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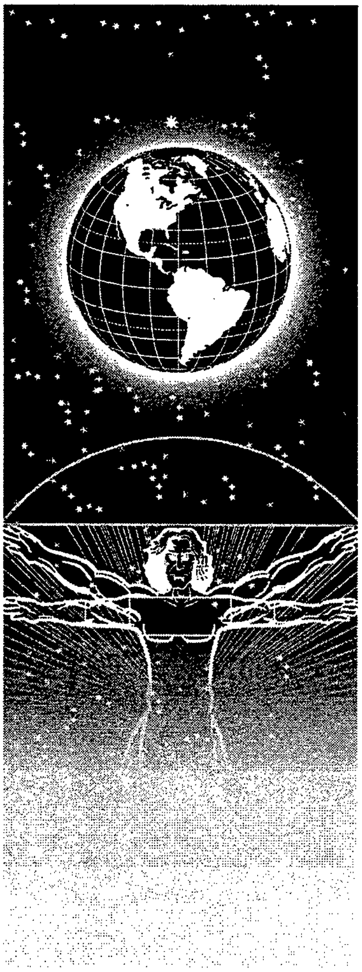

UNITED STATES AIR FORCE RESEARCH LABORATORY

Effects of Low-Altitude Aircraft Overflights on the Desert Kit Fox (Vulpes macrotis arsipus) and its Small Mammal Prey on the Barry M. Goldwater Air Force Range, Arizona, 1991-1994

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Final Report for the Period November 1990 to February 1995

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FOR THE COMMANDER

MARIS M. VIKMANIS
Chief, Crew System Interface Division
Air Force Research Laboratory

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There has been public concern that wildlife could be affected by military training activities. Of particular interest was the hypothesis that noise from military aircraft would disrupt the ecological balance between predator and prey by giving one or the other an advantage. To gauge these effects, this study was conducted under an Air Force Range in an area receiving levels of exposure higher than normally encountered under a Military Training Route. A nearby control site was exposed to much lower levels of noise. Noise monitors recorded actual exposure, and hearing of one heteromyid species, the kangaroo rat, was measured in situ. A total of 14,455 trap-nights were spent monitoring nocturnal small mammal communities on exposed and control plots. Rodent species diversity, numbers, reproductive activity, recruitment, mean weights, and survival were measured. The kit fox, a predator, was also examined. Although differences were uncovered between kit fox and small mammal populations between the control and exposed areas, none was large, and none was at odds with the most parsimonious natural explanations. If the effects observed are assumed to be the result of aircraft noise exposure, the consequences to rodents and fox populations were smaller in magnitude than the natural variability observed during the course of the study.

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FOREWORD

This study was prepared by personnel from the Hubbs-Sea World Research Institute (HSWRI) and its subcontractors under the direction of Dr. Ann Bowles, Principal Investigator. HSWRI is a member of the BBN Systems and Technologies Division (BBN) team of experts engaged in research on the Noise and Sonic Boom Impact Technology Program (NSBIT).

The BBN effort is conducted under NSBIT Contract F33615-90-D-0653, which is under the direction of Mr. Andrew Kugler, BBN Program Manager. The NSBIT program is conducted by the United States Air Force, Armstrong Laboratory/OEBN, under the direction of Lt. Col. Robert Kull, Jr., Program Manager.

The work described herein is in fulfillment of Delivery Order 02, Task 3.2, begun in 1991.

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EXECUTIVE SUMMARY

A major concern of the NSBIT program is the effects of low-altitude aircraft overflights along Military Training Routes (MTRs) scattered across the United States. These routes are flown by a variety of aircraft, often at very low altitudes (200 ft), and extend for thousands of miles. There has been public concern that wildlife could be affected by training activities. In cases where the home range of an animal is small relative to the width of an MTR, effects of chronic exposure might be expected, such as hearing loss, effects on reproduction and survivorship, and interference with perception of natural signals. The potential for these effects has received little attention. In particular, the effects of aircraft noise on the hearing of free-ranging animals has not been studied at all, even though the ear is vulnerable to noise.

This study was conducted under training racetracks of the Barry M. Goldwater Air Force Range (BMGAFR), in an area receiving levels of exposure somewhat above those likely to be encountered under a Military Training Route. It therefore provides a conservative, worst-case scenario for exposure. A control site was selected near this site that was well-matched in habitat type, but exposed to much lower levels of noise. Noise monitors were placed on a 0.5-km sampling grid in the exposed area and a 2-km grid in the control area. Each of 59 sites, 53 in the exposed area and 6 in the control area, was sampled for a minimum of 144 flight hours for a total of 19,035 hours of monitoring from September 1991 to September 1994. The median sampling time for all locations was 254 hrs. A total of 19,171 sound events in excess of 80 dB MXFA (maximum, fast, A-weighted sound pressure level) was recorded.

To compare the most intense events recorded at each sampling station, the mean of the 30 loudest ASELs (single-event A-weighted sound exposure levels) was calculated for each. A few of the sampling stations had all 30 of their highest events greater than 110 dB; these were stations lying under the low-altitude entry to he range and under the "pop-up" point, the point at which aircraft climb rapidly on approach to a bombing arget. The highest ASEL recorded in this area was 115.5 dB. The mean sound level for the loudest 30 events recorded for all stations in the exposed area was 103.4 dB. The mean number of overflights greater han 80 dB MXFA recorded on the exposed site was 30.22 flights/day. Twenty-four hour average equivalent ound exposure levels (24HLs) in the exposed area averaged 68.8 dB and reached highs of 69.2-75.7 dB. The control site received noise levels at least an order of magnitude lower than the exposed area. No ASEL was in excess of 100 dB. The mean sound level for the loudest 30 events recorded in the control area was 7.3 dB. The event rate was 0.99 flights/day greater than 80 dB MXFA, less than one-tenth of the rate on he exposed area. The average of the maximum 24HLs for the control site was 51.3 dB. Although a subtle difference in availability of water in the control area led to slightly greater diversity and cover, the control nd exposed areas were generally very well matched.

