The University of Manitoba

Population, distribution, habitat use and natural history of Ord's kangaroo rat (*Dipodomys ordi*) in the sand hill areas of south-western Saskatchewan and south-eastern Alberta.

by

© Raymond J. L. Kenny

A thesis

submitted to the Faculty of Graduate Studies

in partial fulfillment of the requirements for the degreee

of Master of Science.

Zoology Department

Winnipeg, Manitoba

March 1989

ISBN 0-315-51681-X

POPULATION, DISTRIBUTION, HABITAT USE AND NATURAL HISTORY OF ORD'S KANGAROO RAT (**Dipodomys ordi**) IN THE SAND HILL AREAS OF SOUTH-WESTERN SASKATCHEWAN AND SOUTH-EASTERN ALBERTA

BY

RAYMOND J.L. KENNY

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

Acknowledgements

I express my deepest gratitude to my suervisor, Prof. Roderick R. Riewe who provided helpful advise and encouragement for the competion of this thesis.

Thanks are due to Ernie, Velma and Bill Howes, Pete and Josie Fitterer, Gerald and Lidia Grop, Alec an Charlie Watson and many others who provided logistic and moral support during my stay in southern Saskatchewan. Because of them my field studies were a much more pleasant experience.

I would like to thank Cindy Birdwise and Lynne Bergeron who provided valuable field assistance.

Special thanks are due to the late Dr. Josephine Rauch who initiated this project and without whom none of it would have been possible, and to Sue Kenny who put up with my stress and provided moral support during the final stages of the thesis.

Thanks!

TABLE OF CONTENTS

TABLE OF CONTENTS

CHAPTER TITLE **PAGE NUMBER**

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE NUMBER AND TITLE **PAGE**

Population, Distribution, Habitat Use and Natural History of Ord's Kangaroo Rat (Dipodomys ordi) in the Sand Hills of South-western Saskatchewan and South-eastern Alberta.

Abstract:

Ord's kangaroo rat (*Dipodomys ordi*) is a small, bipedal, nocturnal, granivorous rodent inhabiting the arid regions of western North America from Mexico to the northern United States with a small isolated population in the sand hill areas of south-western Saskatchewan and south-eastern Alberta. Little is known about the biology of the Canadian population. A mark-recapture study of this species was undertaken to determine the natural history, habitat use, distribution, and population as well as the activity relative to climatic conditions of this species in Canada.

A total of 15,078 trap-nights over two seasons captured 110 adult and 40 juvenile kangaroo rats. Habitat use was limited to active complexes (i.e. sand dunes and blow-outs) within the sand hill areas of Saskatchewan and Alberta, but habitat use of an active complex did not differ significantly from random. The natural history was similar to that of southern populations except that the reproductive rate was lower due to drought conditions. Distribution was limited to the sand-hill areas between Swift Current, Saskatchewan and Dinosaur Provincial Park, Alberta, south of the South Saskatchewan River. The total population and upper and lower confidence limits were estimated at 55.3 (49.9, 61.4), 81.5 (73.5, 90.4) and 1233.7 (992.8, 1533.0) kangaroo rats for the Cramersburg Hills, Burstall Hills and Great Sand Hills respectively. No above-ground activity was recorded during the winter of 1984/1985 and circumstantial evidence suggests that this population may be able to use torpor and/or hibernation during extended periods of inclement weather.

Management recommendations are discussed.

CHAPTER 1: INTRODUCTION

Introduction

Ord's kangaroo rat (*Dipoodomys ordi*) inhabits dry areas of western North America from Mexico to the northern United States, with an isolated population in the sandhill areas of southwestern Saskatchewan and southeastern Alberta (Anderson 1946, Kennedy and Schnell 1978, Nero 1956, Nero and Fyfe 1956, Smith 1972, Smith and Hampson 1969, Soper 1964, Stevens 1972). The population in Canada is at the northern limit of this species' distribution (Kennedy and Schnell 1978) and has probably been isolated from its southern kin since the end of the post-Wisconsinian hypsithermal interval, some 4,000 to 6,000 years B.P. (David 1971).

Many aspects of *Dipodomys* biology have been extensively studied in the western United States where they are an important part of the small mammal fauna (Hafner and Hafner 1983, MacMillen 1983, Mares 1983, Nikolai and Bramble 1983, Price and Brown 1983, Reichman 1981, 1983), but the biology of the population in Canada is little known (Erickson pers. com. 1986, Nero and Fyfe 1956, Soper 1964). There is a need for population estimates and for information pertaining to the distribution and general natural history of this potentially rare species in Canada.

In this regard a mark-recapture study of *D. ordi* was begun in May, 1984, in an effort to estimate total population, reproductive potential, habitat selection, overwinter survival and distribution of this species in Canada. In conjunction with the population study, surface activity of kangaroo rats relative to climatic conditions as well as soil temperature at various depths was monitored to determine if activity in this population differs from activity in more southern populations.

Kangaroo rat biology and natural history

Heteromyidae is an exclusively new world family comprising five genera (*Dipodomys, Heteromys, Perognathus, Liomys,* and *Microdipodops*) (Banfield 1981). All are nocturnal and fossorial. The genus *Dipodomys* has existed since the late Miocene, some 13 million years B.P. The 24 currrently recognized *Dipodomys* species closely resemble one another ecologically as well as genetically (Hafner and Hafner 1983). Ord's kangaroo rat (*D. ordi*) is the most widely distributed *Diopodomys* species and the only member of the genus found in Canada (Banfield 1981, Kennedy and Schnell 1978).

Ord's kangaroo rat has long strong hind legs (hind foot 43 mm), small delicate forelegs, a large robust neck and body. The tail (155 mm) is longer than the body (118 mm) and terminates in a furry tuft (Banfield 1981, Burt and Grossenheider 1976, Soper 1964). They have fur lined cheek pouches which open externally on either side of the mouth (Soper 1964, Thompson 1982a). They are light sand brown dorsally with white underparts (Banfield 1981, Burt and Grossenheider 1976, Soper 1964).

Reproduction can occur in any month but normally occurs after spring runoff or after heavy summer rains (Beatley 1969, 1976a, Butterworth 1961, Chew 1958, Daly *et al.* 1984, Hoditschek and Best 1983, VanDeGraff and Balda 1973). Litter size is normally from two to four (Hoditschek and Best 1983, Packard 1941). Life expectancy is up to 7.5 years in captivity but probably shorter in the wild (Day *et al.* 1956, Egoscue *et al.* 1970).

Kangaroo rats dig elaborate burrows up to two meters deep which contain several nest chambers and food caches at several depths (Hawbrecker 1940, Soper 1964, Stevens 1972). Ord's kangaroo rat is aggressively solitary and defends its burrow and home range against all competitors (Banfield 1981, Bartholomew and Caswell 1951, Daly *et al.* 1984, Rauch pers. com.).

Ord's kangaroo rats are central place foragers as described in Pyke *et al.* (1977). They leave their burrows (central place) to forage, gather seeds in their cheek pouches and return to their burrows to eat or cache the seeds. They eat very little outside the burrow (Kenagy 1973b, Stamp and Ohmart 1978). Kangaroo rats can carry more than one day's food supply in one full cheek pouch load (Morton *et al.* 1980). They forage efficiently and can normally meet their nutritional needs with as little as one hour foraging per night (Alcoze and Zimmerman 1973, Behrends *et al.* 1986a, Bowers 1986, Brown 1973, Brown and Lieberman 1973, Brown and Munger 1985, Flake 1973, Grant and Birney 1979, Kenagy 1973a,b, Lawhon and Hafner 1981, Mares 1983, McClenaghan 1983, M'Closkey 1980, 1981, Price 1978a, b, Price and Brown 1983, Rebar and Reichman 1983, Reichman 1977, 1981, Reichman and Oberstein 1977, Rosenzweig 1973, Rosenzweig and Winakur 1969, Schreiber 1979, Smigel and Rosenzweig 1974, Stamp and Ohmart 1978, Thompson 1982b, Trombulak and Kenagy 1980).

Kangaroo rats are almost exclusively granivorous but occasionally eat green vegetation, particularly before and during the reproductive period (Alcoze and Zimmerman 1973, Beatley 1969, 1976a,b, Breyen *et al.* 1973, Brown and Lieberman 1973, Chew 1958, Csuti 1979, Daly *et al.* 1984, Eisenburg and Isaac 1963, Flake 1973, Hawbrecker 1940, Kenagy 1972, 1973b, Kenagy and Bartholomew 1985, Monson 1943, Reichman and VanDeGraaf 1975, Soholt 1977, VanDeGraaf and Balda 1973). Small depressions or other obstructions cause wind shadows which create high density patches of wind born seeds (Reichman 1981, Reichman and Oberstein 1977). Kangaroo rats locate these patches using olfactory and/or visual cues as they travel through an area (Price 1978a, Rosenzweig 1973). They forage along a circuit of sites, "trap line", between and beneath bushes but because they are bipedal kangaroo rats remain toward the edges of bushes

(Alcozeand Zimmerman 1973, Beatley 1969, 1976b). Their bipedality does not allow them to enter dense vegetation because they need to be in contact with a firm substrate.

Although bipedal hopping restricts kangaroo rats' movements in dense vegetation it confers several advantages when foraging in open habitats. Animals which hop can traval more quickly while expending less energy than equivalently sized runners but they require open habitats with smooth firm substrates (Mares 1983, Marlow 1969, Nikolai and Bramble 1983). By hopping bipedally a kangaroo rat can forage over a large area in a short time and expend relatively little energy (Thompson 1982b, Yousef *et al.* 1970). The springing action of bipedal hopping allows kangaroo rats to make high speed, erratic but controlled manoeuvres which allow them to escape most predators while in open habitat (Bartholomew and Caswell 1951, Marlow 1969). Kangaroo rats are thus able to exploit efficiently the high density seed patches on open habitat in safety.

Like most small mammals, kangaroo rats are low on the food pyramid and are the target of many predators, but owls and snakes are their major predators (Brown *et al.* 1986, Kotler 1985, Nikolai and Bramble 1983, Soper 1964, Thompson 1982a, Webster and Webster 1971). The kangaroo rat's dorsally oriented eyes allow it to remain vigilant while foraging (Webster and Webster 1971). Kangaroo rats have huge auditory bullae which are most sensitive to the same range of frequencies as the sounds produced by owls' wings in flight or the sounds of a snake striking (300-3000 Hz) (Webster 1962). The kangaroo rats can thus detect their major predators even in complete darkness and take evasive action when necessary.

By definition water is in short supply in deserts. Kangaroo rats have evolved physiological, morphological and behavioral mechanisms for dealing with the water shortage and need never drink (MacMillen 1972, 1983, MacMillen and Hinds 1983, Scelza and Knoll 1982, Schmid 1976, Schmidt-Nielsen *et al.* 1948, 1970). Kangaroo rats have an efficient digestive system which can concentrate the faeces to 50% water. They also have the most efficient kidneys among mammals and can concentrate urine to 3.0M. NaCl (MacMillen 1972). In their respiratory tracts they have long, convoluted nasal passages which create a thermal gradient causing the air to cool as it is exhaled. As the exhaled air cools moisture condenses on the nasal passage walls. The condensation is resuspended upon the next inhalation of warm dry air and is reabsorbed in the lungs (Schmidt-Nielsen *et al.* 1970). By being nocturnal and fossorial kangaroo rats are always in a relatively cool, moist microclimate (Mullen 1971, Schmidt-Nielsen *et al.* 1948). All of these adaptations allow kangaroo rats to conserve water to such an extent that their water requirements can be met metabolically.

Study areas

The sand hill areas surveyed during this study were the Great Sand HIlls (GSH), the Burstall Hills, the Cramersburg Hills and the Westerham Hills of southwestern Saskatchewan, and the Middle Sand Hills, the Newell Lake Sand Hills and the Pakowki Lake Dunes in southeastern Alberta (Fig 1). The areas are widely spaced and isolated from one another, but because they have similar geology and climate (David 1972) they can be expected to support similar flora and fauna.

The sand hills are more or less continuous areas of surface deposits of unconsolidated sand. They contain areas of high and low relief, sand flats and high dunes. Dunes may be active but stabilized dunes predominate. There is virtually no drainage pattern as whatever precipitation occurs percolates through the sand to the water table with little if any surface runoff. (Epp and Townley-Smith 1980)

The area has on average a cold semiarid steppe climate. Mean monthly temperatures range from -13.9°C in January to 18.7°C in July. The daily maxima and minima range from -8.9°C to -19.0°C in January and from 25.7°C to 11.7°C in July. The frost free period is normally from May 30

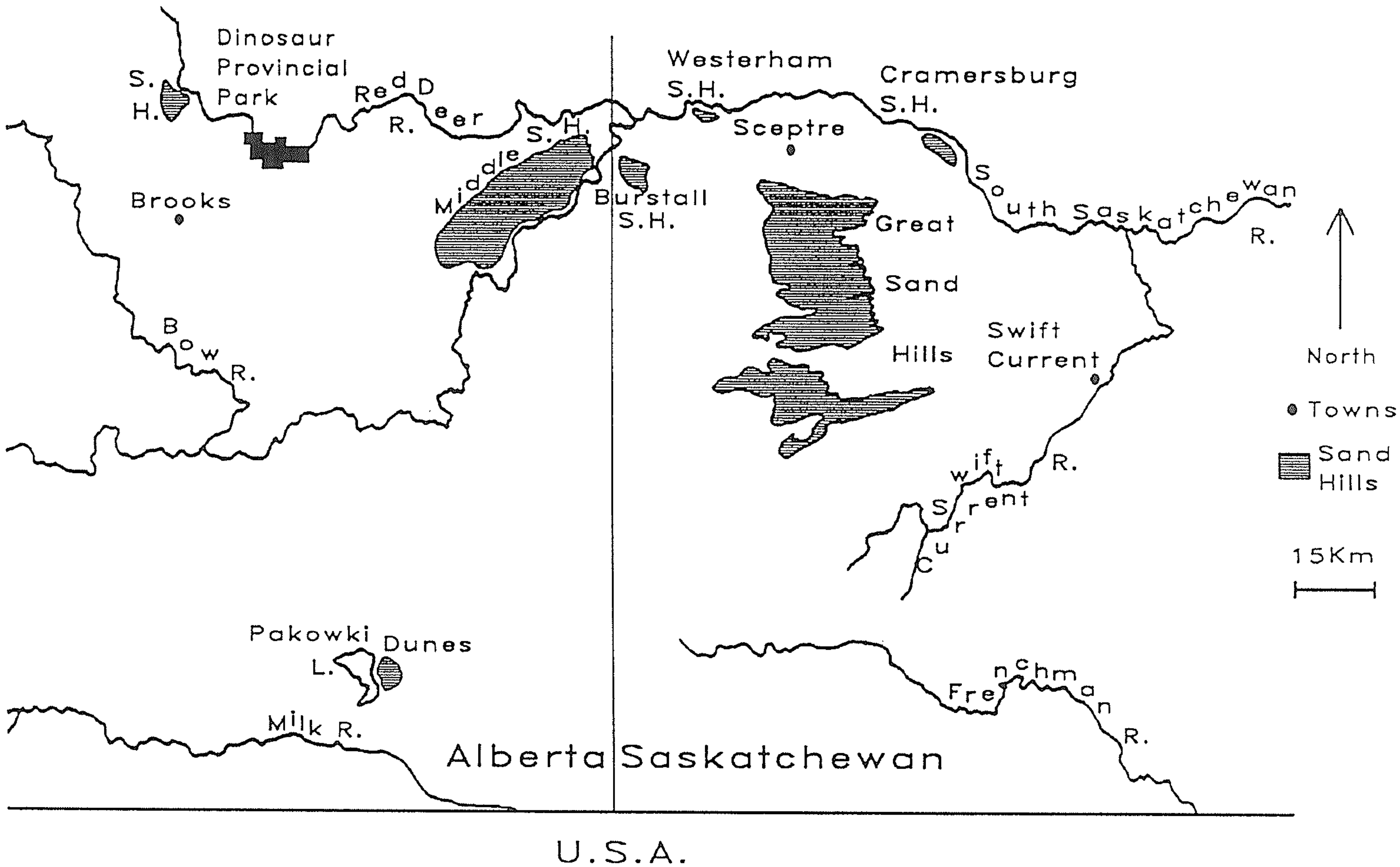

Figure 1: Map of the sand hill areas in sothwestern Saskatchewan and southeastern Alberta.

