studies have shown that *N. micropus* consumes fruits, seeds and green vegetation, but the exact species composition of foods varies among studies in different areas (Bailey, 1905, 1931; Finley, 1958; Box, 1959; Wood, 1969; Bee et al., 1981). In South Texas, berries of *Berberis trifoliata* and *Celtis pallida* were found in dens, *Opuntia* fruits were carried to dens, and *Opuntia* seeds were present in feces (Box, 1959). In Texas and New Mexico, foods of *N. micropus* consisted of a great variety of green vegetation, especially the juicy flesh of cactus, but mainly of seeds, nuts, and fruit. Cactus fruit and pods of mesquite beans were extensively eaten; also acorns, nuts, and any kind of grain (Bailey, 1905, 1931). In southern New Mexico, *N. micropus* consumed green vegetation, *Opuntia* pods, *Yucca* flowers, leaves, and culms, composite heads, *Ephedra,* and Lepidoptera larvae (Wood, 1969).

Because plant fibers we found in stomachs of *N. micropus* were only strands of plant tissue, it was not possible for us to identify them more precisely. However, the close association of dens with *Prosopis* and the gnawed bark on the branches of this shrub lead us to believe that most plant fibers were from *P. glandulosa.* Two other food items listed that possess long string-like fibers are *Y. campestris* and *Q. havardii*; however, we rarely observed evidence (i.e., gnaw marks on stems) that *Neotoma* were harvesting fibrous material from these species. Finally, *Opuntia* could have yielded these fibers. *Opuntia* is not common on the study area; however, when present it frequently showed evidence of gnawing by *Neotoma*. The majority of fibers most likely came from a combination of *Opuntia* and *Prosopis*.

Spermophilus spilosoma primarily consumed Arthropoda, new dicot growth, Graminae, *Croton*, and *P. glandulosa* (Table 1). Previous studies have found that *S. spilosoma* consumes a variety of foods, including insects, green vegetation, seeds, and fruits (Bailey, 1905, 1931; Sumrell, 1949; Wood, 1969; Bee et al., 1981). In southern New Mexico, *S. spilosoma* consumed insects, plant material, and vertebrates (Wood, 1969). Near Albuquerque, New Mexico, it ate (in decreasing order of importance) *Salsola pestifer, Tribulis terrestris, Oryzopsis hymenoides, Cucurbita foetitissima, Thelesperma megapotamicum, Eriogonum, Sporobolus contractus,* and *Echinocactus papyracanthus* (Sumrell, 1949). Because this species hibernates, it is active only when foods are relatively abundant. Its primary food items (i.e., arthropods, seeds, and green vegetation) are most accessible during spring, summer, and autumn.

Sexual Variation—Analysis of variance between sexes of *D. ordii* (Table 2) revealed only two food items that showed differences. More *Sporobolus cryptandrus* was consumed by females ($n = 15$, $\bar{X} = 12.2$, $SD = 10.8$) than by males ($n = 1$, $\bar{X} = 10.0$). Because only one male contained *S. cryptandrus* and its value was well within the range for females, this difference is not statistically valid. However, more *Sphaeralcea* apparently was consumed by males ($n = 21$, $\bar{X} = 14.1$, $SD = 10.0$) than by females ($n = 11$, $\bar{X} = 8.9$, $SD = 7.0$). No previous studies have examined sexual variation in the diet of *D. ordii*. Considering the number of characters examined by the same type of statistical test, it was not surprising to find a few statistically significant differences among food items (possibly due to chance alone). Essentially, there is no difference between diets of male and female *D. ordii*.

Similar comparisons between sexes of *O. leucogaster* (Table 3) revealed that only *Sphaeralcea* differed; females consumed more of this food item ($n = 3$, $\bar{X} = 7.0$, $SD = 3.6$) than males ($n = 1$, $\bar{X} = 2.0$). Again, the small sample of males indicates this is not a valid statistical difference. Like *D. ordii*, there essentially is no difference between diets of males and females of *O. leucogaster*. Previously, Jahoda (1970) found there was no sexual variation in diet of *O. leucogaster*.