As measured by one hour average equivalent sound exposure levels (1HL), levels on both sites varied diurnally from lows of 20 dB (close to the noise floor of the community noise monitors used to make the measurements) to highs of about 45 dB. On average, they ranged around 30-35 dB. During hours when sorties were flown, hourly averages on the exposed site were between 60 and 65 dB, from 0900-1200 hrs and 1300-1600 hrs. There was also an increase in hourly average from 1900-2200 hrs during nighttime sorties. On the most intensely exposed sites, the maximum 24HLs ranged from 61.3 to 76.4 dB.

Many of the species on the BMGAFR spend the day in burrows or dens, which might be thought to protect them from aircraft noise. In fact, ASELs in small mammal burrows averaged less than 3 dB lower than at 1.2 m above the surface. Significant attenuation was seen only above 1300 Hz. The small mammals that were the focus of this study, heteromyid rodents, hear well down to 100 Hz, and were therefore likely to hear the aircraft sounds well in their burrows. Kit fox dens conferred greater protection, with levels attenuated significantly above 500 Hz. Measurements of kit fox hearing indicated that foxes did not hear especially well at low frequencies.

Hearing of one heteromyid species, the kangaroo rat, was measured ***in situ***. Auditory brainstem responses (ABRs) were used to measure the hearing of nine kangaroo rats in each area. A significant difference in latency was uncovered between the two areas (ANOVA; N = 9, 9; Rao's R = 5.365, p = .0054, d.f. = 4, 113), amounting to a 2% dB difference in latency. This difference was small and was best explained by individual differences in the small sample of individuals tested. A single profoundly deaf individual was encountered on the exposed site in good condition and apparently healthy. The hearing loss was profound enough that it was most likely the result of previous illness or congenital or genetic defect, because the noise levels on the BMGAFR are not great enough to produce deafness or profound auditory deficit in laboratory animals.

Population parameters of small mammals were examined by establishing 1.1 ha live-trap grids on the exposed and control areas. Three of five trapping grids established in the exposed area were attacked by predators, probably kit foxes. Therefore, final comparisons were made between three trapping grids in the control area and two trapping grids in the exposed area (February 1993 to September 1994).

Over the course of the study, a total of 14,455 trap-nights were spent monitoring nocturnal small mammal communities on five exposed and three control plots. A total of 7,500 captures were made of 2,328 marked individuals. In order of decreasing abundance, the nocturnal species present on the study plots were Merriam's kangaroo rat (Dipodomys merriami), the Arizona pocket mouse (Perognathus amplus), the desert pocket mouse (Chaetodipus penicillatus), the banner-tailed kangaroo rat (Dipodomys spectabilis), the white-throated wood rat (Neotoma albigula), and the southern grasshopper mouse (Onychomys torridus). The last three species were not common. The banner-tailed kangaroo rat was not known to occur in the area previously. The diurnal round-tailed ground squirrel (Spermophilus tereticaudus) and antelope squirrel

(*Ammospermophilus harrisi*) were also captured incidentally on several occasions, but were not included in any of the analyses.

Species diversity varied seasonally on all the study plots and patterns of temporal change were similar among years. Levels of diversity and patterns of change were very similar when control and exposed plots were compared. Rodent species diversity was greatest on all plots from spring through fall and declined in the winter because the two pocket mouse species (*Chaetodipus penicillatus* and *Perognathus amplus*) hibernated. Species diversity was not significantly different between control and exposed plots (F = 3.77, p = 0.1475, d.f. = 1,3). Biomass on all plots increased over the course of the study, reaching a peak in the fall and winter of 1993 after two years of unusually high rainfall. Declining biomass was observed in 1994 after almost no rain fell in the spring.

Numbers of Merriam's kangaroo rats increased steadily on all plots over the first two years, with peak densities of approximately 50 individuals per plot. Patterns of change were similar on exposed and control plots. Differences in densities on control and exposed plots were not significant (F = 3.95, p = 0.1411, d.f. = 1, 3). Numbers of Arizona pocket mice increased rapidly to a peak during the spring of 1992 and then declined during the summer and fall. The highest density was about 40 individuals per plot. Differences in densities of mice on control and exposed plots were not significant (F = 2.77, p = 0.1947, d.f. = 1, 3). Populations of desert pocket mice were considerably smaller than those of kangaroo rats and Arizona pocket mice on the study plots. Fluctuations in numbers of desert pocket mice were of relatively low magnitude, with peaks of 12-14 individuals per plot in the summer and fall of 1993. Mean densities were not different on control and exposed plots (F = 0.76, p = 0.4470, d.f. = 1, 3).