to September 22, but frost has been recorded in every month except July. (Epp and Townley-Smith 1980)

Mean wind speed ranges from 20.5 km/h in July to 26.4 km/h in January for an annual mean of 24 km/h. Winds are predominantly from the west in summer and from the north to northwest in winter. East winds are rare and usually weak. Conditions are rarely calm during the day but the air is often still after sunset (Pers. obs. 1984). The wind is often strong enough to erode the soil when it is devoid of vegetation, creating dunes and blowouts. (Epp and Townley-Smith 1980)

Mean annual precipitation is 389.9 mm of which 268.8 mm falls as snow. The area is on the eastern edge of the area affected by Chinooks so snow does not normally accumulate to any great thickness. Evapo-transpiration normally exceeds precipitation making for a semiarid climate. (Epp and Townley-Smith 1980)

Vegetation: (App. 1)

Stabilized areas support typical shortgrass prairie vegetation including native prairie grasses of several genera (*Agropogon, Andropogon, Calamagrostis, Elymus, Oryzopsis, Poa, Stipa* and others), sedges (*Carex* spp.), creeping juniper (*Juniperas horizontalis* Moench), cactus (*Opuntia fragilis* Nutt., *Mamillaria vivipera* Nutt.), chokecherry (*Prunus virginiana* L.) and several species of sage (*Artemisia* spp.). Low lying areas support clumps of aspen (*Populus trembuloides* Michx.), birch (*Betula occidentalis* Hook), alder (*Alnus rugosa* Du Roi) and willow (*Salix* spp.). (Epp and Townley-Smith 1980)

Active complexes are largely devoid of vegetation, supporting only a few coarse plants, dominated by indian rice grass (*Oryzopsis hymenoides* Roem. and Shult.) nodding wild rye

(*Elymus canadensis* L.), lance-leaved psoralea (*Psoralea lanceolata* Pursh.) and skeleton weed (*Lygodesmia juncea* Pursh.), (Epp and Townley-Smith 1980).

Vertebrates (App. 2)

The sandhill areas have remained relatively undisturbed by agriculture and are rich in wildlife. The areas have high populations of mule deer (*Odocoileus hemionus* Rafinesque), white-tailed deer (*O. virginianus* Zimmermann) and pronghorn (*Antilocapra americana* Ord). Predatory mammals such as coyotes (*Canis latrans* Say), long-tailed weasels (*Mustela freneta* Lichenstein) and american badgers (*Taxidea taxus* Schreber) are relatively common. There are huge numbers of small mammals including Nuttall's cottontail (*Sylvilagus nuttallii* Bachman), white-tailed jack rabbit (*Lepus townsendii* Bachman), thirteen-lined ground squirrel (*Spermophilus tridecemlineatus* Mitchell), northern pocket gopher (*Thomomys talpoides* Richardson), olive-backed pocket mouse (*Perognathus fasciatus* Wied-Neweed), Ord's kangaroo rat (*D. ordi* Woodhouse), deer mouse (*Peromyscus maniculatus* Wagner), red-backed vole (*Clethrionomys gapperi* Vigors), meadow vole (*Microtus pennsylvanicus* Ord) and porcupine (*Erethizon dorsatum* L.).

The large small-mammal population supports a proportionately large and diverse avian predator population including Cooper's hawk (*Accipiter cooperi* Bonaparte), red-tailed hawk (*Buteo jamaicensis* Gmelin), Swainson's hawk (*B. swainsoni* Bonaparte), ferruginus hawk (*B. regalis* Gray), golden eagle (*Aquila chrysaetos* L.), marsh hawk (*Circus cyaneus* L.) and falcons (*Falco mexicanus* Schlagel, *F. perigrin*us Tunstall, *F. columbarius* L., *F. sparverius* L.). Great horned owls (*Bubo virginianus* Gmelin) and short eared owls (*Asoi flammeus* Pontopidan) are common nocturnal avian predators. Burrowing owls (*Speotyto cunicularia* Molina) are a common site during the day.

The sandhill areas harbor a wide variety of small passerine birds as well as a few species of reptiles and amphibians.

CHAPTER 2; BODY SIZE, REPRODUCTIVE SUCCESS, OVER-WINTER SURVIVAL AND DISTRIBUTION

Materials and Methods

1984

Field studies began May 1 and continued until November 5,1984. One week field investigations were conducted in late November, December and March of 1984/1985. Field studies resumed May 14, 1985 and continued until September 5, 1985. A total of 15,078 trap nights were performed over the two years.

Transects of 100 Sherman live traps spaced 15m apart were set each night from May 1 to May 10, 1984 to determine which habitat types were being used by kangaroo rats in the GSH. Traps were baited with raw sunflower seeds and checked at two hour intervals from dusk untill dawn.

Results from the transects indicated that kangaroo rats preferred active sand dune habitats. Four active sand dunes were selected to represent the range of dune size in the GSH, proximity to other dunes and to allow vehicle access. The dunes were named for easy reference (Fig 2).

Site descriptions

Watson:

The Watson site is located on the Watson Brothers Ranch, approximately 11 km south of Lemsford Saskatchewan in the northern part of the GSH (Fig 2). This is a relatively inactive crescent shaped dune approximately 150 m east-west by 150 m north-south, with a total area of 2.72 ha. It is surrounded by typical short grass prairie vegetation. The dune is about 1/3 open,

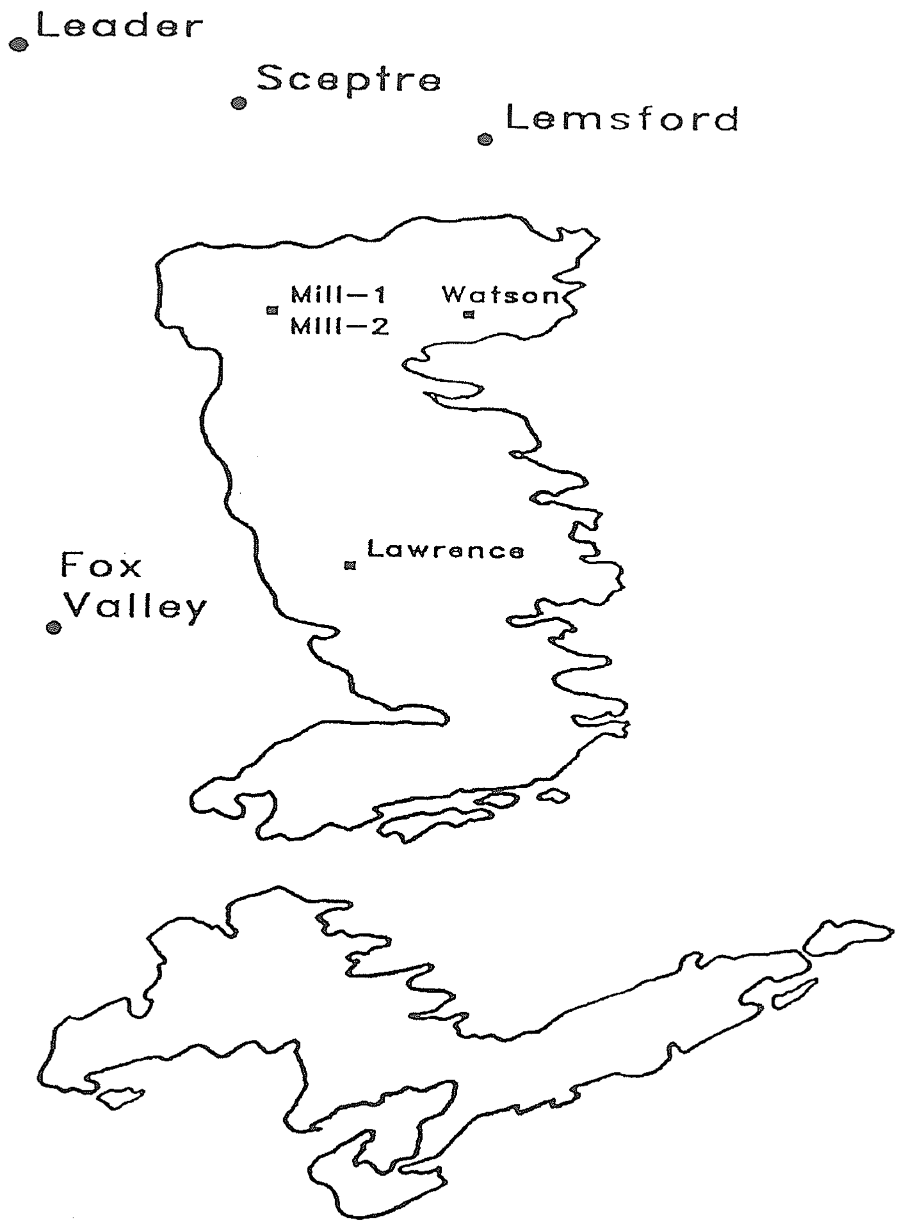

Figure 2; Location of study sites within the Great Sand Hills.

■ Study sites
● Towns
Km
0 10

North

unvegetated sand which is subject to wind erosion. The bulk of the dune is stabilized by lance-leaved psoralea, nodding wild rye, indian rice grass and on the eastern edge, hoary sage brush (*Artemisia cana* Pursh). There are two choke cherry trees on the stabilized western edge of the dune. The next nearest active complex is more than 5 km to the west. This dune was selected because it is relatively stable and isolated from other active complexes.

Mill-1 and Mill-2:

The Mill-1 and Mill-2 dunes are located on the Signal Valley Stockmans' Association land lease, 22 km south of Sceptre Saskatchewan in the north-central GSH (Fig 2). They are a pair of moderately active dunes separated by 200 m of mixed sage/wild rose/juniper brush land which is typical of the area. Both dunes are crescent shaped, approximately 150 m north-south by 150 m east-west, with total areas of 3.45 ha and 3.94 ha for Mill-1 and Mill-2 respectively.

Both dunes are about 1/2 unvegetated sand. The eastern (leeward) edges are invading the surrounding brushland, burying the vegetation. The tops of the partially buried vegetation form clumps separated by unvegetated sand. Nodding wild rye, indian rice grass, skeleton weed and other sand-tolerant vegetation is colonizing the western (windward) edges. Wolf-willow (*Elaeagnus commutata* Bernh) is colonizing the low-lying western edge of the Mill-2 site.

The heavy use of this area by cattle and deer because of the nearby water mill creates well trodden trails. These trails may facilitate inter-dune movements by kangaroo rats.

Lawrence:

The Lawrence site is located on the Yeast Ranch, 40 km east of Fox Valley Saskatchewan in the west-central part of the GSH (Fig 2). This is the largest and most active dune in the GSH. It is about 200 m east-west and about five km north-south, with a total area of 93.91 ha. The Lawrence site is almost entirely unvegetated sand with partially vegetated strips on the western and eastern edges. The partially vegetated strips are similar in width and species composition to the edges of the Mill sites but make up a relatively small area of the dune. This dune was selected because it represents the extreme in size and activity of dunes in the GSH.

Trapping

Each site was sampled for five consecutive nights once per month from May through September.

On the three smaller dunes trap grids were set to trap the entire dune effectively. Sherman live traps were set at 15 m intervals with at least one row of traps extending into the surrounding vegetated habitat on each side of the dune. Rows and columns of traps were individually numbered starting from the northeast corner of the grids.

The Lawrence site could not be completely trapped because of its size. In the first week of the 1984 season a 12 by 12 trap grid (180 m x 180 m) was set on the western side of the dune. This sampled a large area of open sand. Since personal observation and previous studies indicated that kangaroo rats preferentially use the transitional strips between dense vegetation and open sand (Price 1978b, Rosenzweig 1973, Thompson 1982a,b) it was decided that for the remainder of the study long narrow trap grids would be set on the western edge of the dune. The grid was 315 m north-south and extended onto the unvegetated sand to the east and into the dense vegetation to the west. This grid provided a subsample of the dune population from which the total population was later estimated.

Traps were baited with a mixture of raw sunflower seeds, barley, wheat, oats and rye. Kangaroo rats did not exhibit a preference for any of these grains so they were used interchangeably according to availability at the local grain elevators. Insulating material was provided in each trap.

Traps were checked at dawn on warm nights and at two hour intervals on cold or rainy nights, beginning just after sunset and continuing till dawn. Traps were closed at dawn to prevent unnecessarily capturing diurnal mammals and birds.

Trap locations were recorded for each capture using the column and row numbers of the grids. Each kangaroo rat was weighed to the nearest 0.5g using a Pesola spring scale, identified as adult or juvenile based on body weight and head size relative to body size, individually ear tagged and released.

Percent cover within 40 cm of ground level of each plant species was estimated within a three metre radius of each of the 649 trap locations and tabulated.

Climatic conditions

Air and soil temperatures were recorded to the nearest 0.5°C using a Grant temperature recorder with thermistors placed just above (2cm) the dune surface, just below (-2cm) the dune surface and at 23 cm intervals down to -230 cm below dune surface. The thermistors remained on the unvegetated sand portion of the Mill- 1 site for the entire study. Occurence and intensity of precipitation was noted, but no attempt was made to measure the amount of precipitation. The weather records from the Kindersley and Swift Current weather stations were used when an accurate measure of the amount of precipitation was needed.

1985

Site description

Field operations resumed May 14, 1985 and continued till August 21, 1985. The first four weeks were spent sampling the 1984 sites to measure overwinter survival. The remainder of the summer was spent sampling other active complexes within the GSH, Burstall Hills and Cramersburg Hills (Fig 1).

In 1985 active complexes were randomly selected from the GSH, Burstall Hills and Cramersburg Hills. All active complexes visible on high resolution 1/50,000 scale aerial photographs of these areas were individually numbered. Study sites were randomly selected from the aerial photographs using a random numbers table.

Trapping

Trap grids were set as in 1984 on the selected active complex and as many adjacent active complexes as the available number of traps would allow. Each study site was actually a group of active complexes in close proximity to one another. As in 1984, the smaller dunes were completely sampled whereas only the edges of larger active complexes were sampled. Each group of sites was sampled once before July 8 and once after July 18. Sampling sequence for both periods was randomly determined.

The last three weeks of the 1985 season were spent resampling the 1984 sites to determine the 1985 population of these sites.

A survey of other sandhill and sand dune areas in southwestern Saskatchewan and southeastern Alberta was done from July 8 to July 18 to obtain information on the total distribution of Ord's kangaroo rat in Canada. Active complexes were surveyed by searching for kangaroo rat tracks and burrows at dawn. The Westerham Hills, Middle Sand Hills, Lake Newell Sand Hills, Pakowki Lake Dunes, a series of sand hills north of Brooks and Dinosaur Provincial Park were surveyed in this manner.