Seasonal Variation—For *D. ordii* 35 of 55 food items differed significantly among seasons (Table 2). The largest *F*-ratios were for *T. purpurea*, Arthropoda, *Bouteloua, Aristida,* and *Euphorbia*. More individuals of *D. ordii* consumed *T. purpurea* during autumn and winter than in spring and summer. Arthropods were consumed most commonly during spring and summer, when they are more abundant. *Bouteloua* mainly was consumed in winter, and not consumed at all during spring. More individuals consumed *Aristida* during summer, with few consuming it during spring or autumn. *Euphorbia* mainly was consumed during summer, although a large numbers of individuals consumed it during all seasons.

Nine of the 35 items that had significant seasonal variation appeared to be consumed mainly during the season the majority of seeds were produced. Most plants in this area flower and set seed during summer and autumn, and for these nine species, consumption by *D. ordii* reflects this pattern. Many other species that showed significant seasonal variation in consumption mainly were consumed during winter and spring. Because most plants flower during summer and autumn, winter and spring are the seasons of lowest abundance of seeds. Because seeds are less abundant during these seasons, seeds that are consumed may be from the species that *D. ordii* prefers least. Because we do not have data on abundance of seeds, and because *D. ordii* is known to cache seeds for use at a later time, we cannot show conclusively that these trends reflect preference. However, the striking pattern of some seeds being consumed more frequently during the season of greatest production seems likely to reflect a preference by *D. ordii*.

Previous studies of *D. ordii* also indicate seasonal variation in diet; for example, in Colorado, the percent volume of animal matter ranged from 1 to 10% (Flake, 1973). In that study, percent volumes of plant matter for sample periods were: May–June, 93; July–August, 99; September–October, 98; November–December, 98; January–February, 92; March–April, 90 (Flake, 1973). In westcentral Texas, insects and other arthro-

TABLE 2—*F*-ratios resulting from single-classification analysis of variance between sexes and years and among seasons and months for food items consumed by *Dipodomys ordii* in southeastern New Mexico (* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$). Food item numbers correspond to those listed in Table 1.

Food item	Sexes	Seasons	Years				Months
			Autumn	Winter	Spring	Summer	
2	1.00	0.91	—	—	0.37	—	0.67
3	0.01	3.66**	1.69	0.81	21.48***	0.41	6.05***
4	0.50	4.07**	1.85	—	—	—	3.54***
5	0.16	2.27	—	—	8.59**	1.52	7.70***
6	1.00	0.87	—	—	—	2.45	1.67*
7	1.28	1.02	6.25**	—	0.75	0.04	1.20
8	3.00	4.37**	4.11*	11.47***	4.30*	0.83	5.25***
9	2.59	3.03*	2.57	5.09*	0.37	—	1.71*
10	2.01	1.76	—	—	—	0.83	0.62
11	1.73	5.56***	20.29***	—	—	14.75***	24.45***
12	0.10	6.35***	—	1.41	2.72	—	4.31***
13	0.01	3.76**	—	21.86***	10.64**	—	5.91***
14	0.19	0.53	2.18	0.33	0.72	1.46	1.69*
15	0.23	13.31***	13.58***	0.82	9.60**	2.75	12.05***
16	0.18	24.23***	31.27***	5.93*	0.53	11.56***	20.07***
17	1.00	0.87	—	—	—	2.45	1.87**
18	0.64	1.51	—	—	0.95	1.17	1.64*
19	0.24	5.63***	0.09	1.29	3.58	0.57	7.63***
20	0.11	25.06***	0.18	1.72	0.37	0.00	11.65***
21	0.04	28.58***	3.03	0.23	—	0.83	16.51***
22	0.28	7.29***	4.77*	2.16	2.48	0.00	3.35***
23	1.46	1.81	—	—	5.58*	—	3.94***
24	1.10	3.69**	—	0.17	—	1.96	3.39***
25	0.59	7.49***	25.33***	—	2.85	1.81	21.85***
26	7.88**	1.82	0.11	1.19	3.43	—	1.84**
27	1.45	45.57***	28.54***	4.19	3.09	1.37	21.56***
28	0.39	3.37*	1.44	0.17	—	14.44***	3.58***
29	1.46	2.22	—	—	2.72	6.74**	5.15***
30	0.84	12.03***	0.39	1.15	0.68	7.64**	8.84***
31	1.00	0.87	—	—	—	0.41	0.67
32	1.97	3.04*	—	0.33	—	—	4.09***
33	0.33	17.35***	9.42**	0.18	3.73	13.91***	22.78***
34	0.03	16.60***	—	—	—	4.89*	19.20***
35	0.70	5.97***	—	—	0.86	—	4.11***
36	5.56*	1.89	0.57	—	2.04	1.62	1.63*
37	0.05	4.46**	1.07	0.57	—	—	2.43***
38	0.55	20.33***	3.33	0.25	8.83**	0.33	14.91***
39	0.05	3.98**	10.90***	0.31	1.98	2.82	5.58***
40	1.34	4.30**	—	—	1.78	—	3.60***
41	2.54	2.32	—	—	3.17	—	3.35***
42	1.73	11.41***	2.57	—	—	0.18	6.64***
43	0.30	5.90***	13.06***	2.05	1.39	4.40*	4.27***
44	0.50	19.92***	—	—	8.81**	—	32.87***
45	2.80	2.57*	—	—	1.06	—	2.01**
46	1.23	0.53	1.45	3.54	9.20**	24.46***	3.26***
48	0.79	4.53**	—	—	3.48	2.84	3.35***
49	0.75	7.96***	—	—	0.68	4.04*	4.96***
50	1.00	0.87	—	—	—	0.41	0.67
52	2.97	2.62*	8.11**	—	—	—	4.82***
53	1.00	0.87	2.57	—	—	—	1.39