Not unexpectedly, levels of reproductive activity varied greatly over seasons. Males with scrotal testes were found on exposed and control plots during all seasons, but were most numerous in spring and early summer. Breeding females were present only in spring and summer. There was also significant year-to-year variation for both sexes on all plots. Reproductive activity was generally reduced on all plots during the spring and summer of 1994, after the failure of the spring rains. Comparisons of kangaroo rat males on control and exposed plots revealed significant differences in breeding activity in five out of eleven seasons; reproductive activity was greater on control plots in four out of the five significant comparisons. For females, only two comparisons were significant and reproductive activity was greater on the exposed plots in both. Arizona pocket mice also had lowered breeding activity during 1994. When control and exposed plots were compared, the proportion of reproductive males on control plots was greater than that on exposed plots during he spring of 1993; all other comparisons were not statistically significant. In desert pocket mice, the presence of reproductive individuals of both sexes was restricted to spring and summer. However, among-year heterogeneity was only observed for spring in females on the control plots and for spring in males on exposed plots. When control and exposed plots were compared, only the comparison involving males during the spring of 1994 was statistically significant, with more reproductive activity being observed on the control plots.

For each species, recruitment on study plots was measured as the proportion of the animals that were captured for the first time in that month relative to the number known to be alive in each month. Rates were greatest in 1992 and 1993. When control and exposed grids were compared for each season, for Merriam's kangaroo rats, six out of ten comparisons were statistically significant; recruitment rates were greater on exposed grids in all six significant comparisons (X^2 heterogeneity test, $p < 0.05$). Recruitment in Arizona pocket mice was greatest in spring for both control and exposed plots and in fall for control plots; recruitment was greatest in the spring of 1992 and 1993. Rates of recruitment were significantly greater on the exposed grids than on the control grids in three out of eight seasonal comparisons. For desert pocket mice, significant within-season differences in recruitment between control and exposed plots were found in three out of seven comparisons; exposed plots had greater recruitment in fall 1992 and spring 1993, while control plots had greater recruitment in summer 1994. Thus, there was evidence for a marginal increase in recruitment rate on exposed plots in the kangaroo rat and Arizona pocket mouse.

For each month, mean weights on each plot were assessed by ANOVA with repeated measures. Body weights for both male and female kangaroo rats on all plots fluctuated in a seasonal fashion, with the heaviest animals typically being found in spring and the lightest animals being present in the winter. Mean male body weight did not differ between exposed and control plots ($F = 0.45$, $p = 0.5512$, d.f. = 1, 3) nor did mean female body weight ($F = 4.87$, $p = 0.1145$, d.f. = 1,3). Patterns of temporal changes in Arizona pocket mice were similar, with largest body weights for both sexes being observed in the spring and the lowest weights in the fall, just before hibernation. Mean weights for males did not differ between control and exposed areas ($F = 1.33$, $p = 0.3321$, d.f. = 1, 3) nor did mean weights for females ($F = 0.15$, $p = 0.7247$, d.f. = 1, 3). The pattern was similar for the desert pocket mouse.

Survival was measured as the minimum monthly survival rate of individuals in the trappable population for each plot. Survival rates were calculated separately for males and females, and monthly rates were pooled by season. These values included losses due to mortality and to dispersal. When data for the predator-disturbed plots were removed, average monthly survival of kangaroo rats on exposed plots was 0.778 for males and 0.775 for females; these rates were significantly different from rates on control grids (0.822 and 0.845, respectively; males: $X^2 = 4.83$, $p = 0.0279$, d.f. = 1; females: $X^2 = 6.43$, $p = 0.0112$, d.f. = 1). The difference in the rates between the two areas was about 8%. For males, survival rates were significantly greater on control plots than on exposed plots in spring 1992, fall 1992, and spring 1993, seasons when conditions were good. Females on control plots enjoyed higher survival rates than females on exposed plots in fall 1992 and fall 1993, when conditions were good; exposed-plot females had higher survival rates than control plot females in summer 1994, when conditions were poor. For Arizona pocket mice, monthly survival was 0.541 and 0.530 for males and females, respectively, but these rates were still significantly less than on control plots (0.658 and 0.630 respectively; males: $X^2 = 12.52$, $p = 0.0004$, d.f. = 1; females: $X^2 = 6.83$, $p = 0.0091$, d.f. = 1); the difference between the two was approximately 18%. Both males and females on control plots displayed better survival than their counterparts on exposed plots in spring 1993. Overall survival rates for male and female desert pocket mice on control plots were 0.618 and 0.660, respectively, *vs.* rates of 0.570 and 0.664 on exposed plots. These values did not differ significantly.

Survival was also examined by estimating times of persistence, the mean number of months that elapsed between when an individual was first marked and when it disappeared from a study area, a conservative estimate of life span. Differences were assessed by t-tests. Mean time of persistence for Merriam's kangaroo rat on control grids was significantly greater than that for the species on exposed plots. For Arizona pocket mice, mean length of persistence was also significantly greater on control plots than on exposed plots. Mean persistence time for desert pocket mice on control plots was greater than that for exposed plots, although the difference was not statistically significant.

The mild increase in recruitment observed in the exposed areas could have balanced lower survival and greater losses, leading to comparable densities in the two areas. Several plausible explanations are suggested for the differences between control and exposed areas in recruitment, loss rates, and life spans. An obvious explanation was the presence of jet noise, but other factors could have explained some or all of the differences. Vegetation surveys indicated that available rainfall was probably greater on the plots in the control area, hence food may have been somewhat more available. The differences in vegetation between the two areas were greatest during good years, when annual vegetation was abundant, and this is when survivorship in the control area was highest. The corresponding increase in recruitment in the exposed area was probably a density-dependent response to the lower survival of individuals under slightly poorer conditions. The most parsimonious explanation for the differences in rodent survivorship and recruitment was the difference in the vegetation.

n addition, there may have been differences in predator activity between the two areas. Owls and snakes, which are usually the most important predators of heteromyid rodents, were not studied, but another important predator, the kit fox, was examined. Bait stations equipped with cameras were used to determine relative densities of kit foxes and other canids in the two study areas. In April 1993 and January 1994, camera tation surveys showed greater numbers of kit foxes in the control area and larger numbers of gray foxes in he exposed area.