RESULTS

Body size

In 1984, 54 adult kangroo rats were captured over 8588 trap nights. Fifteen, 12, 10 and 17 adult kangaroo rats were captured at the Mill-1, Mill-2, Lawrence and Watson sites respectively. Weights of adults ranged from 60g to 86.5g with a mean of 70.7g ($\hat{Var}$ = 30.07). Mean weight of adults increased linearly over the summer (β = 1.5g/month, r^2 = 0.93).

Sixteen juveniles were captured in 1984, six each from the Mill-2 and Watson sites and four from the Lawrence site. Juveniles ranged from 20g to 53g at first capture with a mean of 38.4g. The overall mean weight of juveniles increased rapidly over the summer (β = 0.44 g/day, r^2 = 0.95). The first two juveniles were captured June 11 at the Mill-2 site, with the remainder being first captured between August 2 and September 11. No new juveniles were first captured between June 11 and August 2 or after September 11.

In 1985, 56 adult kangaroo rats were captured on the 12 active complexes over 6490 trap nights. Twenty-two, 21 and 14 adult kangaroo rats were captured in the GSH, Burstall Hills and Cramersburg Hills respectively. Weights of adult kangaroo rats captured before July 8 ranged from 53.5g to 76.5g with a mean of 66.2g ($\hat{Var}$ = 39.08) while the weights of adult kangaroo rats captured after July 18 ranged from 63.5g to 87.5g with a mean of 72.1g ($\hat{Var}$ = 39.08). The mean weight of adults captured after July 18 was significantly greater than the mean weight of adults captured before July 8 (T = 1.26, df = 55). The overall mean weight of adults captured in 1985 was 68.8g (Vâr = 52.80). The mean weight of adult kangaroo rats captured in 1984 was significantly greater than the mean weight of adult kangaroo rats captured in 1985 at the 0.05 level of significance (T = 3.279, df = 97).

Twenty-four juvenile kangaroo rats were captured in 1985, 11, 10, and 3 from the Burstall Hills, Cramersburg Hills and GSH respectively. Weights of juveniles ranged from 28.5g to 66.5g with a mean of 45.7g. The first juvenile was captured June 13 and the last was captured August 25. Juveniles were first captured intermittently over the summer with an increase in frequency between August 13 and August 21 when 18 new juveniles were first captured.

Overwinter survival

Of the number of kangaroo rats captured in 1984, six, five, five and zero were recaptured on the Mill-1, Mill-2, Lawrence and Watson sites respectively in 1985. No 1984 juveniles were recaptured in 1985. Mean overwinter survival was 25.75% (Vâr = 318.92, df = 3). Of the dunes with some overwinter survival a mean of 34% (Vâr = 36.33, df = 2) survived the winter to be recaptured in 1985.

Distribution

Kangaroo rat sign was found in the GSH, Burstall Hills, Cramersburg Hills, Westerham Hills, and the Middle Sand Hills. No kangaroo rat sign was found in Dinosaur Provincial Park, the Pakowki Lake Dunes, the Lake Newell Sand Hills or the sand hills north of Brooks.

DISCUSSION

Body size

The adult kangaroo rats captured in this study were similar in weight to kangaroo rats captured in other areas of their range (Kenagy 1972, Wrigley 1986). The significant weight difference between the two years may have been due to the worsening of the drought but I have no data to support this idea.

Reproductive success

Total reproductive success was below the theoretical maximum in both summers. Duke (1940, 1944) found that 55% of the female *D. ordi* he captured in Nevada showed evidence of reproduction; with a mean of 3.6 embryos per female. Hoditschek and Best (1983) found similar results with *D. ordi* in Oklahoma but with 2.8 embryos per female. If these ratios are applied to the population in this study it becomes apparent that the reproductive success of this population was well below that reported for previous studies. Assuming a high capture success and 50% sex ratio (Jones *et al.* 1983) the expected number of juveniles should be from 42 to 52 in 1984 and from 43 to 55 in 1985, based on the adult population. From these approximations it is clear that *D. ordi* which produced only 16 and 24 juveniles in 1984 and 1985 respectively expressed less than 1/2 its reproductive potential in both years. The low reproductive success could be due to the drought.

Kangaroo rats are well adapted to life in xeric environments (Carpenter 1966, Csuti 1979, Scelza and Knoll 1982, Schmidt-Nielson *et al.* 1970) their reproductive success is influenced by environmental conditions, particularly the amount and the timing of precipitation (Beatley 1969, 1976b, Daly *et al.* 1984, Kenagy and Bartholomew 1985). Reproduction can only occur when sufficient resources are available to satisfy the additional energetic and nutritional demands of reproduction. In the deserts of North America this normally occurs after a period of relatively high precipitation (Beatley 1969, 1976b, Kenagy and Bartholomew 1985, Reichman and VanDeGraaf 1975, Soholt 1977) in early spring and/or mid to late-summer (Behrends *et al.* 1986a, Hoditschek and Best 1983, Epp and Townly-Smith 1980). The increase in reproduction may be linked to some nutritional component of the vegetable matter in their diet or the increase in water intake which may be neccessary for lactation (Beatley 1976a, Beverstock *et al.* 1979, Daly *et al.* 1984, Hudson and Rummel 1966, Kenagy and Bartholomew 1985, Reichman and VanDeGraff 1975, Soholt 1977).

It is reasonable to assume that the kangaroo rats in this study are under the same reproductive constraints as their southern kin. They should be reproductively active all summer with peaks in reproduction in the spring because of snow melt and in late summer after the mid-summer rains (Epp and Townly-Smith 1980). These peaks occured to some extent in both study years.

Estrous is 12 to 13 days duration (Wilson *et al.* 1985), gestation is about 30 days (Day *et al.* 1956, Eisenburg and Isaac 1963) and the young are weaned and first leave the burrow at about 14 days (Reichman 1983) for a total of 56 to 57 days from the begining of estrous to the time that juveniles are active above ground. If adults come out of "hibernation" in mid April or early May and are immediately reproductively active the first juveniles should appear in mid to late June. There should be new juveniles all summer with a peak in August after the mid suummer rains. This occurred in both study years, thus we can assume that kangaroo rat reproduction in Canada is linked to precipitation as it is in other parts of their range.

Both study years were in the grips of one of the worst droughts ever recorded (Kindersley Weather Station Data). The spring runoff was very low because of the lack of snowfall during the previous winter (Howes pers. com.) and the usual mid-summer rains were greatly reduced (Wagner and others pers. com.). Under these conditions it is possible that the kangaroo rats could not reproduce to their full potential because some limiting resource was unavailable at the time of reproduction.

Overwinter survival

Overwinter survival was highly variable because of the extinction of the Watson population. If this population is excluded from the calculations, the survival rate is more constant at 34%.

The kangaroo rat population in the GSH resembles an island population in many respects. There are small isolated populations living on islands (active complexes) of habitat surounded by a sea of unsuitable habitat (prairie scrub). Because of this the species population dynamics can be expected to behave much like an island species (Cox *et al.* 1976)

Small isolated populations such as these are subject to frequent extirpation due to local catastrophe such as radical change in the environment or the invasion of a predator (Cox *et al.* 1976). In the case of the Watson population it is possible that some predator such as a badger learned to find the readily identifiable kangaroo rat burrows, dug them up and exterminated the inhabitants.

The Watson site will probably be recolonized at some later date when the kangaroo rat population rises to the point when they are forced to emigrate from some other dune due to intraspecific competition.

The lack of over-winter survival by juveniles is possibly a direct result of the drought. Because of the poor seed production the previous summer (Howes pers. com., Russell pers. com.), juveniles may have been unable to cache enough seeds to survive the winter. Under these conditions the juveniles perhaps starved in their burrows or died of while trying to forage during the winter. Because of the reduced time in which they can store seeds and their inexperience, it is possible that juveniles need at least normal seed crops to survive the winter.

It is possible that 34 percent overwinter survival is normal for adult kangaroo rats in Saskatchewan, but it is likely that the winter survival rate was reduced because of the drought. Under these conditions, only the most efficient foragers could cache enough seeds to survive the winter, the other 66 percent died.

Distribution

Kangaroo rat distribution closely follows the sand hill habitat east of Dinosaur Provincial Park and south of the South Saskatchewan River. This can be explained by their probable route of immigration from more southern areas during the last hypsithermal interval, some 4,000 to 6,000 years B.P. (David 1971, 1972). During this period the area south of the Saskatchewan river between Brooks and Swift Current had dry, desert-like conditions. This area was surrounded by dry grassland unsuitable for kangaroo rats.

Kangaroo rats invaded the area from the south and occupied all suitable habitats. As the area returned to a grassland climate, the suitable habitat was reduced to the present day sand hill areas. The kangaroo rats distribution was effectively reduced to islands of sand hill areas within a larger area of unsuitable habitat. Kangaroo rats never occupied the Pakowki Lake Dunes because they are relatively recent beach dune habitat and not true sand hill habitat.

CHAPTER 3; ACTIVITY RELATIVE TO ATMOSPHERIC CONDITIONS

Materials and methods

The ratio of total number of captures per night for a study site relative to the total number of captures for that site was used as the measure of kangaroo rat activity (as described in Beatley 1969, O'Farrell 1974). This ratio was compared to climatic conditions to measure the effect of temperature on kangaroo rat activity. Because of malfunctions in the Grant temperature recorder, only 25 nights had both trap success and a complete temperature record.

Results

The entire area was in the midst of a severe drought (Fig 3) (Environment Canada).

Temperature remained relatively constant at -170 cm, varying from 8°C to 15°C from May to November, with a high in August. Sand surface temperature varied from -20°C in November to over 50°C in July. Sand surface temperature varied widely each day, with the coldest point being just before sunrise and the highest just after noon (Fig 4). These data are consistent with the results of other soil temperature studies done in similar soil conditions (Tucker 1966). Sand surface temperature was similar to air temperature at night but was usually higher than air temperature during the day due to solar radiation.

Kangaroo rats were never active during rain, but were active before and in the case of light rains were also active immediately afterwards.

There was a positive and significant correlation between kangaroo rat activity and sunset temperature for three of the four 1984 study sites ($T = 3.56$, $df = 16$, $r^2 = 0.46$), but a negative correlation between kangaroo rat activity and sunset termperature on the Watson site. When the data are pooled the correlation remains slightly positive ($r^2 = 0.08$) but is not significant at the 0.5

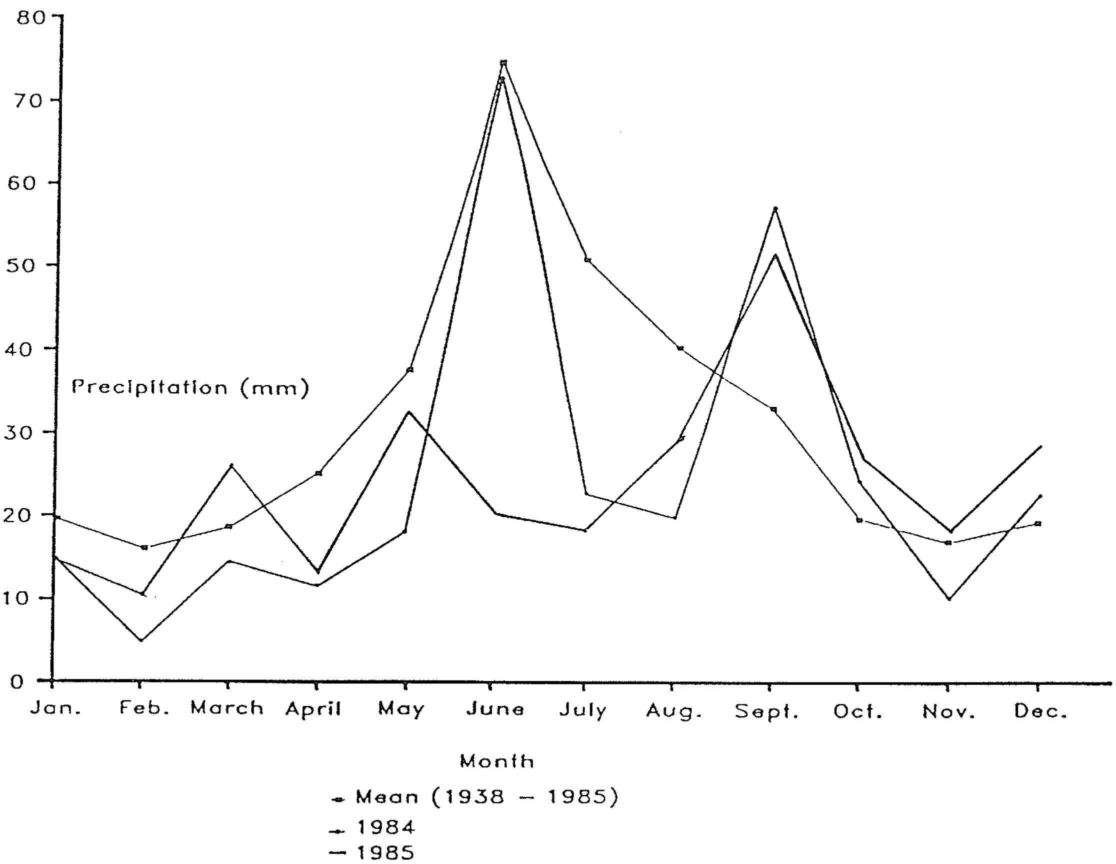

Figure3: Plot of the precipitation data for 1984, 1985, and the mean precipitation for 1938 through 1985. The reduced precipitation of 1985 and the winter of 1984 is of particular significance to kangaroo rats.

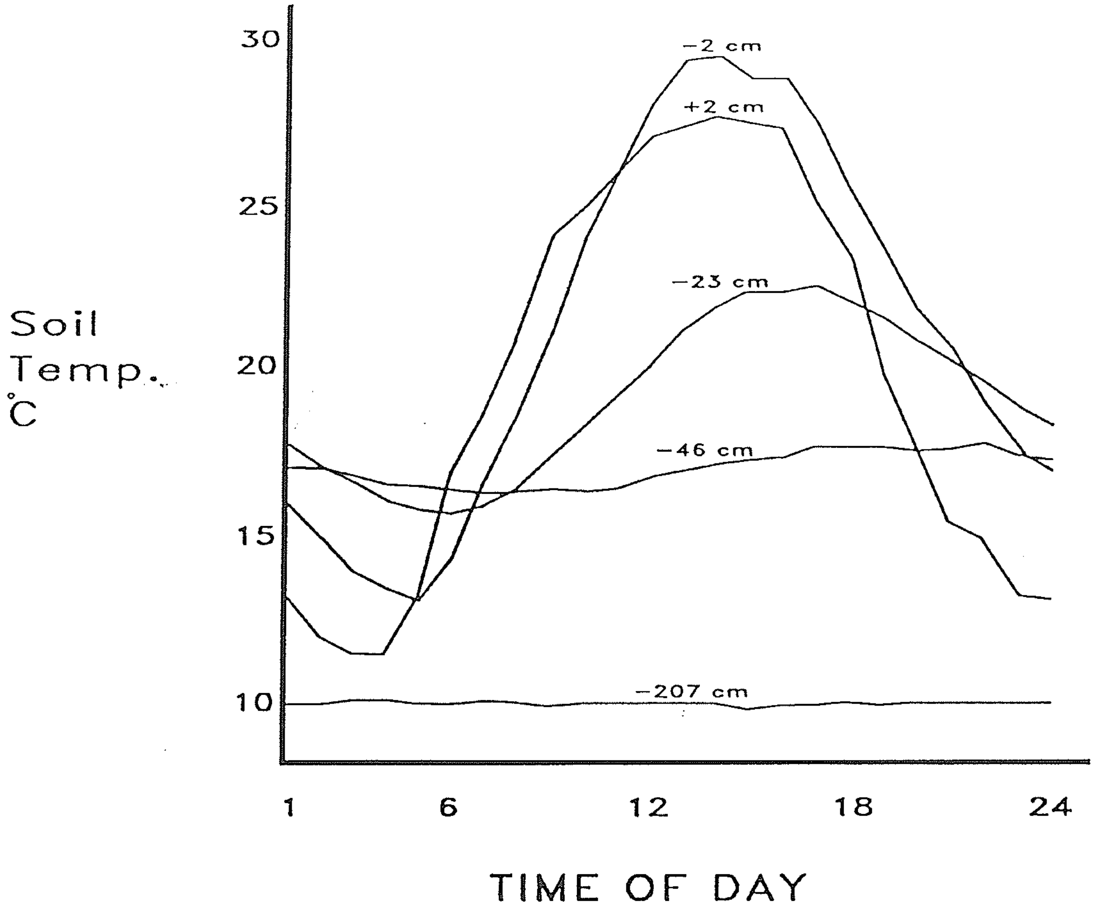

Figure 4: Hourly mean soil temperature 2 cm above soil surface and 2 cm, 23 cm, 46 cm and 207 cm below soil surface on the Mill-1 dune during the summer of 1984.

level of significance with 24 degrees of freedom (T = 1.42). It can therefore be concluded that under the environmental conditions of this study there is no significant correlation between kangaroo rat activity and sunset temperature.