TABLE 2—Continued.

Food item	Sexes	Seasons	Years				Months
			Autumn	Winter	Spring	Summer	
54	1.00	1.53	—	6.37**	—		1.87**
55	0.66	5.01**	2.57	0.71	3.95*	2.14	2.98***
56	2.36	1.78	2.98	0.17	13.32***	4.82*	2.85***
57	0.04	1.87	9.37**	0.21	—	14.01***	2.97***
58	0.14	31.82***	1.26	0.48	15.98***	15.53***	11.55***

pods comprised 8% of the winter diet and 18% of the spring diet (Alcoze and Zimmerman, 1973). The higher incidence of arthropods during some periods probably reflects the greater availability of arthropods during spring and summer, and the abundance of seeds during autumn.

Onychomys leucogaster (Table 3) exhibited significant differences among seasons for 8 of 30 food items. Largest *F*-ratios were for *T. purpurea*, new dicot growth, Arthropoda, and *Euphorbia*. Arthropods were an important part of the diet of this species during all seasons. During winter,

TABLE 3—*F*-ratios resulting from single-classification analysis of variance between sexes and years and among seasons and months for food items consumed by *Onychomys leucogaster* in southeastern New Mexico ($^{*} P \leq 0.05$, $^{**} P \leq 0.01$, $^{***} P \leq 0.001$). Food item numbers correspond to those listed in Table 1.