Kit foxes were certainly important predators of heteromyids in both areas. Based on hard matter in scats known to have been left by kit foxes, heteromyids and scorpions represented the most important part of their diet, measured in proportions of scats containing their remains. Scorpions probably represented a smaller part of the diet by weight than heteromyids, making heteromyids the most important prey of foxes on the

BMGAFR. Lagomorphs were not as important as reported by other authors, but may have been under-represented in the scat samples.

A total of 67 foxes were trapped 109 times during 1,286 trap nights from September 1991 to September 1994. Direct enumeration gave the most conservative estimate of the number of animals in the study area. These numbers were influenced by the effort and seasonal timing of trapping surveys. Survival rates were over 80% in 1993, but during the winters of 1992 and 1994, foxes suffered high mortality rates (16 of 25 radio-collared foxes died in 1994, a 64% loss). Fifteen individuals were captured in the 1991-1992 season, 18 in the 1992-1993 season, and 34 in the 1993-1994 season. After the foxes suffered high mortality during January and February 1994, there would have been only twelve left, based on losses in radio-collared animals.

The longest-lived fox (fox #148) on the exposed site was 584 days old, and fox #1 on the control site was alive for at least 862 days. No significant difference was found between days known alive in the exposed site (median = 223 days; 25% and 75% quartiles = 35 and 325 days) and control site (median = 209 days; 25% and 75% quartiles = 43 and 326 days; n = 49, Mann-Whitney U = 247.5, p = 0.782).

Densities of kit foxes on the study site were estimated to be 0.35 foxes/km^2 during the 1991-1992 field season, 0.45 foxes/km^2 in the 1992-1993 season, and 0.63 foxes/km^2 in the 1993-1994 season. These estimates were made by dividing the minimum number known alive by the size of the study area. The values agreed well with estimates based on home range size. The average home range size for both exposed and control areas was 3.73 km^2, which would allow 16 pairs of kit foxes to live within the 60 km study area, for a total of 38 animals and a density of 0.63/km^2. There was no significant difference in home range size between the control and exposed area (t-test = 0.369, p = 0.716, n = 20).

There was no significant difference between the mean weight of foxes on the exposed and control sites (two-way ANOVA, n = 48, F = 1.28, p = 0.263, d.f. = 54). There was also no significant interaction between sex and site (n = 58, F = 0.003, p = 0.987, d.f. = 54). Adult males were significantly heavier than adult females (n = 58, F = 17.9, p << 0.0001, d.f. = 56).

In summary, although differences were uncovered between kit fox and small mammal populations between the control and exposed areas, none was large, and none was at odds with the most parsimonious natural explanations. The only way to determine whether aircraft noise was the relevant factor would have been to expose the control site and leave the exposed site free of noise for a significant period, say one to two years. If the effects observed are assumed to be the result of aircraft noise exposure, the consequences to rodents and fox populations were smaller in magnitude than the natural variability observed during the course of the study. While there was a statistically significant difference in survival rates and life spans of rodents in the exposed plots, these species compensated for lower survivorship by having higher recruitment rates in the exposed area. The rodent species examined on control and exposed plots were indistinguishable based on density, proportions of reproductively active individuals, mean body weights, species diversity and biomass.

Future studies should focus on observations and experimental manipulations that would detect the subtle differences suggested by this study. These should include:

1) Measurements of physiological factors that might result in increased mortality or reduced natality in both foxes and small mammals;

2) Altered flight patterns to determine whether the natural differences observed could be altered;

3) Measurements of dispersal, to determine if changes were due to animals moving toward or away from aircraft noise rather than changes in natality and mortality; and

4) Measurements of auditory capacities at a population level in exposed and unexposed areas.

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1 INTRODUCTION

1.1 RATIONALE FOR THE PROGRAM

A major concern of the NSBIT program is the effects of low-altitude aircraft overflights along Military Training Routes (MTRs) scattered across the United States. These routes are flown by a variety of aircraft, often at very low altitudes (200 ft), and extend for thousands of miles over largely uninhabited areas. They often cross prime wildlife areas, and there has been public concern that wildlife could be affected by the training activities (SAIC International, 1990).

Most previous studies of the effects of aircraft overflights on animals have concentrated on the behavioral responses of large diurnal animals, such as ungulates and raptors (Bowles, 1994). These animals sometimes exhibit a flight response to aircraft, which has led many authors to hypothesize that they are particularly vulnerable to disturbance. However, these animals are unlikely to encounter aircraft at close proximity because their home ranges are large relative to the width of the MTRs, and because they habituate to aircraft overflights quickly (*e.g.*, Harrington and Veitch, 1990; Ellis, 1981; Workman and Bunch, 1991). Acute exposure of naïve animals can cause accidents (although rarely) and temporary abandonment of favored habitat. Chronic effects, such as long-term effects on reproduction, have not been documented in any large bird or mammal, despite repeated attempts.