Winter activity

There was no evidence of surface activity by kangaroo rats after the first heavy snow between October 15 to 19, 1984. After these dates temperature plummeted and winter began. Kangaroo rat surface activity ceased after this snowfall; there were no longer any tracks in the sand and all kangaroo rat burrows were plugged from the inside with sand. This condition persisted throughout the winter of 1984/1985. The burrows were reopened and used in the spring of 1985.

Discussion

The lack of surface activity by kangaroo rats during inclement weather is similar to that reported in other cold deserts in Idaho and Nevada (Groves and Keller 1983, Kenagy 1973a, O'Farrell 1974). Kenagy (1973a) found that *D. microps* in Nevada could be active at temperatures below -19°C with light snow, but retreated under ground when snow got too thick. O'Farrell (1974) and Groves and Keller (1981) had similar results with *D. ordi* in Idaho but activity ceased for longer periods of time with less snow cover (40% of surface). *D. ordi* in Saskatchewan demonstrated a similar tolerence to cold and snow but remained inactive for a much longer period of time than reported in any of these previous studies. It is probably not the cold that prevented surface activity during the winter, but the combination of snow and frozen ground which rendered foraging unprofitable (Kenagy 1973a, Lockard 1978, O'Farrell 1974, Groves and Keller 1983).

It is well known that the basal metabolic rate (BMR) of placental mammals tends to vary logarithmically with body mass (Dawson 1955, MacMillen 1983). *Dipodomys* spp. have a BMR that is slightly lower than expected, but tend to follow this relation (Dawson 1955, MacMillen 1983, McNab 1971) and have rather high energetic demands. Maintenance of a positive energy balance depends on efficient foraging strategies and the selection of energetically favorable microclimates. The kangaroo rats in this study appeared to be selecting favorable microclimates on three of the four sites.

All endothermic animals have a biologically optimum temperature (BOT), the ambient temperature at which no energy is expended beyond normal metabolism to maintain a constant body temperature. BOT is not fixed but is influenced by endogenous and exogenous factors such as age and acclimation (Nichelmann 1983). BOT for *Dipodomys* spp. is about 30°C (Kenagy 1973a).

In the Canadian range of *D. ordi* night-time temperature invariably falls below BOT for this species (Fig 3). Kangaroo rats must necessarily forage in unfavorable temperatures so there is no correlation between temperature and night time activity. During particularly unfavorable conditions they limit their foraging activity to short periods separated by long warm-up periods, but they must forage. During this study traps were checked only in the mornings so that kangaroo rat capture frequency is not a good measure of surface activity except during extremely unfavorable conditions when kangaroo rats did not forage at all and survived on stored seeds. Groves and Keller (1983) and O'Farrell (1974) had similar findings in the cold deserts of Idaho. O'Farrell (1974) found no correlation between activity and atmospheric temperature on a nightly basis except during extreme cold when surface activity ceased. During this study kangaroo rats were active every night except during periods of extreme energetic stress such as very cold or rainy nights.

Because of the high energetic cost of thermoregulation among small animals of all taxonomic groups, many are able to abandon activity and homeothermy for variable periods of time and enter torpor and/or hibernation (Bartholomew and Cade 1957, Breyen *et al.* 1973, Brown and Bartholomew 1969, Chew *et al.* 1965, Gumma and South 1970, Hainsworth *et al.* 1977, MacMillen 1983, Walker *et al.* 1983). All heteromyid species will spontaneously enter torpor when under cold stress if food intake is reduced, but the larger *Dipodomys* species enter torpor only under extreme conditions of food stress. For these species torpor is usually associated with weight loss and often death (Bartholomew and Cade 1957, Breyen *et al.* 1973, Brower and Cade 1971, Brown and Bartholomew 1969, Chew *et al.* 1965, French 1976, MacMillen 1983, Tucker 1966, Walker *et al.* 1983). Except for a few species (Breyen *et al.* 1973, Carpenter 1966, Yousef and Dill 1971) there appears to be little evidence that torpor is ecologically important in *Dipodomys* spp. (MacMillen 1983). These studies were done in the deserts of the southern and western United States which have considerably warmer and drier climates than southwestern Saskatchewan.

Although *Dipodomys* in the southern part of their range resist torpor and appear unable to hibernate, kangaroo rats in this study were frequently torpid in the traps on cold nights but quickly recovered when warmed in my pocket. O'Farrell (1974) has suggested that under cold conditions *D. ordi* may use torpor to reduce their metabolic demands during extended periods of inactivity. *D. ordi* in Saskatchewan spend the entire winter underground and I think it reasonable to assume that they use torpor and/or hibernation to reduce their energetic requirements during the long period of inactivity. This however remains to be tested.

CHAPTER 4; HABITAT USE BY KANGAROO RATS

Materials and methods

Transects in the spring of 1984 showed that kangaroo rats were always associated with sparsely vegetated habitats such as active complexes in the sand hill areas of Saskatchewan and Alberta. In order to define habitat preference by kangaroo rats more precisely on the active complexes, kangaroo rat activity was compared to the percent cover within 40cm of ground level of each plant species, total percent cover and species assemblages.

The number of captures at a trap location relative to the expected number of captures (assuming random movements by kangaroo rats) was used as a measure of preference for the habitat type around that trap location (as described in Price 1977). The expected number of captures at trap location i (Ec_i) was calculated using the formula:

$$Ec_i = \frac{\text{Total captures on dune i}}{\text{Number of trap sites on dune i}} = \frac{Tc_i}{n_i}$$

Preference data were pooled over all dunes into groups of trap sites with a similar habitat type. The expected number of captures for a group of trap sites (g) assuming random movements by kangaroo rats (Ec_g) was calculated using the formula:

$$Ec_g = \sum Ec_i \times n_{gi}$$

where:

Ec_i = the expected number of captures at a trap site on dune i

n_{gi} = the number of trap sites on dune i in group g

Habitat use was assessed relative to the percent cover of lance-leaved psoralea, grasses, shrubs, species assemblages and total percent cover for all plant species combined. χ^2 tests were used to test for significant differences from random.

Results

Lance-leaved psoralea:

Trap locations were grouped according to percent cover of lance-leaved psoralea; 0%, 1-25%, 26-50%, 51-75%, 76-100%.

Habitat use relative to percent cover of lance-leaved psoralea was not significantly different from random at the 0.05 level in either early summer (χ^2 = 7.01, df = 4) or late summer (χ^2 = 4.70, df = 4) though kangaroo rats used the 76-100% cover class less than random in early summer.

Grasses:

Percent cover of all species of grasses were pooled because they have similar growth forms and provide a similar resource to kangaroo rats. Grasses never made up more than 75% of the cover on any of the active complexes used in this study.

Habitat use relative to percent cover of grasses was not significantly different from random in either early summer (χ^2 = 7.89, df = 3) or late summer (χ^2 = 0.27, df = 3).

Shrubs:

Percent cover of all shrubs including wild rose, northern gooseberry (*Ribes orycanthoides* L.), sage, juniper and low chokecherry bushes were pooled because they have similar growth forms and can be expected to accumulate similar wind born seed deposits.

Kangaroo rat habitat use relative to percent cover of shrubs was significantly different from random at the 0.05 level of significance in early summer ($\chi2$ = 10.10, df = 4). Kangaroo rats used the 0% and 76-100% cover areas less than random and used the 1-50% cover areas more than expected. Habitat use relative to percent cover of shrubs was not significantly different from random in late summer (χ^2 = 4.20, df = 4).

Total percent cover:

Percent cover below 40cm of all plant species was sumed to determine total percent cover. Habitat preference relative to total percent cover of all plant species was significantly different from random at the 0.05 level of significance in early summer (χ^2 = 20.55, df = 4) but not in late summer (χ^2 = 3.21, df = 4). In both cases kangaroo rats used the 0% and 75-100% cover areas less than expected and the 1-75% areas more than expected; ie. they prefered to use areas with some vegetation and avoided areas which were either devoid of vegetation or densely vegetated.

Species assemblages:

Cluster analysis was used to cluster trap locations into eight clusters of similar vegetative composition and plant cover; ie.habitat type. The cluster analysis used all but the very rare plant species as variables. The rare species were pooled into two additional variables; grasses and forbes. The clusters do not all contain the same number of trap locations, but each active complex sampled had trap sites in more than one cluster. Clusters are described in appendix 3.

Habitat use relative to species assemblages did not differ significantly from random at the 0.05 level in either early (χ^2 = 3.145, df = 4) or late summer (χ^2 = 1.162, df = 9). However, when trap sites with 0% total cover are placed in a separate cluster (App 3) habitat selection differs significantly from random at the 0.10 level in early summer (X^2 = 6.44, df = 5). Though habitat selection did not differ from random in late summer, kangaroo rats still used the 0% class less than expected.

Discussion

Habitat use by kangaroo rats in this study appears to be similar to that reported for kangaroo rats in other parts of their range. Previous studies report that kangaroo rats forage for seeds mainly near or beneath the canopies of shrubs but avoid dense vegetation (Mares 1983, Stamp and Ohmart 1978). They are however well adapted for traversing unvegetated areas to get to important foraging sites (Alcoze and Zimmerman 1973, Beatley 1976a, b, Behrends *et al.* 1986a, b, Boweres 1986, Brown and Lieberman 1973, Csuti 1979, Groves and Keller 1983, Kenagy 1973a, Stamp and Ohmart 1978, Thompson 1982b, Trombulak and Kenagy 1980).

In the present study the unvegetated areas of all but the largest dunes were small and probably easily traversable by kangaroo rats. This was confirmed from observations of tracks on all areas of the dunes. Individuals captured on the unvegetated sand areas were probably in transit from one partially vegetated area to another (Price 1978b) and were probably not foraging there. This conclusion about their apparent habitat use was confirmed from observations done in the spring of 1984.

In the spring of 1984, the unvegetated area of the Lawrence site was sampled more completely. The sample grid was a 180m by 180m grid which sampled a large area of unvegetated sand. On this grid most of the trap sites on the unvegetated sand had zero captures while the sites in the partially vegetated area had a number of captures. This is probably indicative of the kangaroo rats true habitat preference in which it avoids the large areas of unvegetated sand.

In early summer foraging by kangaroo rats was more natural because the kangaroo rats were foraging for natural seed deposits caused by wind shadows on the leeward side of vegetation. Later in the summer the seed deposits became exhausted and the kangaroo rats became "trap happy". Under these conditions the kangaroo rats began foraging for the traps rather than the naturally occuring seed deposits. This caused the kangaroo rat habitat use in this study to appear random in late summer but selective in early summer.

In conclusion, kangaroo rats use habitat according to total percent plant cover with little or no regard for species composition. This habitat selection is a result of their foraging behavior in which they forage for seed patches around shrubs, avoiding heavily vegetated and unvegetated areas. Because the seed patches are not dependent on the species of plant, only on its ability to stop the wind, the kangaroo rats do not select their habitat according to the plant species.

CHAPTER 5; POPULATION ESTIMATE

Materials and methods

The 1984 trapping experiments indicated that on the smaller active complexes all adult kangaroo rats could be captured within five nights trapping. After three or four nights, no new adults were captured. This reduced the population estimate on these dunes to a simple census (Hilborn *et al.* 1976). The three largest dunes could not be censused in this manner so the population had to be estimated.

Because of the small sample sizes the usual mark-recapture models proved unsatisfactory for estimating the populations on the large active complexes. Populations were estimated using a more ad hoc method.

Assuming that, as on the smaller active complexes, all kangaroo rats using the area within the grids were captured and marked, the population estimate for the entire dune reduces to:

$$\text{Dune population} = \frac{\text{Total suitable habitat} \times \text{Number captured}}{\text{Grid area} + \text{Overlap}}$$

where:

total suitable habitat = the total area of all the edge habitat on that dune as estimated from aerial photographs.

grid area = the area of edge habitat covered by the grid

overlap = the area around the grid from which kangaroo rats can come and be captured. Overlap is assumed to be 1/2 the normal home range size [25m-38m (Banfield 1981, Groves and Keller 1981)]. The number living away from this suitable habitat is assumed to be negligible. (See App 4 for a list of areas of dunes sampled and populations).

Active complex areas were estimated using a gravimetric technique. Aerial photographs were projected onto uniform density tracing paper with an opaque projector. The outline of each active complex was traced with a fine (0.3mm) lead pencil and cut out with a fine scapel. The projector was in a fixed position perpendicular to the wall so all active complexes were equally magnified. A square cm and fractions thereof were also drawn to establish scale.

Active complex areas were calculated by comparing the mass of the complex cut-outs to the mass of the cm square. Error of the cm was in the order of 0.0001g, 0.006 ha or 59.77 m^2. The error is unimportant because the dune areas are in constant change because of wind erosion, and the magnitude of error is beyond the resolution of the aerial photographs.

Sample calculation:
1 cm square = 0.2788g
Lawrence mass = 0.4373g
Lawrence = 0.4373/0.2788 = 1.5710 cm square
Lawrence area = 1.5710 x 59.77 = 93.91 ha.

The same calculation was repeated over all active complexes visible on the aerial photographs including dunes, blow-outs, unimproved roads and over-grazed pasture land. (See App 5 for list of areas)

The total population in a sandhill area was estimated using the regression method as described in Poole (1974). The relation between dune size and population per dune was assumed to be the same in all sandhill areas, but this was not tested because the sample sizes were too small to draw meaningful conclusions from tests (Smith 1968). Population data from the three sand hill areas were pooled.

Results

The relation between dune size (ha) and population per dune took the form:

$$\ln(\text{pop}) = \alpha + \beta \ln(\text{dune size}) + \text{error}$$

The relation is not linear because large active complexes have less dense populations than small ones.

Linear regression was performed on the ln transformed data using the APL simple regression (SR) routine, producing the data in table 1 and Fig 5.