Food item	Sexes	Seasons	Years				Months
			Autumn	Winter	Spring	Summer	
11	1.12	1.07	1.74	—	1.16	2.12	1.69*
12	0.18	1.32	1.76	—	—	—	1.97**
13	0.59	1.40	—	0.36	—	—	2.07**
14	0.40	0.83	1.17	—	—	0.48	1.00
15	1.40	1.39	2.18	0.36	1.16	0.48	1.96*
16	0.47	7.07***	0.22	1.64	0.86	0.00	4.40***
18	1.55	0.67	1.17	—	1.79	2.12	1.25
19	2.67	1.99	1.17	—	0.17	0.15	1.68*
20	1.71	1.40	—	0.36	—	—	0.89
21	0.03	3.45*	—	0.91	—	—	1.49
25	1.71	0.89	1.17	—	—	—	1.01
26	0.14	2.87*	—	0.54	—	—	0.76
27	2.03	11.21***	0.24	2.64	1.40	—	5.33***
28	1.20	1.15	—	6.27*	1.36	—	1.32
30	0.14	0.81	1.17	0.36	—	—	1.46
33	1.16	5.31**	0.85	0.22	0.05	2.73	4.09***
34	0.79	1.42	—	—	—	0.65	1.11
36	3.87*	2.26	—	—	1.16	0.33	1.18
38	0.11	2.54	2.90	—	0.86	—	3.56***
42	1.71	0.80	—	—	1.16	—	1.65*
43	0.16	3.41*	6.63**	1.44	1.16	1.30	1.02
44	3.33	1.74	2.35	—	—	—	2.20**
47	2.23	0.83	—	—	1.60	0.48	0.81
48	0.91	0.85	—	—	0.86	0.48	0.87
49	1.06	1.93	—	—	—	0.88	0.78
51	0.14	1.81	2.45	—	—	—	2.01**
55	0.05	7.98***	1.78	—	0.61	4.27*	13.89***
56	1.92	0.37	0.90	0.72	1.02	2.12	0.80
57	0.94	1.14	0.85	0.36	—	—	0.74
58	0.96	7.72***	1.20	3.22	1.13	8.72**	5.26***

arthropods were consumed at a lower frequency, probably reflecting the lower abundance during this season. More *O. leucogaster* consumed new dicot growth during summer and autumn, probably reflecting the greater availability of green vegetation during the rainy season. For most species of plants that *O. leucogaster* consumed as seeds, their consumption increased during autumn and winter. This likely reflects decreasing abundance and activity of arthropods during autumn and winter, causing these rodents to increase consumption of seeds. All species that *O. leucogaster* consumed frequently during winter, flower during summer and autumn. Seeds from these species would be available during autumn and winter, but probably not at their greatest abundance. The one exception to this pattern is *P. glandulosa*. This species was consumed frequently during summer. In our study area, *P. glandulosa* flowers from May until August, and the season of greatest seed abundance should be summer. Increase in consumption of seeds by *O. leucogaster* may reflect the increase in abundance, or it may reflect a preference for seeds of *P. glandulosa*.

Jahoda (1970) reported a seasonal change in diet of *O. leucogaster* in the laboratory; with onset of cold weather, the regular diet of seeds and red meat shifted to beef fat. In Colorado, the largest percentage of animal matter was found in the diet in late spring and early summer and the lowest level in mid-winter, with a range of 62 to 86%. Vertebrate remains were most common from mid-autumn through mid-winter and likely increased in importance with the decrease in availability of many arthropods. Adult Coleoptera were in highest concentration in the diet from mid-summer through mid-winter and in least amounts in spring and early summer, whereas larvae of Lepidoptera and Coleoptera were most frequent in late spring and early summer. Grasshoppers were in the diet in substantial numbers throughout the year, increasing through summer and peaking in autumn, in concordance with a general increase of grasshoppers in the Colorado study area (Flake, 1973). Differences in seasonal changes between Colorado and southern New Mexico probably reflect differences in availability of different items. Arthropods probably remain more abundant throughout winter in southern New Mexico than in Colorado, and consequently, our data show less of a shift in diet. Bailey and Sperry (1929) noted that the frequency of seeds in the diet increased from autumn through mid-winter, probably in response to lower populations of arthropods. Shrubs were more abundant in their sample from March and April than during other periods.

Annual Variation—Annual variation in diets of *D. ordii* and *O. leucogaster* previously has not been examined. However, considering that there is annual variation in diets of other vertebrates in our study area (Best and Gennaro, 1984, 1985; Best and Smartt, 1985, 1986), annual differences in food items consumed were expected. There were significant changes in food items consumed during the same season between years for *D. ordii* (Table 2). Of the 55 food items, 29 exhibited statistically significant differences between years for one or more seasons. Largest *F*-ratios were between autumn samples for *Euphorbia, T. purpurea, Paspalum setaceum,* and *Helianthus petiolaris,* between winter samples for *Gutierrezia sarothrae,* between spring samples of *Amaranthus alba,* and between summer samples of Unknown 59. These differences most likely reflect environmental variation among years. Environmental variation also has been shown to influence reproduction by *D. ordii* in this area (Best and Hoditschek, 1986). For example, rainfall may affect reproductive activity through diet, a point that has received considerable attention in other studies (Beatley, 1969, 1976; Reichman and Van De Graaff, 1975).