Greater effects might be expected in cases where the home range of an animal is small relative to the width of an MTR, confining the animal to an area of high noise exposure. There is good evidence from laboratory studies of small mammals that high levels of continuous noise can affect their hearing, health and reproductive success (Gamble, 1982). The effect of intermittent noise is more difficult to detect, however (Borg, 1981). Whether intermittent overflights can cause detectable physiological effects is controversial. One study (Chesser *et al.*, 1975) found enlarged adrenals in wild mice exposed to constant jet traffic near an airfield; however, populations of these animals were as dense as those in areas with less exposure. Hypertrophy of the adrenals is a questionable measure of stress, because the link between hypertrophy and biologically-important impact is tenuous (Moberg, 1985). In addition, it is unknown whether such changes can be found in small mammals exposed to overflights along MTRs, which experience significantly less exposure.

The effects of aircraft noise on the hearing of free-ranging animals have not been studied at all, even though he ear is vulnerable to aircraft noise in the laboratory. Animals with the most sensitive hearing are typically nocturnal, such as cats and small desert mammals. In these species, hearing is a crucial source of information in communication, predator avoidance, prey capture, and navigation. Thus, if exposed, these animals are potentially more vulnerable to the effects of aircraft noise than diurnal species.

Most of the low-altitude training routes are in desert areas, so desert animals receive disproportionate exposure to aircraft overflights. Many of these species are fossorial; that is, they dwell in burrows and dens that protect them from the noise of most overflights. However, those immediately under the flight path are exposed to substantial noise even in burrows and dens, and they may spend considerable time at the surface during the day, particularly immediately before and after weaning, and thus would be directly exposed to overflights. In an environment where the natural background noise is around 20-30 dB[1], an aircraft overflight can be 70-100 dB above the background noise; so, temporary effects on the auditory system might be expected. Also, the burrow may not confer significant protection unless it is deep. The degree to which noise compromises the animals' ability to function is unknown. Hearing is important both to predator avoidance (Webster and Webster, 1971) and prey detection, so predator-prey systems of nocturnal animals are expected to be particularly sensitive.

Some have hypothesized that hearing-dependent animals are much less tolerant of noise than vision-dependent animals because they are restricted to auditory input for information about their environment. In addition, it has been speculated that they are vulnerable to sleep interference (Asherin and Gladwin, 1988). The potential for these effects is completely unknown because no one has studied the effects of frequent exposure to anthropogenic noise on nocturnal or hibernating species. If present, these effects would manifest themselves as changes in circadian activity levels, distribution, survivorship, and reproductive success.

Not only are effects on nocturnal animals unknown, but almost nothing is known about the effects of anthropogenic noise on ecosystems. No previous study of effects on community dynamics has selected measures sufficiently sensitive to detect subtle differences between control and experimental populations.

The goals of this study were thus to:

- Determine whether auditory effects of intermittent low-altitude jet overflights can be uncovered in prey and predator species,
- Determine whether activity or predator-prey interactions are affected, and
- Determine whether there are differences in population dynamics of small nocturnal mammals with good low-frequency hearing as compared with unexposed populations.

Many of the smaller or sedentary species confined to areas with heavy aircraft overflights are threatened, endangered, or closely related to endangered species. These include desert tortoises (Gopherus agassizii), kit foxes, kangaroo rats (Dipodomys spp.), leopard lizards (Gambelia spp.), fringe-toed lizards (Uma spp.), ridge-nosed rattlesnakes (Crotalus willardi), and a number of fish endemic to desert areas, such as the desert

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[1] All noise levels are A-weighted sound pressure levels unless otherwise noted.

pupfish (Cyprinodon macularis). The species considered most vulnerable would be those with sensitive low-frequency hearing, the heteromyid rodents (particularly the kangaroo rat), fish, the leopard lizard, and possibly the kit fox. Environmental Impact Statements (EISs) for activities in desert areas would require estimates of effects on endangered species, although there are currently no data to support such estimates. Thus, the data collected during this project not only provides important basic information on noise effects, but are directly applicable to the NEPA requirements for desert areas.

2 LITERATURE REVIEW

The following is a general introduction to the natural history of the Luke Air Force Range and the Barry M. Goldwater Air Force Range, particularly the species of interest (kit fox and heteromyid rodents), the auditory capacities of these animals, and their predator-prey interactions.

2.1 INTRODUCTION TO THE GEOGRAPHY AND PLANT COMMUNITIES OF THE BARRY M. GOLDWATER AIR FORCE RANGE

The Barry M. Goldwater Air Force Range (BMGAFR) lies in the Sonoran Desert about 40 miles south and east of Phoenix, Arizona. This vast area abuts the Organ Pipe Cactus National Monument and Cabeza Prieta National Wildlife Area in the south and Interstate 8 in the north. In the west it extends almost to the city of Yuma and in the east it encompasses the entirety of the Sauceda and Sand Tank mountain ranges. The air-to-ground "racetracks" on four training ranges are located in the vicinity of State Highway 85, which splits he BMGAFR into two parts (Figure 2-1). Training Range 2 was considered the "exposed area" and a matched area immediately to the north was treated as the "control area" for the purposes of this study.

The BMGAFR is characterized by a series of northwest to southeast trending mountain ranges separated by broad valleys filled with alluvium (the product of erosion), hereafter called alluvial fans or flats. The shoulders of these ranges are called bajadas, and are composed largely of alluvium and rubble from rockfalls. These ranges were formed during the late Tertiary and early Quaternary Basin and Range disturbances, which hrust up the ranges during a series of intense earthquakes. Thus, the mountains are of fairly recent origin. The Sauceda Mountains, two arms of which delimit the northern end of the control and exposed areas, are mainly of volcanic origin (sierra-type mountains) with mesas composed of upthrust sediment. Hat Mountain is an example of such a mesa.