A T-test of the hypothesis Ho:$\beta = 0$ gave a value of 8.68. This is significant at the 5 percent level of significance with 10 degrees of freedom. We can therefore reject Ho and conclude that $\beta \neq 0$; there is a significant relation between ln(dune size) and ln(population per dune). $R^2 = 0.893$ indicating that the regression explains 89.3% of the variation of kangaroo rat population over dune size. The residual plot falls on zero and does not show any significant trend, indicating that the regression on the ln/ln transformation is appropriate and that variance is constant over the range of dune sizes in this study (Fig 6).

The mean ln (kangaroo rat population per dune) for each sand hill area was calculated using the formula:

$$\overline{Y}_i = \overline{Y} + \beta(\overline{X}_i - \overline{X})$$

where:

$\overline{Y}_i$ = the overall mean population per dune for area i

$\overline{Y} = 2.35$ = the sample mean population per dune

$\beta = 0.82$ = the estimated slope of the regression

$\overline{X}_i$ = the true ln(mean dune size in an area)

$\overline{X} = -2.99$ = the sample ln(mean dune size).

Table 1: Data produced by the regression of ln [dune area (ha)] versus ln (population per dune).

Mean ln (dune area) = 1.619 ha.	$S^2x = 1.319$	$\alpha = 1.021$
Mean ln (population per dune) = 2.345	$S^2y = 1.141$	$T = 8.684$
$\beta = 0.818$	$S^2e = 0.094$	$R^2 = 0.833$

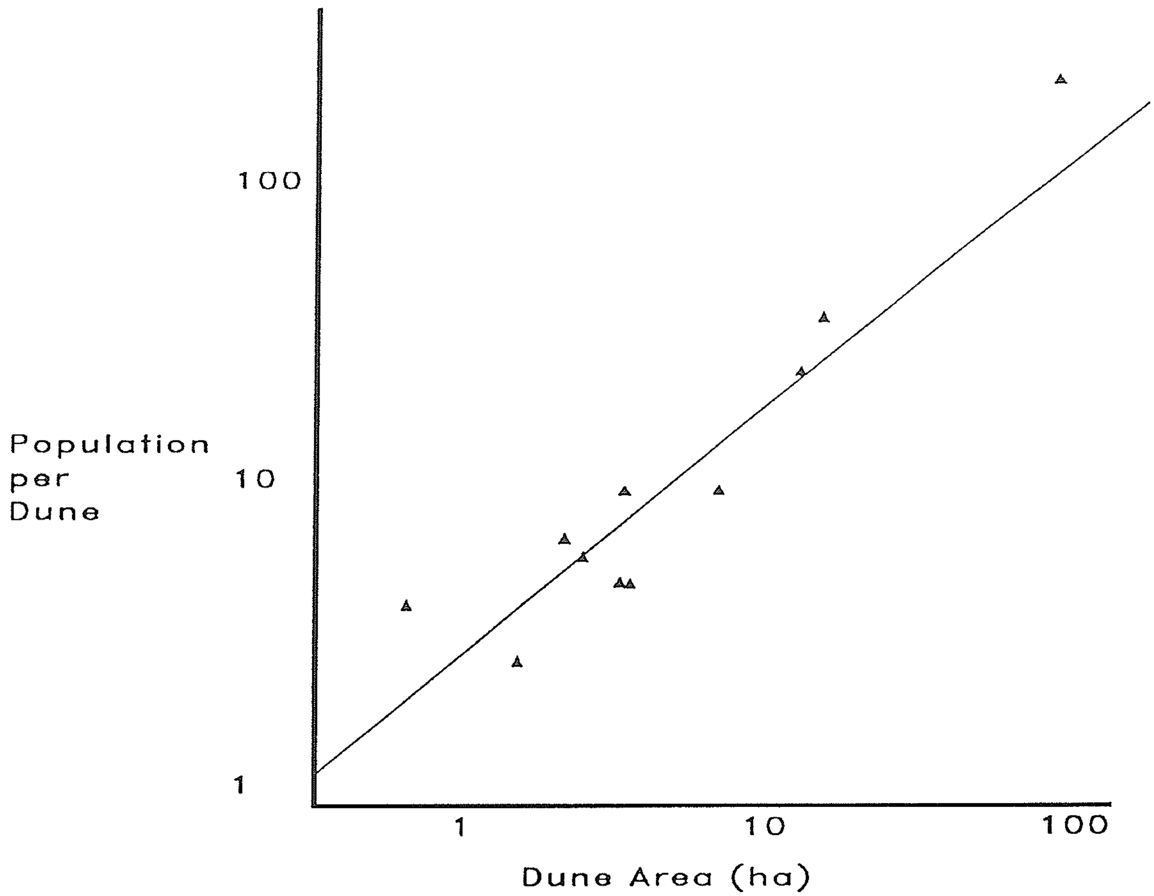

Figure 5: Plot of ln (kangaroo rat population per dune) versus ln [dune area (ha)]; $\beta = 0.82$, $r^2 = 0.983$.

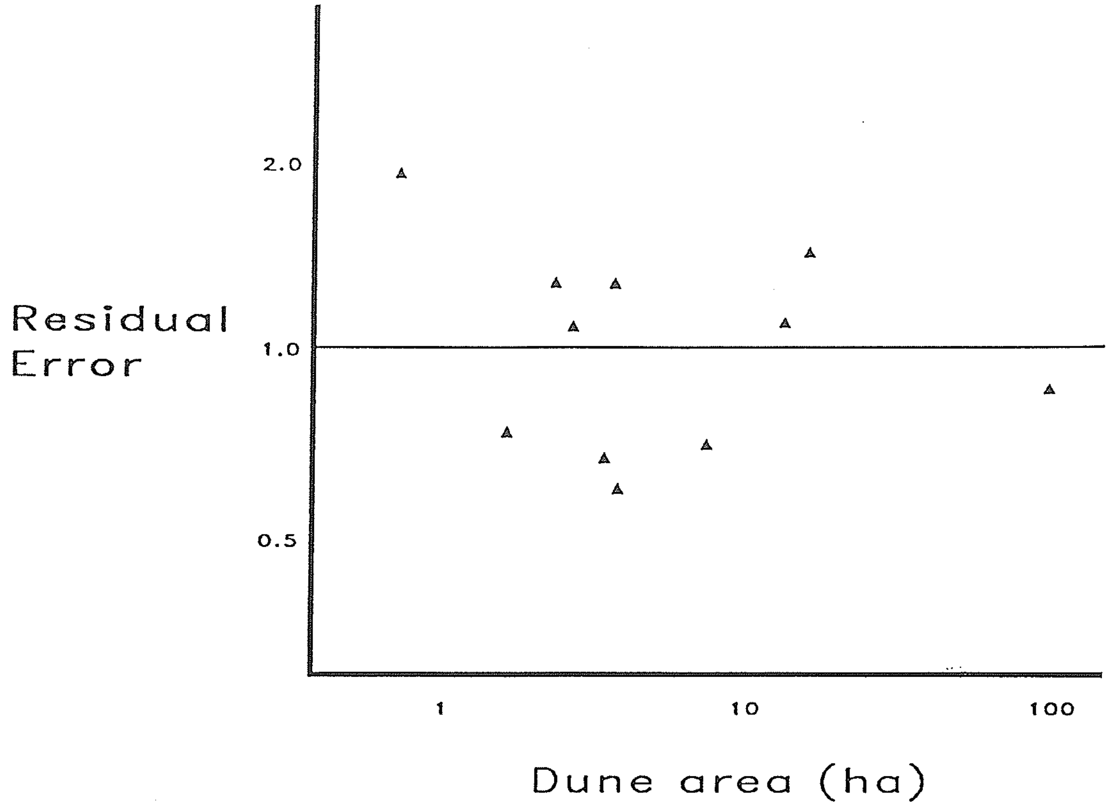

Figure 6: Plot of residual errors. B = 0, with a constant variance over the regression, indicating that the regression of ln (population per dune) versus ln [dune size (ha)] is truly linear.

The variance of the estimate was calculated using the formula:

$$\hat{Var}(\bar{Y}_i) = \frac{Se^2}{n}(1 + 1/n)(1 - n/N_i)$$

where:

$Se^2 = 0.154$ = the residual variance about the regression

$n = 11$ = the sample size

N_i = the number of dunes in area i = 14, 14, 182 for Cramersburg, Burstall, and GSH respectively.

The total population in an area was calculated using the formula:

$$Population_i = \bar{Y}_i \times N_i$$

APL routines were used to calculate the total populations and confidence intervals for the three areas in this study. Populations and confidence intervals were calculated before back transformation of the data.

The total population, upper and lower confidence limits were estimated at 55.3 (49.9, 61.4), 81.5 (73.5, 90.4) and 1233.7 (992.8, 1533.0) kangaroo rats for the Cramersburg hills, Burstall hills and GSH respectively. The estimates have an accuracy of +/- 19.5% of the mean.

Discussion of the estimate

During this study it was assumed that kangaroo rats existed only on active complexes within the sandhill areas. This is for the most part reasonable, but there could be a small number living on cattle trails, overgrazed pastures or other such unvegetated ground. One kangaroo rat was caught on such a trail just off the Mill-1 site. It manoeuvered well on the beaten trail, but did not stray far from the dune even when pursued. The same individual was also caught on the dune and was probably always closely associated with the dune. I have no estimate of the number living on such cattle trails but I assume it to be small. The trails probably provide corridors for kangaroo rat movements to other unoccupied dunes during periods of high populations but are probably not important habitat.

The assumption that all adult kangaroo rats were captured could be erroneous. It is possible that some avoided traps and were never captured but because kangaroo rats tend to be "trap happy" (Beatley 1976b) I believe the assumption of 100% catchability to be reasonable. During 1984/1985 seed production was very low (Russell pers. com.). Under these conditions seeds become a scarce, intensely sought and probably irresistable resource. Since the traps were a major source of seeds, the assumption of 100% catchability is probably correct.

Discussion of the population status

Interviews with local ranchers and farmers indicate that the kangaroo rat population and local distribution is considerably reduced from that of only a few years prior to the study (Fitterer pers. com., Minor pers. com., Watson pers. com., Yeast pers. com.). They report that kangaroo rats used to be seen much more frequently along roads and were occasionaly seen in overgrazed pastures and wind eroded fields. There were no reports of kangaroo rats in these areas during this study. Baron (pers. com.) reported that with relatively few traps he captured 30 kangaroo rats on one dune several years prior to the present study whereas only six were caught in this study. These observations indicate a declining population.

Although kangaroo rats are well adapted for living in desert environments (Carpenter 1966, Csuti 1979, McNab 1971, Scelza and Knoll 1982, Schmidt-Nielsen *et al.* 1970) their reproductive success is influenced by environmental conditions, particularly the amount and timing of precipitation (Beatley 1969, 1976a, Daly *et al.* 1984, Kenagy and Bartholomew 1985). Because of the drought, the suitable conditions for reproduction may not have occurred and reproductive success was well below the theoretical maximum.

Dipodomys spp. depend primarily on cached seeds for sustenance when conditions are unfavorable for foraging above ground because of low food availabilty or poor weather conditions (Behrends *et al.* 1986b). In Saskatchewan such conditions normally persist from November through March. Individuals failing to cache sufficient seeds will inevitably perish through starvation or hypothermia. Thus kangaroo rat overwinter survival is dependent on seed production the previous summer. The drought of recent years, including 1984/1985 has reduced seed production by native plants (Russell pers. com., Pers. obs.) as it has for agricultural crops. Because of the low seed production it is possible that overwinter survival, particularly for the young of the year, was lower than normal (Nicolai and Bramble 1983).

The kangaroo rat population in Saskatchewan is probably lower than normal because the drought has reduced the reproductive success and overwinter survival particularly among the young of the year.

CHAPTER 6; SUMMARY AND CONCLUSIONS

Kangaroo rat distribution in Canada is limited to the sandhill areas of southwestern Saskatchewan and southeastern Alberta between Swift Current and Dinosaur Provincial Park and south of the South Saskatchewan River. Their habitat use within these areas is similar to that reported for kangaroo rats in other parts of their range; they are limited to dunes and other sparsely vegetated areas within the general sandhill areas. Kangaroo rat activity relative to environmental conditions is similar to that reported in other cold deserts, with a slight northern adjustment. Their activity is not affected by cold except in extreme conditions or when there is snow or rain. They remain inactive from November through late April, possibly using torpor as a method of resource conservation.

The kangaroo rat population has declined in recent years, but is probably not in danger of extirpation. The decline can be attributed to reduced reproductive success and overwinter survival due to the seed crop failure brought about by the drought. The population will undoubtedly rebound after the drought breaks and seed production returns to normal.

CHAPTER 7; MANAGEMENT RECOMMENDATIONS

Although the population is low it is probably not in danger of disappearing provided the habitat remains available. The population is probably normal for the environmental conditions encountered during this study. The population will undoubtedly increase when the drought breaks and perhaps recolonize dunes where kangaroo rats have been extirpated. Of a more serious nature is the overall habitat loss to kangaroo rats as well as other prairie species that has occurred since the turn of the century.

Photographs of the area from the turn of the century show that prior to the arrival of Europeans the entire area was dominated by short grass prairie with virtually no trees or brush. At that time the brush was controlled by frequent range fires. These fires helped maintain sand dune habitat as well as the prairie (Daubenmire 1968, Wright and Bailey 1982).

When the vegetation is burned off, the land may become destabilized and allow wind erosion to occur. When this occurs dunes and/or blowouts are often formed and expanded (Epp and Townley-Smith 1980, Minor pers. com.) thus creating more kangaroo rat habitat and perhaps corridors of suitable habitat which would allow kangaroo rats access to hitherto unavailable dunes. As well as creating new habitat the fires prevent vegetation from stabilizing already existing dunes. Regular fires have the effect of creating new habitat and maintaining existing habitat (Geluso 1986, Wright and Bailey 1982).

Regular fires also have the effect of improving the habitat for other prairie wildlife as well as cattle. At present large areas of the sand hills are dominated by hoary sage brush and juniper which is unpalatable to most ungulates (Daubenmire 1968, Wright and Bailey 1982). Regular fires on about a 30 year cycle would control undesirable shrubs such as these and allow the more palatable grasses to thrive. Several ranchers in the area have suggested controlled burning as a method of long term range management but have been refused burning permits (Watson pers. com.). My management recomendation is that ranchers should be allowed to proceed with burning as a form of range management with about a 30 year rotation. The fires would improve the habitat for kangaroo rats as well as other wildlife and cattle.