Although annual variation in diet also is present for *O. leucogaster,* differences between years were not as pronounced (Table 3). Only four significant differences occurred between years: between autumn samples for Unknown 3; between winter samples for *Phacelia corrugata*; between summer samples for new dicot growth; between summer samples for Arthropoda. *O. leucogaster* relies heavily on arthropods throughout the year. Arthropods are the predominant food item and the average percent volume and frequency of consumption do not vary much among seasons, and this lack of annual variation probably is a reflection of the large amount of arthropods consumed. If we had been able to identify arthropods to order or family, we may have found more variation within *O. leucogaster,* because types of arthropods that are available during different seasons and different years varies.

Monthly Variation—Variation among months in diet of *D. ordii* was highly significant for most food items (Table 2). Of the 55 food items, 49 exhibited significant differences among months.

TABLE 4—Classification table resulting from discriminant function analysis of diets among four species of rodents in southeastern New Mexico.

		Predicted group membership			
Actual group	*n*	*D. ordii*	*O. leucogaster*	*N. micropus*	*S. spilosoma*
D. ordii	384	329 (85.7%)	13 (3.4%)	6 (1.6%)	36 (9.4%)
O. leucogaster	190	15 (7.9%)	159 (83.7%)	5 (2.6%)	11 (5.8%)
N. micropus	66	2 (3.0%)	2 (3.0%)	55 (83.3%)	7 (10.6%)
S. spilosoma	70	9 (12.9%)	12 (17.1%)	4 (5.7%)	45 (64.3%)

Largest *F*-ratios were for Unknown 6, *H. petiolaris, P. glandulosa, P. setaceum, T. purpurea,* and *Euphorbia.* Though not as numerous, differences also existed among months for *O. leucogaster* (Table 3); 14 of 30 food items were significantly different. Largest *F*-ratios were for new dicot growth, *T. purpurea,* and Arthropoda. Changes in diet from month to month for *D. ordii* and *O. leucogaster* most likely reflect changes in availability, and were responsible for shifts among seasons and between years.

Interspecific Relationships—Examination of variation in diet among species revealed that 27 of the 58 food items differed significantly (Table 1). Largest *F*-ratios were for Arthropoda, plant fibers, *T. purpurea,* new dicot growth, and Gramineae. Discriminant function analysis (Table 4) produced a classification that correctly placed 64–86% of individuals in their respective species. More than 80% of *D. ordii, O. leucogaster,* and *N. micropus* were correctly classified. Most misclassified specimens of *D. ordii* and *N. micropus* were placed with *S. spilosoma.* For *O. leucogaster,* the greatest percentage of misclassified individuals were placed with *D. ordii* and the next highest percentage was placed with *S. spilosoma.* Only 64% of *S. spilosoma* were correctly classified. Of the misclassified individuals, most were placed with *O. leucogaster* and *D. ordii.* These misclassifications mainly reflect the fact that *S. spilosoma* eats a wide variety of food, ranging from arthropods to green vegetation to seeds. Diets of the other three species have been categorized as follows: *D. ordii* mainly consumes seeds and fruits; *O. leucogaster* mainly consumes arthropods; *N. micropus* mainly consumes green vegetation. Because *S. spilosoma* consumes all of these in fairly equal proportions, it is not surprising that many individuals of this species would be misclassified as one of the other three species. Those individuals of *D. ordii, O. leucogaster,* and *N. micropus* that were misclassified as *S. spilosoma* were most likely the few individuals that had a variety of items in their stomachs.