The typical vegetation found on the BMGAFR is Sonoran Desert-scrub. Six subdivisions of the Sonoran Desert are currently recognized (Brown, 1982). Two of these subdivisions are represented on the BMGAFR: he lower Colorado River Valley subdivision and the Arizona Upland subdivision. Alluvial fans in both the ontrol and exposed areas are of the Lower Colorado Valley community type. This subdivision is the driest f the Sonoran desert subdivisions, with an average of 131.2 mm of annual precipitation (Sellers and Hill, 974). Vegetation is typically open and simple, consisting of widely spaced shrubs. The most important species in this community are creosote bush (Larrea divaricata) and white bursage (Ambrosia dumosa). A umber of winter annual species are also found here, including Gordon bladderpod (Lesquerella gordoni), esert chicory (Rafinesquia neomexicana), hairy-leaved comb bur (Pectocarya heterocarpa), as well as the introduced Mediterranean grass (Schismus barbatus).

mmediately upslope of this community is the Arizona Upland vegetation type. On the upper bajadas and illsides of the Sauceda Mountains, a diverse assemblage of species occurs, including foothills paloverde

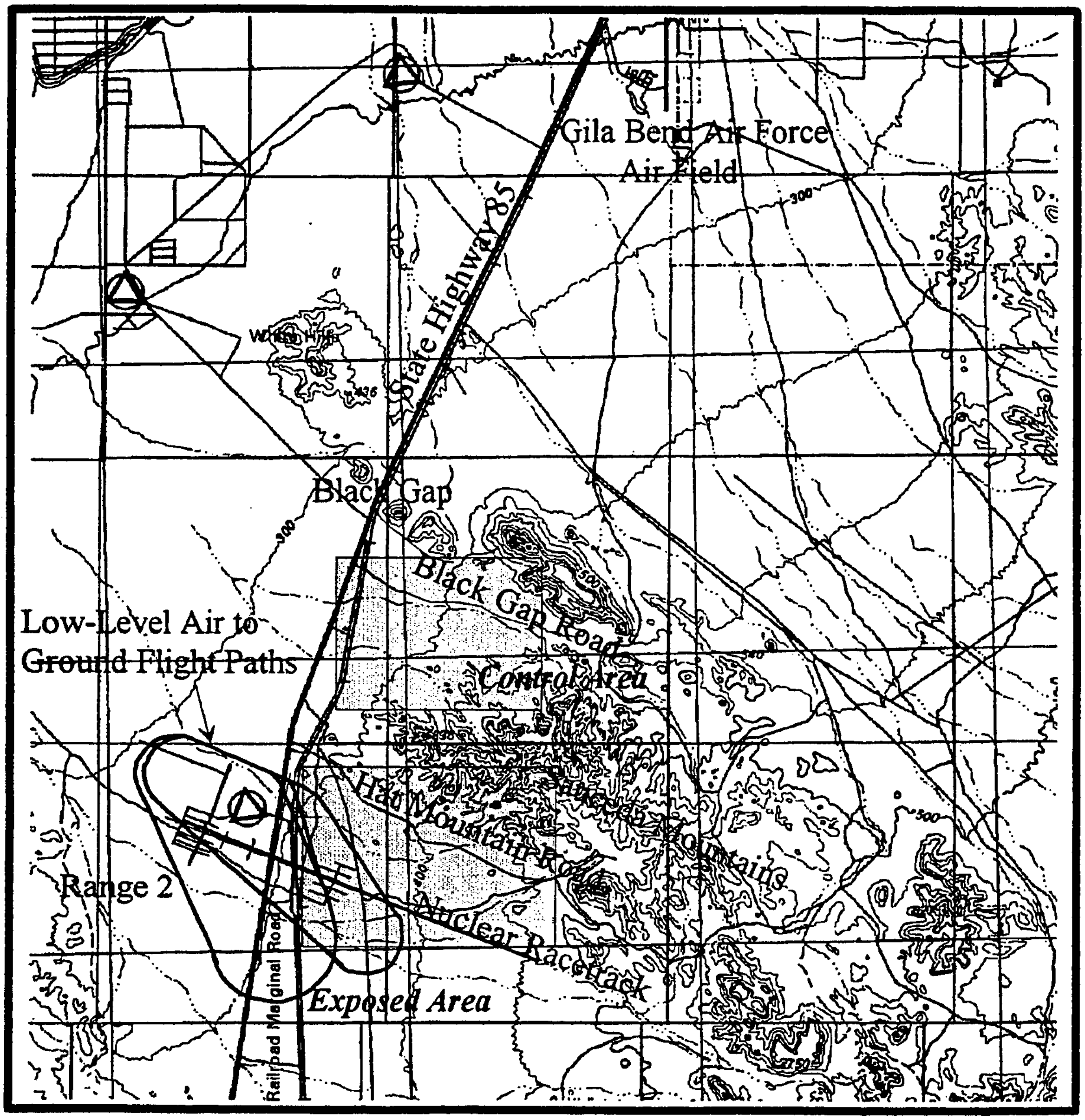


Figure 2-1 *Map of the Barry M. Goldwater Air Force Range showing Gila Bend Air Force Auxiliary Field, training ranges and access roads. Study sites are shaded.*

(Cercidium microphyllum), mesquites (Prosopis spp.), triangleleaf bursage (Ambrosia deltoidea) and numerous species of cacti. Cactus species are represented by saguaro (Carnegiea gigantea), buckhorn cholla (Opuntia acanthocarpa var. major), teddy bear cholla (O. bigelovii), and fishhook cactus (Mammillaria tetrancistra) (see the LAFB Management Plan, Tunnicliff *et al.*, 1986).