Appendices

Appendix 1: List of vascular plants occuring in the Great Sand Hills area. Those marked with an * were observed on active complexes. (From Epp and Townley-Smith 1980)

Common Name	Scientific names
Common scouring rush	*Equisetum hymale* L.
Smooth scouring rush	*Equisetum laevigatum* A. Br.
Prairie selaginella	*Selaginella densa* Rydb.
Low juniper	*Juniperus communis* L.
*Creeping juniper	*Juniperus horizontalis* Moench
Common cattail	*Typha latifolia* L.
Seaside arrow-grass	*Triglochin maritima* L.
Narrow-leaved water-plantain	*Alisma gramineum* K. C. Gmel.
Broad-leaved water-plantain	*Alisma plantago-aquatica* L.
Arum-leaved arrowhead	*Sagittaria cuneata* Sheld.
*Northern wheat grass	*Agropyron dasystachyum* (Hook) Scribn.
*Crested wheat grass	*Agropyron pectiniforme* Roem.and Shult
Couch grass	*Agropyron repens* (L.) Beauv.
Slender wheat grass	*Agropyron trachycaulum* (Link) Malte
Rough hair grass	*Agrostis scabra* Willd.
Little bluestem	*Andropogon scoparius* Michx.
Slough grass	*Beckmannia syzigachne* (Steud.) Fern.
*Blue grama grass	*Bouteloua gracilis* (HBK.) Lag.
Northern reed grass	*Calamagrostis inexpansa* A. Gray
Plains reed grass	*Calamagrostis montanensis* Scribn.
Narrow reed grass	*Calamagrostisneglecta* (Ehrh.) Gaertn.
*Sand grass	*Calamovilfalongifolia* (Hook.) Scribn.
Tufted hair grass	*Deschampsia caespitosa* (L.) Beauv.
Alkali grass	*Distichlis stricta* (Torr.) Rydb.
*Nodding wild rye	*Elymus canadensis* L.
*Six-weeks fescue	*Festuca octofloa* Walt.
*Sheep fescue	*Festuca ovina* L.
Wild barley	*Hordeum jubatum* L.
June grass	*Koeleria cristata* (L.) Pers.
Scratch grass	*Muhlenbergia asperifolia* Parodi
Mat muhly	*Muhlenbergia richardsonis* (Trin.) Rydb.
*Indian rice grass	*Oryzopsishymenoides* (Roem.and Shult.) Ricker
Little-seed rice grass	*Oryzopsismicrantha* (Trin.and Rupr.) Thurb.
Indian blue grass	*Poa interior* L.
Kentucky blue grass	*Poa pratensis* L.
Sandberg's blue grass	*Poa secunda* Presl
Rabbitfoot grass	*Polypogon monspeliensis* (L.) Desf.
Nuttall's salt-meadow grass	*Puccinellia nuttalliana* (Shultes) Hitchc.

Alkali cord grass	*Spartina gracilus* Trin.
*Sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray
*Spear grass	*Stipa comata* Trin. and Rupr.
Douglas sedge	*Carex douglasii* Boott
Thread-leaved sedge	*Carex filifolia* Nutt.
	Carex oederi Retz.
	Carex peckii Howe
	Carex pensylvanica Lam.
	Carex scirpoidea Michx.
	Carex sprengelii Dewey
Schweinitz's cyprus	*Cyperus schweinitzii* Torr.
Nevada bulrush	Scirpus nevadensis S. Wats.
Prairie bulrush	*Scirpus paludosus* A. Nels
Baltic rush	*Juncus balticus* Willd.
Long-styled rush	*Juncus longistylis* Torr.
Prairie onion	*Allium textile* Nels. and Macbr.
Western red lily	*Lilium philadelphicum* L.
*Star-flowered Solomon's-seal	*Smilacina stellata* (L.) Desf.
Yucca	*Yucca glauca* Nutt.
Common blue-eyed grass	*Sisyrinchium montanum* Greene
Green-flowered bog-orchid	*Habenaria hyperborea* (L.) R. Br.
*Balsam poplar	*Populus balsamifera* L.
*Western cottonwood	*Populus deltoides* Marsh
*Aspen	*Populus trembuloides* Michx.
Beaked willow	*Salix bebbiana* Sarg.
Short-capsuled willow	*Salix brachycarpa* Nutt.
Sandbar willow	*Salix interior* Rowlee
Yellow willow	*Salix lutea* Nutt.
River birch	*Betula occidentalis* Hook.
Pale comandra	*Comandra pallida* A. Dc.
Doorweed	*Polygonium aviculare* L.
Narrow-leaved field dock	*Rumex stenophyllus* Ldb.
*Sand dock	*Rumex venosus* Pursh
Nuttall's atriplex	*Atriplex nuttallii* S. Wats.
Fremont's goosefoot	*Chenopodium fremontii* S. Wats.
Maple-leaved goosefoot	*Chenopodium hybridum* L.
Narrow-leaved goosefoot	*Chenopodium leptophyllum* Nutt.
Bugseed	*Corispermum hyssopifolium* L.
Villose bugseed	*Corispermum orientale* Lam.
Red samphire	*Salicornia rubra* A. Nels.
*Russian thistle	*Salsola kali* L.
Hairy umbrellawort	*Mirabilis hirsuta* (Pursh) MacM.
Blunt-leaved sandwort	*Arenaria lateriflora* L.
Field chickweedd	*Cerastium arvense* L.
Long-stalked chickweed	*Cerastium nutans* Raf.

Night-flower catchfly	*Silene noctiflora* L.
Salt-marsh sand spurry	*Spergularia marina* (L.) Griseb.
Long-stalked stitchwort	*Stellaria longipes* Goldie
Long-fruited anemone	*Anemone cylindrica* A. Gray
Cut-leaved anemone	*Amemone multifida* Poir.
Crocus anemone	*Anemone patens* L.
Western virgin's-bower	*Clematis ligusticifolia* Nutt.
Seaside buttercup	*Ranunculus cymbalaria* Pursh
Spiderflower	*Cleome serrulata* Pursh
Reflexed rock cress	*Arabis holboellii* Hornem.
Short-fruited tansy mustard	*Descurainia pinnata* (Walt.) Britt.
Gray tansy mustard	*Descurainia richardsonii* (Sweet) O. E. Schulz
*Flixweed	*Descurainia sophia* (L.) Webb.
Western wallflower	*Erysimum asperum* (Nutt.) DC.
Small-flowered prairie-rocket	*Erysimum inconspicuum* (S. Wats.) MacM.
Common pepper-grass	*Lepidium densiflorum* Schrad.
Sand bladderpod	*Lesquerella arenosa* (Richards.) Rudb.
Alumroot	*Heuchera richardsonii* R. Br.
Northertn grass-of-parnassus	*Parnassia palustris* L.
*Northern gooseberry	*Ribes oxycanthoides* L.
*Saskatoon	*Amelanchier alnifolia* Nutt.
Three-flowered avens	*Geum triflorum* Pursh
Silverweed	*Potentilla ansernia* L.
Plains cinquefoil	*Potentilla bipinnatifida* Dougl.
*Black-fruited choke cherry	*Prunus virginiana* L.
*Wood's rose	*Rosa woodsii* Lindl.
Wild red raspberry	*Rubus idaeus* L.
Canadian milk-vetch	*Astragalus canadensis* L.
Prickly milk-vetch	*Astragalus kentrophyta* A. Gray
Missouri milk-vetch	*Astragalus missouriensis* Nutt.
Narrow-leaved milk-vetch	*Astragalus pectinatus* Dougl.
Prush's milk-vetch	*Astragalus purshii* Dougl.
Ascending purple milk-vetch	*Astragalus striatus* Nutt.
Loose-flowered mil-vetch	*Astragalus tenellus* Pursh
Common caragana	*Caragana arborescens* Lam.
Wild licorice	*Glycyrrhiza lepidota* (Nutt.) Pursh
*Small lupine	*Lupinus pusillus* Pursh
Alfalfa	*Medicago sativa* L.
White sweet-clover	*Melilotus alba* Desr.
Early yellow locoweed	*Oxytropis sericea* Nutt.
White prarie-clover	*Petalostemon candidum* (Willd.) Michx.
Purple prairie-clover	*Petalostemon purpureum* (Vent.) Rydb.
Silverleaf psoralea	*Psoralea argophylla* Pursh
*Lance-leaved psoralea	*Psoralea lanceolata* Pursh
Golden-bean	*Thermopsis rhombifolia* (Nutt.) Richards

Narrow-leaved vetch	*Vicia sparsifolia* Nutt.
Lewis wild flax	*Linum lewisii* Pursh
Large-flowered wild flax	*Linum rigidum* Pursh
Poison ivy	*Rhus radicans* L.
Skunkbush	*Rhus trilobata* Nutt.
Manitoba maple	*Acer negundo* L.
Scarlet mallow	*Aphaeralcea coccinea* (Pursh) Rydb.
Early blue violet	*Viola nutallii* Pursh
*Purple cactus	*Mamillaria vivipara* (Nutt.) Haw.
*Fragile prickly pear	*Opuntia fragilis* (Nutt.) Haw.
*Wolf-willow	*Elaeagnus commutata* Bernh.
*Buffaloberry	*Shepherdia argentea* Nutt.
*Nothern willowherb	*Epilobium glandulosum* Lehm.
*Scarlet butterflyweed	*Gaura coccinea* Pursh
White evening-primrose	*Oenothera nuttallii* Sweet
Plains cymopterus	*Cymopterus acaulis* (Pursh) Raf.
Water parsnip	*Sium suave* Walt.
Red-osier dogwood	*Cornus stolonifera* Michx.
Pink wintergreen	*Pyrola asarifolia* Michx.
One-sided wintergreen	*Pyrola secunda* L.
*Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.
Pygmyflower	*Androsace septentrionalis* L.
Saline shootingstar	*Dodecatheon pauciflorum* (Durand) Greene
Sea-milkwort	*Glaux maritima* L.
Mealy primrose	*Primula incana* M. E. Jones
Oblong-leaved gentian	*Gentiana affinis* Griseb.
*Showy milkweed	*Asclepians speciosa* Torr.
Moss phlox	*Phlox hoodii* Richards
Nodding stickseed	*Hackelia americana* (Gray) Fern.
Large-flowered stickseed	*Hackelia floribuna* (Lehm.) Johnst.
Spatulate-leaved heliotrope	*Heliotropium curassavicum* L.
*Western bluebur	*Lappula redowskii* (Hornem.) Greene
Narrow-leaved puccoon	*Lithospermum incisum* Lehm.
Wild mint	*Mentha arvensis* L.
Owl's clover	*Orthocarpus luteus* Nutt.
White beardtongue	*Penstimon albidus* Nutt.
Clustered broom-rape	*Orobanche fasciculata* Nutt.
Louisiana broom-rape	*Orobanche ludoviciana* Nutt.
Sasline plantain	*Plantago eriopoda* Torr.
Pursh's plantain	*Plantago purshii* R. & S.
*Western snowberry	*Symphoricarpos occidentalis* Hook.
Harebell	*Campanula rotundifolia* L.
Dowingia	*Dowingia laeta* Greene
Kalm's lobelia	*Lobelia kalmii* L.
Yarrow	*Achillea millefolium* L.

Large-flowered false dandelion	*Agoseris glauca* (Pursh) Raf.
Small-leaved everlasting	*Antennaria parviflora* Nutt.
*Plains wormwood	*Artemisia campestris* L.
*Hoary sagebrush	*Artemisia cana* Pursh
*Pasture sage	*Artemisia frigida* Willd.
Prairie sagewort	*Artemisia ludoviciana* Nutt.
Smooth aster	*Aster laevis* L.
Many-flowered aster	*Aster pansus* (Blake) Croquist
Hairy golden-aster	*Chrysopsis villosa* (Pursh) Nutt.
Flodman's thistle	*Cirsium flodmanii* (Rydb.) Arthur
Wavy-leaved thistle	*Cirsium undulatum* (Nutt.) Spreng.
Canada fleabane	*Erigeron canadensis* L.
Bur-ragweed	*Franseria acanthicarpa* (Hook.) Coville
Great-flowered gaillardia	*Gaillardia aristata* Pursh
Gumweed	*Grindelia squarrosa* (Pursh) Dunal
Broomweed	*Gutierrezia sarothrae* (Pursh) Britt. and Rusby
Narrow-leaved sunflower	*Helianthus maximilianii* Schrad.
*Prairie sunflower	*Helianthus petiolaris* Nutt.
*Blue lettuce	*Lactuca pulchella* (Pursh) DC.
Dotted blazingstar	*Liatris punctata* Hook.
*Skeletonweed	*Lygodesmia juncea* (Pursh) D. Don
Annual skeletonweed	*Lygodesmia rostrata* A. Gray.
Long-headed coneflower	*Ratibida columnifera* (Nutt.) Woot. and Standl.
Silvery groundsel	*Senecio canus* Hook.
Balsam groundsell	*Senecio pauperculus* Michx.
Thin-leaved ragwort	*Senecio pseudaureus* Rydb.
Low goldenrod	*Solidago missouriensis* Nutt.
Velvety goldenrod	*Solidago mollis* Bartl.
Prickly sow-thistle	*Sonchus asper* (L.) Hill
Low townsendia	*Townsendia sercea* Hook.
Yellow goat's-beard	*Tragopogon dubius* Scop.

Appendix 2: List of vertebrate species in the Sand Hill habitat of Saskatchewan and Alberta. The species marked with an * were captured in traps on the dunes of this study.

MAMMALS

Common name	**Scientific name**
Silver haired bat	*Lasionycteris noctivagans* (Le Conte)
Nuttall's cottontail	*Sylvilagus nuttallii* (Bachman)
Wite-tailed jack rabbit	*Lepus townsendii* Bachman
Richardson's ground squirrel	*Spermophilus richardsonii* (Sabine)
*Thirteen-lined ground squirrel	*Spermophilus tridecemlineatus* (Mitchell)
Northern pocket gopher	*Thomomys talpoides* (Richardson)
*Olive-backed pocket mouse	*Perognathus fasciatus* Wied-Newied
*Ord's kangaroo rat	*Dipodomys ordi* Woodhouse
*Deer mouse	*Peromyscus maniculatus* (Wagner)
Gapper's red-backed vole	*Clethrionomys gapperi* (Vigors)
Muskrat	*Ondatra zibethicus* (Linnaeus)
*Meadow vole	*Microtus pennsylvanicus* (Ord)
American porcupine	*Erethizon dorsatum* (Linnaeus)
Coyote	*Canis latrans* Say
Long-tailed weasel	*Mustela freneta* Lichtenstein
American badger	*Taxidea taxus* (Schreber)
Mule deer	*Odocoileus hemionus* (Rafinesque)
White-tailed deer	*Odocoileus virginianus* (Zimmerman)
Pronghorn	*Antilocapra americana* (Ord)

BIRDS

Common name	**Scientfic name**
Eared grebe	*Podiceps nigricollis* Heerman
White pelican	*Pelecanus erythrorhynchos* Gmelin
Double-crested cormorant	*Phalacrocorax auritus* (Lesson)
Black-crowned night heron	*Nycticorax nycticorax* (Linnaeus)
Canada goose	*Branta canadensis* (Linnaeus)
Mallard	*Anas platyrynchos* Linnaeus
Gadwall	*Anas strepera* Linnaeus
Pintail	*Anas acuta* Linnaeus
Green-winged teal	*Anas crecca* Linnaeus
Blue-winged teal	*Anas discors* Linnaeus
American widgeon	*Anas americana* (Gmelin)
Northern shoveler	*Anas clypeata* (Linnaeus)
*Cooper's hawk	*Accipiter cooperi* (Bonaparte)
Red-tailed hawk	*Buteo jamaicensis* (Gmelin)