Though differences in diet among the four species we studied have not previously been examined, Rebar and Conley (1983) did examine the interactions in microhabitat use between *D. ordii* and *O. leucogaster* in southern New Mexico. They found a shift in habitat by *D. ordii*; however, they could not determine the cause of the shift. Because interactions between these species may be as competitors or as predator-prey, diet may or may not play a role in their cohabitation of desert ecosystems. While both species rely heavily upon arthropods, it is clear that *D. ordii* consumes a wide variety of plant material. Thus, while arthropods are an overlapping component of the diet, it is likely that arthropods are not in short supply through the portions of the year that both rodent species consume them. Considering the aggressive nature of *O. leucogaster* (Bailey and Sperry, 1929), *D. ordii* may avoid contact when possible (Rebar and Conley, 1983).

Like *D. ordii* and *O. leucogaster, N. micropus* is active throughout the year. However, its selection of food items scarcely overlaps these species. The greatest potential for interspecific competition between *S. spilosoma* and the other three rodent species occurs in late winter or early spring when it first emerges from hibernation. However, because it is not active throughout the year, its interactions with the other three species when food supplies are most limited is reduced. The usual abundance of new dicot growth, grasses, and arthropods during spring and summer when *S. spilosoma* is most active probably reduces any interspecific competition for food.

Sample Size—Figure 1 depicts the effect of sample size on ascertaining the number of different kinds of food items consumed. Data for *D. ordii* indicate that about 60 specimens are required to recover 47 of the 55 (85%) kinds of food items; examination of about 300 specimens would

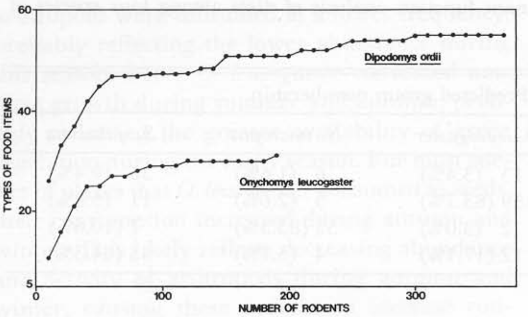

FIG. 1—Number of types of food items recovered from samples of various sizes for *Dipodomys ordii* and *Onychomys leucogaster*.

be required to obtain all 55 items. Data for *O. leucogaster* indicate that approximately 60 specimens are required to recover 27 of the 30 (90%) kinds of food items; approximately 190 specimens would be required to obtain all 30 items.

Our calculation that about 60 randomly selected specimens are required to determine the number of kinds of food items consumed may be of interest in determining the sampling effort and techniques that would be most useful in future studies. While our data primarily are useful in determining kinds of food items, similar sampling also may yield estimates of volume of items consumed. However, these calculations do not take into account the seasonal variation that we found. For example, *Froelichia* was eaten only during autumn by *D. ordii*. A study that examined animals only during spring or summer probably would not record consumption of this food species, and probably would find less variation in diet than we did. Several other species of plant seeds show similar variation, being eaten only during one or two seasons, and not consumed at all during the others. Considering the numbers of trap-nights, person hours, and sacrifice of specimens that are required for a study such as ours, it would be useful to know the minimum effort required to get maximum results.

Dipodomys ordii, *N. micropus*, *O. leucogaster*, and *S. spilosoma* are divergent in most foods they consume. All of these species occur throughout our study area; however, they are separated by behavioral and microhabitat differences (e.g., the association of *N. micropus* with clumps of *P. glandulosa*), by time of activity (e.g., *S. spilosoma* hibernates and is diurnal and the other species are active year round and are nocturnal), and by diet (Table 1). Whether this separation is the result of competition or differences in physiological, dietary, or habitat requirements is not clear.

The large seasonal and annual differences found in this study reflect the changing abundance of plant species from month to month. Short-term studies that collect animals for only one or two months of the year cannot discover this type of variation. These differences are important and their elucidation may help determine the potential for competition for a given resource among different species at a given time.

This project was partially funded as a portion of the Los Medaños Waste Isolation Pilot Plant studies by Sandia National Laboratories (Contract 13-2097) and Westinghouse Electric Corp. (Subcontract WFC-53431-SD). L. K. Hawkins, N. R. Holler, R. S. Lishak, O. P. Pearson, L. C. Wit, and an anonymous reviewer critically reviewed early drafts of the manuscript. This is journal article no. 15-913120 of the Alabama Agricultural Experiment Station.

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