Herbaceous plants are an important source of food and water for small mammals during the rainy seasons. The 1991-1992 and 1992-1993 winter seasons were marked by higher than average rains, which stimulated profuse bloom and growth among the annual, herbaceous species. Below average rain fell in winter and spring of the 1993-1994 season, reducing the biomass of annual herbaceous plants.

2.2 CLIMATE AND SEASONALITY

Olin (1977) provides a summary of the climate in the Sonoran Desert, including the BMGAFR. The most dramatic climatic feature of the BMGAFR is the summer "monsoons," a period of precipitation occurring from late June through August of most years. Over half the annual precipitation (of about 25.4 cm) falls during this period. These storms bring moist, warm air from hurricanes that originate on the tip of Baja California and are guided north into the Sonoran Desert by the range of the Sierra Madre Occidental. Precipitation is intense and localized, accompanied by thunder and lightning, and brings flash floods to the washes and alluvial flats. Many plants in the area are dependent on these flash floods for seed burial and dispersion; however, little of this water remains long enough to replenish water reserves. Occasional cachements provide water for longer periods, especially in the larger washes, but most of the underground water is replenished in the winter. Plants, insects, and small mammals take advantage of the short rainy season by growing and reproducing rapidly.

There is a second rainy season in the late winter and early spring, from January through March. A large portion of this precipitation comes from the few coastal winter storms that can surmount the Sierra Nevada and Little San Bernardino ranges. These rains are more beneficial because they are less severe and of longer duration, allowing replenishment of underground water supplies. This period coincides with the start of eproduction for most of the mammals and birds in the area.

Temperatures can drop below freezing in the winter (to -7°C at night and to 18-24°C in the day) and become extremely hot in the summer (>49°C). Except for the period during the summer monsoons, humidity is always low, ranging from 10-50%. Even in cool weather, low humidity can cause animals to lose water apidly when they move about; thus, water is at a premium year round. Surface soil temperatures can approach 65°C in the summertime, hot enough to kill most small vertebrates. To adapt to these conditions, mall desert animals have evolved a fossorial (burrowing) lifestyle.

2.3 INTRODUCTION TO THE LIFE HISTORY OF THE KIT FOX

n November of 1885, the first specimen of the kit fox was collected in Riverside, California by Dr. C. Hart Merriam. He distinguished it from what was then called the kit fox, V. velox, by its unusually long ears Merriam, 1888). Since then, eight different subspecies have been recognized throughout the west Figure 2-2). One of these subspecies, V. macrotis macrotis is now extinct; it was last seen in 1908 (Grinnell *t al.*, 1937). Another subspecies, V. macrotis mutica, the San Joaquin kit fox, is listed as an endangered species, its habitat severely constricted by agricultural development of the San Joaquin Valley. The geographical distributions of the subspecies of the kit fox, V. macrotis, and the swift fox, V. velox, are given in Figure 2-2.