Swainson's hawk	*Buteo swainsoni* Bonaparte
Ferruginous hawk	*Buteo regalis* (Gray)
Golden eagle	*Aquila chrysaetos* (Linnaeus)
Marsh hawk	*Circus cyaneus* (Linnaeus)
Prairie falcon	*Falco mexicanus* Schlegel
Perigrine falcon	*Falco peregrinus* Tunstall
Merlin	*Falco columbarius* Linnaeus
American kestrel	*Falco sparverius* Linnaeus
Sharp-tailed grouse	*Pediocetesphzxiznellus* (Linnaeus)
Ring-necked pheasant	*Phasianus colchicus* Linnaeus
American coot	*Fulica americana* Gmelin
Killdeer	*Charadrius vociferus* Linnaeus
Long-billed curlew	*Numenius americanus* Bechstein
Upland sandpiper	*Bartramia longicauda* (Bechstein)
American avocet	*Recurvirostra americana* Gmelin
Wilson's phalorope	*Steganopus tricolor* Vieillot
Ring-billed gull	*Larus delawarensis* Ord
Franklin's gull	*Larus pipixcan* Wagler
Black tern	*Chlidonias niger* (Linnaeus)
Mourning dove	*Zenaida macroura* (Linnaeus)
Black-billed cuckoo	*Coccyzus erythropthalmus* (Wilson)
Great-horned owl	*Bubo virginianus* (Gmelin)
Burrowing owl	*Speotyto cunicularia* (Molina)
Short-eared owl	*Asio flammeus* (Pontoppidan)
Poor-will	*Philaenoptilus nuttallii* (Audubon)
Common nighthawk	*Chordeiles minor* (Forster)
Hairy woodpecker	*Dendrocopos villosus* (Linnaeus)
Eastern kingbird	*Tyrannus tyrannus* (Linnaeus)
Western kingbird	*Tyrannus vertucalis* Say
Least flycatcher	*Empidonax minimus* (Baird and Baird)
Horned lark	*Eremophila alpestris* (Linnaeus)
Barn swallow	*Hirundo rustica* (Linnaeus)
Black-billed magpie	*Pica pica* (Linnaeus)
Common crow	*Corvus brachyrhynchos* Brehm
Black-capped chickadee	*Parus atricapillus* Linnaeus
Red-breasted nuthatch	*Sitta canadensis* Linnaeus
House wren	*Troglodytes aedon* Vieillot
Brown thrasher	*Toxostoma rufum* (Linnaeus)
American robin	*Turdus migratorius* Linnaeus
Veery	*Catharus fuscescens* (Stephens)
Mountain bluebird	*Silia currucoides* (Bechstein)
Sprague's pipit	*Anthus spragueii* (Audubon)
Cedar waxwing	*Bombycilla cedrorum* Vieillot
Loggerhead shrike	*Lanius ludovicianus* Linnaeus
Yellow warbler	*Dendroica petechia* (Linnaeus)

Yellow-breasted chat	*Icteria virens* (Linnaeus)
Western meadowlark	*Sturnella neglecta* Audubon
Yellow-headed blackbird	*Xanthocephalus xanthocephalus* (Bonaparte)
Red-winged blackbird	*Agelaius phoeniceus* (Linnaeus)
Northern oriole	*Icterus galbula* (Linnaeus)
Brewer's blackbird	*Euphagus cyanocephalus* (Wagler)
Brown-headed cowbird	*Molothrus ater* (Boddaert)
Rose-breasted grosbeak	*Pheucticus ludovicianus* (Linnaeus)
American goldfinch	*Spinus tristis* (Linnaeus)
Rufous-sided towhee	*Pipilo eruthrophthalmus* (Linnaeus)
Vesper sparrow	*Pooecetes gramineus* (Gmelin)
Lark sparrow	*Chondestes grammacus* (Say)
Clay-colored sparrow	*Spizella pallida* (Swainson)
Song sparrow	*Melospiza melodia* (Wilson)

AMPHIBIANS:

Common name	**Scientific name**
Tiger salamander	*Ambystoma tigrinum* (Green)
Plains spadefoot	*Scaphiopus bombifrons* Cope
Canadian toad	*Bufo hemiophrys* Cope
Great plains toad	*Bufo cognathus* Say
Leopard frog	*Rana pipiens* Schreber

Appendix 3: Cluster analysis.

Percent cover of each plant species was estimated within a 3 m radius of each trap location and tabulated. Cluster analysis was used to cluster trap locations into groups of similar vegetative composition and percent cover; ie. habitat type (as described in Sokal and Rohlf 1981). The SAS cluster analysis package was used to perform the analysis.

The cubic clustering criterion (CCC) indicates that there are about 10 significantly different clusters (Fig 6). The CCC indicates the true number of clusters if the variables (plant species) can be assumed to be independently distributed. Although the vegetation in this study could not be assumed to be independently distributed the cluster analysis is robust to violations of this assumption, and the CCC is still a reasonable indicator of the number of clusters when this assumption is violated.

The percent cover of the plant species in each cluster is described in table 1. The habitat types were not all equally represented on the active complexes (Table 2) but each active complex had more than one habitat type. Clusters number four, five, six, seven and eight did not occur in early summer of but did in late summer indicating that the habitat changed over the summer as vegetation grew.

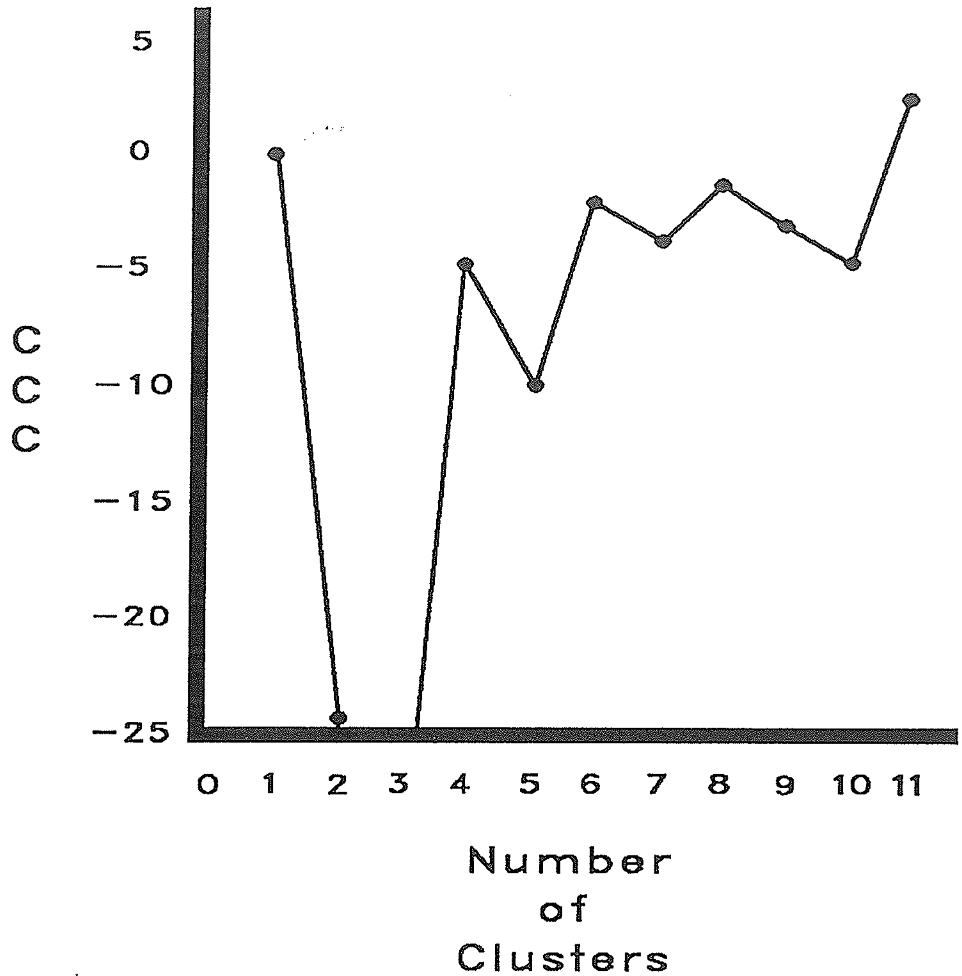

Figure 7: Plot of the Cubic Clustering Criterion (CCC) versus the number of clusters for the cluster analysis of the vegetation data taken during the 1985 field season. The point of inflection, where the graph recrosses the zero point indicates that there are 10 statistically different clusters.

Table 1: The range of percent cover of each plant species in the clusters resulting from the cluster analysis and the number of trap sites in each of the clusters.

	Percent cover								
Cluster	Lance-leaved psoralea	Wild rye	Hoary sage	Wild rose	Goose-berry	Creeping juniper	Other grasses	Other forbes	Trees
0	0	0	0	0	0	0	0	0	0
1	0-50	0-20	0-20	0-20	0-10	0-10	0-70	0-30	0-20
2	30-90	0-40	0-10	0-10	0-10	0-40	0-30	0-40	0-20
3	0-30	0	0-10	30-70	0-20	0-30	0-10	0-30	0-10
4	0-20	0-5	0-25	0-30	0-30	40-50	0-5	0-15	0-10
5	0-10	0	0-20	0-40	25-35	0-20	0-10	0-10	0
6	0-35	0-10	20-70	0-30	0-30	0-15	0-30	0-20	0-20
7	0	0	0-10	0-10	0-10	70-80	0-10	0-10	0-10
8	10	10	10	0	0	0	10	45	0
9	5	0	0	0	0	0	0	0	50
10	30	0	0	0	0	0	5	0	0

Table 2: Number of trap sites in each of the clusters for early and late summer of 1985.

	Early Summer	Late Summer
Cluster	Number of sites	Number of sites
0	44	88
1	184	281
2	118	139
3	11	19
4	4	8
5	0	14
6	0	30
7	0	3
8	0	1
9	1	1
10	1	1
Total captures	363	585

Appendix 4: List of the areas of the dunes sampled in this study with their respective kangaroo rat populations during the summer of 1985. The populations marked with an * are estimates and not censuses.

Area (ha.)	Population	Name
2.72	6	Watson
3.94	5	Mill-2
13.42	*25	
1.63	3	
3.45	5	Mill-1
93.91	*137	Lawrence
15.67	*37	
3.65	10	
2.37	7	
7.50	10	
0.70	4	

Appendix 5: The calculated areas in hectares of active complexes in the Great Sand Hills, Burstall Sand Hills and Cramersburg Sand Hills.

GREAT SAND HILLS:

14.12	54.06	2.93	9.95	0.5	0.89	1.9	0.42	1.53	1.92	6.37
1.46	2.12	3.42	0.19	3.39	0.99	1.62	1.51	8.16	4.41	4.92
2.89	2.12	3.11	4.13	2.24	8.99	0.69	0.86	0.37	6.84	1.00
1.90	2.80	1.28	2.78	3.24	4.18	1.68	1.10	1.93	1.88	2.18
0.69	2.70	1.57	0.44	0.91	1.19	7.47	0.43	1.05	0.26	0.29
0.32	0.45	0.88	0.33	0.29	0.69	0.38	0.06	0.24	0.89	0.18
0.36	6.64	0.30	0.51	0.54	1.10	0.32	0.49	1.99	0.65	0.56
0.46	3.96	0.54	2.07	0.33	0.85	52.27	20.58	3.77	5.91	5.42
7.77	9.62	5.75	3.72	5.33	7.65	3.97	2.37	2.15	0.36	2.68
20.46	43.73	2.00	1.92	7.02	22.29	2.59	0.58	4.65	3.27	2.10
10.07	0.79	1.95	8.18	1.99	0.40	2.33	3.80	2.27	1.66	2.06
0.64	0.50	4.39	3.66	0.91	0.37	0.55	2.00	1.26	2.86	5.62
5.91	0.53	1.51	3.35	2.30	2.34	1.56	1.00	3.25	1.01	3.30
0.61	1.64	1.33	1.33	1.84	1.39	0.80	8.57	2.19	2.19	1.90
1.59	1.70	3.84	3.73	2.06	3.55	1.58	5.03	0.26	0.70	0.80
1.76	0.91	2.99	1.98	0.58	2.47	0.81	1.08	1.73	1.04	0.99
0.62	0.45	0.32	0.41	0.27	0.26					

Total number = 182

BURSTALL:

8.72	2.42	1.10	1.60	9.98	1.81	3.59	1.00	1.27	0.37	1.16
2.03	1.32	1.00								

Total number = 14

CRAMERSBURG:

7.44	4.23	3.21	1.73	0.39	0.71	1.10	0.64	0.10	0.27	1.24
1.02	0.95	0.64								

Total number = 14

LITERATURE CITED

Alcoze, T. M., and E. G. Zimmerman 1973. Food habits and dietary overlap of two heteromyid rodents from the mesquite plains of Texas. J. Mammal. 54: 900-909.

Anderson, R. M. 1946. Catalog of Canadian recent mammals. Nat. Mus. Can., Bull 102.69, Biol. Ser. 18; 162 pp.

Banfield, A.W.F. 1981. The mammals of Canada. U of Toronto Press, Toronto. 438 pp.

Bartholomew, G. A. and T.J. Cade 1957. Temperature regulation, hibernation and aestivation in the little pocket mouse, Perognathus longimembris. J.Mammal. 38: 60-72.

Bartholomew, G. A. and H. H. Caswell 1951. Locomotion in kangaroo rats and its adaptive significance. J. Mammal. 32: 155-169.

Beatley, J. C. 1969. Dependence of desert rodents on winter annuals and precipitation. Ecology 50: 721-724.

Beatley, J. C. 1976a. Environments of kangaroo rats (Dipodomys) and effects of environmental change on populations in southern Nevada. J. Mammal. 57: 67-93.

Beatley, J. C. 1976b. Rainfall and fluctuating plant populations in relation to distribution and numbers of desert rodents in southern Nevada. Oecologia (Berl.) 24: 21-42.

Behrends, P., M. Daly and M. I. Wilson 1986a. Range use and spatial relationships of Merriam's kangaroo rats (Dipodomys merriami). Behaviour 96: 187-209.

Behrends, P., M. Daly and M. I. Wilson 1986b. Aboveground activity of Merriam's kangaroo rats (Dipodomys merriami) in relation to sex and reproduction. Behaviour 96: 210-226.

Beverstock, P. R., C. H. S. Watts and L. Spencer 1979. Water-balance of small lactating rodents V. The total water-balance piceture of the mother young unit. Comp. Biochem. Physiol. 63A: 247-252.

Breyen, L. J., W. G. Bradley and M. K. Yousef 1973. Physiological and ecological studies on the chisel-toothed kangaroo rat, Dipodomys microps. Comp. Biochem. Physiol. 44a: 543-555.

Brower, J. E. and T. J. Cade 1971. Bicircadian torpor in pocket mice. Bioscience 21: 181-182.

Bowers, M. A., 1986. Geographic comparison of microhabitats used by three heteromyids in response to rarefaction. J. Mammal. 67: 46-52.

Brown, J. H. 1973. Species diversity of seed-eatiing desert rodents in sand dune habitats. Ecology 54: 775-787.

Brown, J. T. and G. A. Bartholomew 1969. Periodicity and energetics of torpor in the kangaroo mouse *Microdipodops pallidis.* Ecology 50: 705-709.

Brown, J. H., and G. A. Lieberman 1973. Resource utilization and coexistence of seed-eating desert rodents in sand dune habitats. Ecology 54: 788-797.

Brown, J. H., and J. C. Munger 1985. Experimental manipulation of a desert rodent community: food addition and species removal. Ecology 66: 1545-1563.

Brown, A. B., J. O. Whitaker, T. W. French and C. Maser 1986. Note on the food habits of the screach owl and the burrowing owl of south eastern Oregon. Great Basin Nat. 46: 421-426.

Burt, W. H. and R. P. Grossenheider 1976. A field guide to the mammals, Field marks of all North American species found north of Mexico. Houghton Mifflin Co., Boston 289pp.

Butterworth, B. B. 1961. The breeding of *Dipodomys deserti* in the laboratory. J. Mammal. 42: 413-414.

Carpenter, R. M. 1966. A comparison of thermoregulation and water metabolism in the kangaroo rats *Dipodomys agilis* and *Dipodomys merriami.* Univ. Calif. Publs. Zool. 78: 1-36.

Chew, R. M. 1958. Reproduction by *Dipodomys merriami* in captivity. J. Mammal. 39: 597-598.

Chew, R. M., R. G. Lindburg and P. Hayden 1965. Circadian rhythm of metabolic rate in pocket mice. J.Mammal. 46: 477-494.

Cox, C. B., I. N. Healey and P. D. Moore 1976. Biogeography: an ecological and evolutionary approach, 2nd ed. Blackwell Scientific Publ., Oxford. 194 pp.

Csuti, B. A. 1979. Patterns of adaptation and variation in the great basin kangaroo rat (*Dipodomys microps*). University of California Publications in Zoology vol. 111. University of California Press, Berkley 75pp.

Daly, M., M. I. Wilson and P. Behrends 1984. Breeding of captive kangaroo rats, *Dipodomys merriami* and *D. microps*. J. Mammal. 65: 338-341.

Daubenmire, R. 1968. Ecology of fire in grasslands. Adv. Ecol. Res. 5: 209-266.

David, P. P. 1971. The Brookdale road section and its significance in the chronological studies of dune activities in the Brandon Sand Hills of Manitoba. The Geological Association of Canada, Special Paper Num. 9; 1971.

David, P. P. 1972. Great Sand Hills, Saskatchewan. In Quaternary geology and geomorphology between Winnipeg and the Rocky Mountains, 24th International Geological Congress Field Excursion, C-22, Guidebook. N. W. Rutter and E. A. Christiansen (eds.).

Dawson, W. R. 1955. The relation of oxygen consumption to temperature in desert rodents. J.Mammal. 36: 543-553.

Day, B. N., H. J. Egoscue and A. M. Woodbury 1956. Ord kangaroo rat in captivity. Science 124: 485-486.

Duke, K. L. 1944. The breeding season in two species of Dipodomys. J. Mammal. 25: 155-160.

Duke, K. L. 1940. A preliminary histological study of the ovary of the kangaroo rat, *Dipodomys ordii columbianus.* The Great Basin Nat. 1: 63-72.

Egoscue, H. J., J. G. Bittmenn and J. A. Petrovich 1970. Some fecundity records for captive small mammals. J. Mammal. 51: 622-623.

Eisenburg, J. F. and D. E. Isaac 1963. The reproduction of heteromyid rodents in captivity. J. Mammal. 44: 61-67.

Epp, H. T. and L. Townley-Smith 1980. The great sand hills of Saskatchewan. Saskatchewan Dept. of the Environment publ. 156pp.

Fitterer, P. 1984, 1985. Grazier and range manager for the Signal Valley Stockman's Association land lease. Frequent communications concerning range management.

Flake, L. D. 1973. Food habits of four species of rodents on a shortgrass prairie in Colorado. J. Mammal. 54: 636-647.

French, A. R. 1976. Selection of high temperatures for hibernation by the pocket mouse, *Perognathus longimembris* : ecological advantages and energetic consequences. Ecology 57: 185-191.

Geluso, K. N. 1986. Fire-avoidance behavior of meadow voles (*Microtus pennsylvanicus*). Amer. Midl. Nat. 116: 202-205.

Grant, W. E., and E. C. Birney 1979. Small mammal community structure in North American grasslands. J. Mammal. 60: 23-36.

Groves, C. R. and B. L. Keller 1981. Movements by small mammals on a radioactive waste disposal area in southwestern Idaho. Great Basin Nat. 46: 404-410.

Groves, C. R. and B. L. Keller 1983. Ecological characteristics of small mammals on a radioactive waste disposal area in southwestern Idaho. Amer. Midl. Nat. 109: 253-263.

Gumma, M. R. and F. E. South 1970. Hypothermia and behavioral thermoregulation by the hamster (*Mesocricetus auratus*). Anim. Behav. 18: 504-511.

Hafner, J. C. and M. S. Hafner 1983. Evolutionary relationships of heteromyid rodents. Great Basin Naturalist Memoirs 7: 3- 29.

Hainsworth, F. R., B. G. Collins and L. L. Wolf 1977. The function of torpor in hummingbirds. Physiol. Zool. 50: 215-220.

Hawbrecker, A. C. 1940. The burrowing and feeding habits of *Dipodomys venustus.* J. Mammal. 22: 388-396.

Hilborn, R. J. A. Redfield, and C. J. Krebs 1976. On the reliability of enumeration for mark and recapture census of voles. Can. J. Zool. 54: 1019-1024.

Hoditschek, B. and T. L. Best. 1983. Reproductive biology of Ord's kangaroo rat (*Dipodomys ordi*) in Oklahoma. J. Mammal. 64: 121-127.

Howes, B. 1984, 1985. Farmer and Grazier. Frequent communications concerning agricultural crops and range management.

Hudson, J. W. and J. A. Rummel 1966. Water metabolism and temperature regulation of the primitive heteromyids, *Liomys salvani* and *Liomys irroratus.* Ecology 47: 345-354.

Jones, J. K., D. H. Armstrong, R. S. Hoffman and C. Jones 1983. Mammals of the northern Great Plains. U of Nebraska Press, Lincoln, 379 pp.

Kenagy, G. J. 1972. Saltbush leaves: excision of hypersaline tissue by a kangaroo rat. Science 178: 1094-1096.

Kenagy, G. J. 1973a. Adaptations to leaf eating in the great basin kangaroo rat, *Dipodomys microps.* Oecologica 12: 383-412.

Kenagy, G. J. 1973b. Daily and seasonal patterns of activity and energetics in a heteromyid rodent community. Ecology 54: 1201-1219.

Kenagy, G. J. and G. A. Bartholomew 1985. Seasonal reproductive patterns in five coexisting California desert rodent species. Ecol. Monogr. 55: 371-397.

Kennedy, M. L., and G. A. Schnell 1978. Geographic variation and sexual dimorphism in Ord's kangaroo rat, *Dipodomys ordi.* J. Mammal. 59: 45-59.

Kotler, B. P. 1985. Owl predation on desert rodents which differ in morphology and behavior. J. Mammal. 66: 824-828.

Lawhon, D. K., and M. S. Hafner 1981. Tactile discriminatory ability and foraging strategies in kangaroo rats and pocket mice (Rodentia: Heteromyidae). Oecologia (Berl.) 50: 303-309.

Lockard, R. B. 1978. Seasonal change in the activity pattern of *Dipodomys spectabilis.* J. Mammal. 59: 563-568.

MacMillen, R. E. 1972. Water economy of nocturnal desert rodents. pp. 147-174. In Comparative Physiology of Desert Animals. G. M. O. Maloiy (ed.). Academic press, New York.

MacMillen, R. E. 1983. Adaptive physiology of heteromyid rodents. Great Basin Nat. Memoirs 7: 65-76.

MacMillen, R. E. and D. S. Hinds 1983. Water regulatory efficiency in heteromyid rodents: a model and its application. Ecology 64: 152-164.

Mares, M. A. 1983. Desert rodent adaptation and community structure. Great Basin Nat. Memoirs 7: 30-43.

Marlow, B. J. 1969. A comparison of the locomotion of two desert-living australian mammals, *Antechinomys spenceri* (Marsupialia: Dasyuridae) and *Notomys cervinus* (Rodentia: Muridae). J. Zool., Lond. 157:159-167.

McClenaghan, L. R. 1983. Comparative ecology of sympatric *Dipodomys merriami* populations in southern California. Acta theriol. 29: 175-185.

McNab, B. K. 1971. On the ecological significance of Bergmann's rule. Ecology 52: 845-854.

M'Closkey, R. T. 1980. Spatial patterns in sizes of seeds collected by four species of heteromyid rodents. Ecology 61: 486-489.

Minor, J. 1984, 1985. Grazier, owner of the Minor Bros. ranch. Frequent communications concerning range management and fire suppression

M'Closkey, R. T. 1981. Microhabitat use in coexisting desert rodents: the role of population density. Oecologia 50: 332-336.

Monson, G. 1943. Food habits of the bannertailed kangaroo rat in Arizona. J. Wildl. Manage. 7: 98-102.

Morton, S. R., D. S. Hinds and R. E. MacMillen 1980. Cheek pouch capacity in heteromyid rodents. Oecologia (Berl.) 46: 143-146.

Mullen, R. K. 1971. Energy metabolism and body water turnover rates of two species of free living kangaroo rats, *Dipodomys merriami* and *Dipodomys microps.* Comp. Biochem. Physiol., 39A: 379-390.

Nero, R. W. 1956. The kangaroo rat in Saskatchewan. Blue Jay 14: 3-4.

Nero, R. W. and R. W. Fyfe 1956. Kangaroo rat colonies found. Blue Jay 14: 107-110.

Nichelmann, M. 1983. Some characteristics of the biological optimum temperature. J. Therm. Biol. 8: 69-71.

NIkolai, J. C. and D. M. Bramble 1983. Morphological structure and function in desert heteromyid rodents. Great Basin Nat. Memoirs 7: 44-64.

O'Farrell, M. J. 1974. Seasonal activity patterns of rodents in a sagebrush community. J. Mammal. 55: 809-823.

Packard, F. M. 1941. Counts of embryos in nevadan kangaroo rats (Genus *Dipodomys*). J. Mammal. 22: 88-90.

Porter, W. P. and D. M. Gates 1969. Thermodynamic equilibria of animals with environment. Ecological monographs 39; 227-244.

Potter, L. D. 1956. Yearly soil temperatures in eastern North Dakota. Ecology 37: 62-70.

Price, M. V. 1977. Validity of live trapping as a measure of foraging activity of Heteromyid rodents. J. Mammal. 58: 107-110.

Price, M. V. 1978a. Seed dispersion preferences of coexisting desert rodent species. J. Mammal. 59: 624-626.

Price, M. V. 1978b. The role of microhabitat in structuring desert rodent communities. Ecology 59: 910-921.

Price, M. V. and J. H. Brown 1983. Patterns of morphology and resource use in North American desert communities. Great Basin Nat. Memoirs 7: 117-134.

Pyke, G. H., H. R. Pulliam and E. L. Charnov 1977. Optimal foraging: a selective review of theory and tests. Quart. Rev. Biol. 52: 137-154.

Rebar, C. and O. J. Reichman 1983. Ingestion of moldy seeds by heteromyid rodents. J. Mammal. 64: 713-715.

Reichman, O. J. 1977. Optimization of diets through food preferences by heteromyid rodents. Ecology 58: 454-457.

Reichman, O. J. 1981. Factors influencing foraging in desert rodents. In Foraging behavior. A. C. Kamil and T. D. Sargent (eds.). Garland STPM Press, New York pp. 195-213.

Reichman, O. J. 1983. Behavior of desert heteromyids. Great Basin Nat. Memoirs 7: 77-90.

Reichman, O. J. and D. Oberstein 1977. Selection of seed distribution types by *Dipodomys merriami* and *Perognathus amplus.* Ecology 58: 636-643.

Reichman, O. J. and K. M. VanDeGraff 1975. Association between ingestion of green vegetation and desert rodent reproduction. J. Mammal. 56: 503-506.

Rosenzweig, M. L. 1973. Habitat selection experiments with a pair of coexisting heteromyid rodent species. Ecology 54: 111-117.

Rosenzweig, M. L. and J. Winakur 1969. Population ecology of desert communities: Habitats and environmental complexity. Ecology 50: 558-572.

Russell, B. 1984, 1985. Manager of Paterson's Grain Elevator, Sceptre Saskatchewan. Frequent communications concerning agricultural crops.

Scelza, J. and J. Knoll 1982. Seasonal variation in the rate of evaporatative water loss in the kangaroo rat, *Dipodomys panamintinus.* Comp. Biochem. Physiol. 71A: 579-584.

Schmid, W. D. 1976. Temperature gradients in the nasal passages of small mammals. Comp. Biochem. Physiol. 54A: 305-308.

Schmidt-Neilsen, K., F. R. Hainsworth and D. E. Murrish 1970. Counter-current heat exchange in the respiratory passages: effect on water and heat balance. Resp. Physiol. 9: 263-276.

Schmidt-Neilsen, B., K. Schmidt-Neilsen, A. Brokaw and H. Schneiderman 1948. Water conservation in desert rodents. J. Cell. Comp. Physiol. 32: 331-360.

Schreiber, R. K. 1979. Coefficients of digestability and caloric diet of rodents in the northern Great Basin Desert. J. Mammal. 60: 416-420.

Smigel, B. W. and M. L. Rosenzweig 1974. Seed selection in *Dipodomys merriami* and *Perognathus penicillatus.* Ecology 55: 329-339.

Smith, H. C. 1972. Some recent records of Alberta mammals. Blue Jay 30: 53-54.

Smith, M. H. 1968. A comparison of different methods of capturing and estimating numbers of mice. J, Mammal. 49: 455-462.

Smith, H. C. and M. J. Hampson 1969. A kangaroo rat colony in Alberta. Blue Jay 27: 224.

Soholt, L. F. 1977. Consumption of herbaceous vegetation and water during reproduction and development of Merriam's kangaroo rat, *Dipodomys merriami.* Amer. Midland Nat. 98: 445-457.

Soper, J. D. 1964. The mammals of Alberta. Hamley Press, Edmonton pp. 177-178.

Stamp, N. E. and R. O. Ohmart 1978. Resource utilization by desert rodents in the lower sonoran desert. Ecology 59: 700-707.

Stevens, W. 1972. Kangaroo rats and rattlesnakes, 4th. ed. Department of National Defence Publ. Canadian Forces Base Suffield: 21pp.

Thompson, S. D. 1982. Microhabitat utilization and foraging behavior of bipedal and quadrupedal heteromyid rodents. Ecology 63:1303-1312.

Thompson, S. D. 1982. Structure and species composition of desert heteromyid species assemblages: effects of a simple habitat manipulation. Ecology 63: 1313-1321.

Trombulak, S. C. and G. J. Kenagy 1980. Effects of seed distribution and competitors on seed harvesting efficiency in heteromyid rodents. Oecologia (Berl.) 44: 342-346.

Tucker, V. A. 1966. Diurnal torpor and its relation to food consumption and weight changes in the California pocket mouse, *Perognathus californicus.* Ecology 47: 245-252.

VanDeGraff, K. M. and R. P. Balda 1973. Importance of green vegetation for reproduction in the kangaroo rat, *Dipodomys merriami merriami*. J. Mammal. 54: 509-512.

Walker, L. E., J. M. Walker, J. W. I. Palca and R. J. Berger 1983. A continuum of sleep and shallow torpor in fasting doves. Science 221: 194-195.

Watson, A. 1984, 1985. Senior member of the Watson Bros. Ranch. Frequent communications concerning fire suppression and range management.

Webster, D. B. 1962. A function of the enlarged middle-ear cavities of the kangaroo rat, *Dipodomys.* Physiol. Zool. 35: 248-255

Webster, D. B. and M. Webster 1971. Adaptive value of hearing and vision in kangaroo rat predator avoidance. Brain, Behav. Evol. 4: 310-322.

Wilson, M., M. Daly and P. Behrends 1985. The estrous cycle of two species of kangaroo rats (*Dipodomys microps* and *D. merriami*). J. Mammal. 66: 726-732.

Wright, H. A. and A. W. Bailey 1982. Fire ecology: United States and southern Canada. John Wiley and Sons Inc., New York 501pp.

Wrigley, R. E. 1986. Mammals in North America. Hyperion Press Ltd., Winnipeg 360 pp.

Yousef, M. K. and D. B. Dill 1971. Daily cycles of hibernation in the kangaroo rat, *Dipodomys merriami.* Cryobiology 8: 441-446.

Yousef, M. K., W. D. Robertson and H. D. Johnson 1970. Energy expenditure of running kangaroo rats *Dipodomys merriami.* Comp. Biochem. Physiol. 36: 387-393.