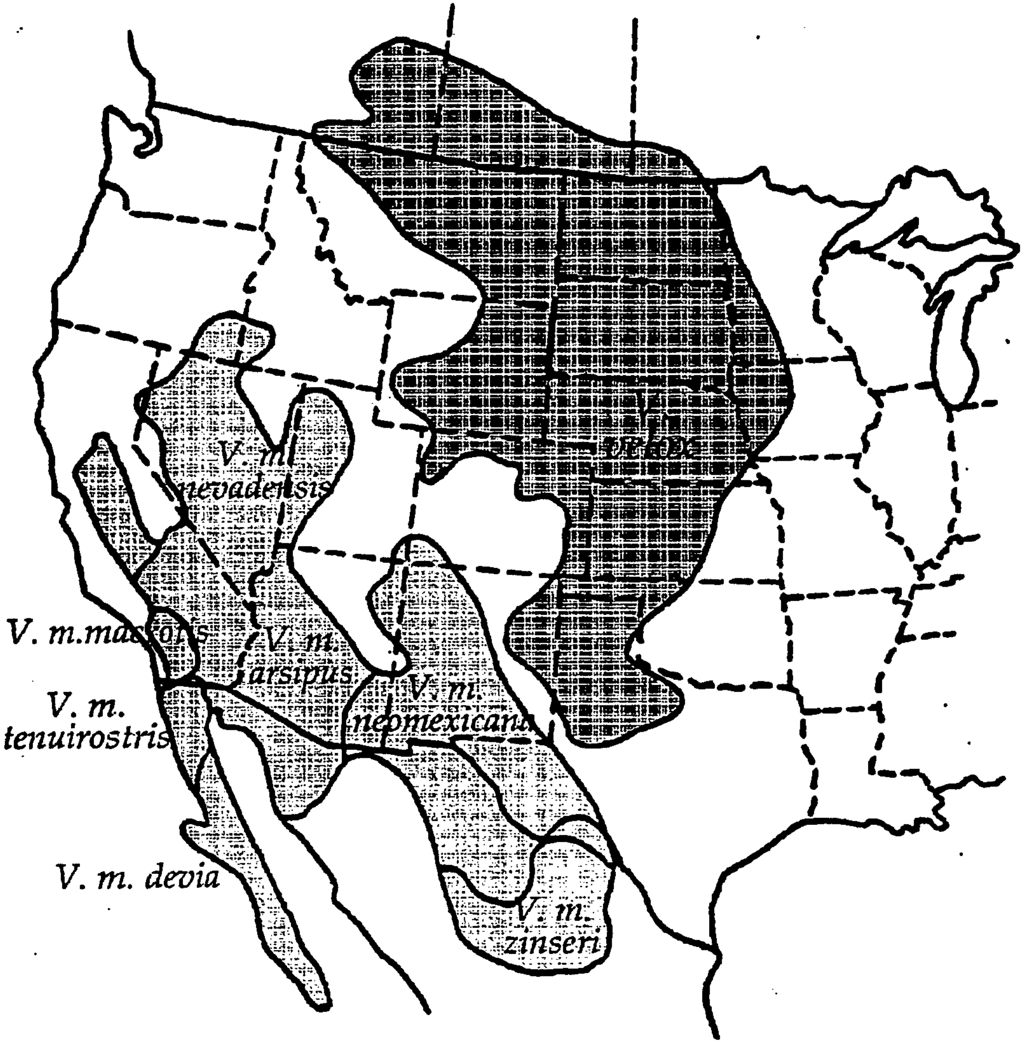


Figure 2-2 *Geographic distribution of the seven subspecies of kit fox (Vulpes macrotis) and the swift fox (Vulpes velox).*

2.3.1 Taxonomy

There is disagreement in the literature as to the specific status of the kit fox. Vulpes macrotis and V. velox were at one time considered conspecifics (Blair *et al.*, 1968). Both populations live in arid and semi-arid environments, have similar life histories, are similar in appearance, and have no immediately apparent spatial or temporal mechanisms that reproductively isolate them. However, investigations in the 1960s and 1970s (Thornton and Creel, 1975; Rohwer and Kilgore, 1973) began to cast doubt on their similarities, and specific status was given to Vulpes macrotis. Researchers found measurable differences in skull characteristics. On V. macrotis the ears are positioned closer together than on V. velox, and V. macrotis has a narrower snout and larger auditory bullae (Thornton and Creel, 1975). In New Mexico and Texas, Rohwer and Kilgore (1973) found a sharp interface in the distribution of V. velox and V. macrotis that correlates to the distribution of grasslands and deserts, respectively. Although these two species have the capability of living in sympatry, interspecific competition and superiority in their respective habitats maintain the integrity of their distribution.

Electrophoretic analysis of several subspecies of kit fox and of the swift fox suggests a cline of genetic difference. The subspecies of kit fox (V. m. arsipus and V. m. neomexicana) spatially nearest to the swift fox are also the most genetically similar, while those subspecies that are further away have fewer genetic similarities (Dragoo *et al.*, 1990). It is clear that there are subtle yet consistent differences in morphology and genetics between these two arid-land foxes. Whether these differences warrant specific status for the kit fox is still being debated. Dragoo *et al.* conclude that V. velox and V. macrotis should be listed as being conspecifics with subspecific distinctions.

2.3.2 Preferred Habitat

Kit foxes prefer the arid climate and open scrubland of the deserts of the southwest (Egoscue, 1956 and 1962; Laughrin, 1970; Zoellick *et al.*, 1989). Dens are situated in areas of creosote bush associations and shadscale flats with herbaceous cover ranging from 2.25-10.5% (Hardenbrook, 1987). Preferred hunting sites are located at the base of large bushes and in xeric riparian stream beds (Egoscue, 1956; Zoellick *et al.*, 1989).

Many investigators have noted the close association between soil types and kit fox distribution. Denning locations are almost always found on sandy loam or loamy sand that has good drainage (Egoscue, 1956; Morrell, 1972; Hardenbrook, 1987). Hardenbrook found that in an area with fourteen different soil types, kit fox dens were found in only four types, all of which fit the above description. The other ten types of soil either had poor drainage or lacked good particle cohesion. Kit foxes do not begin excavation in areas that have desert hardpan on the surface, but will sometimes modify and utilize a den in hardpan that was originally built by a better digger, such as a badger (Morrell, 1972).

2.3.3 Adaptations For Desert Living

The kit fox is the smallest of all North American canines, weighing only 1.8 kg. Like other small and medium-sized desert carnivores, it does not require an independent source of water; it acquires all the water it needs through prey consumption (Morrell, 1972). Golightly (1981) estimates that in the summer the kit fox requires only 101 grams of prey daily to satisfy its energy requirements, yet must consume no less than

175 g of prey daily to satisfy its water needs. This is a small amount when compared with the needs of a larger sympatric canine such as the coyote (Canis latrans), which requires 504 grams of prey for energy, but must consume over 1,700 grams of prey for water (Golightly, 1981). The morphological and behavioral adaptations that allow the kit fox to effectively combat overheating and water loss are small body size, light color, a fossorial and nocturnal lifestyle, and large ears. Golightly and Ohmart (1984) note that other species of fox that live in arid environments around the world have body sizes similar to the kit fox. In addition, the kit fox is physiologically adapted to use a minimum of water in excretion.

2.3.4 Home Range

Table 2-1 summarizes the data on home ranges of kit foxes in the literature. These home ranges were estimated with radio-telemetry. The kit fox is very peripatetic, particularly when prey densities are low. Foraging individuals can travel 14 km per night (Zoellick, *et al.*, 1987). As a result, estimates of home range size can vary tremendously depending on the age and sex of the individual, the season, and the method used to estimate home range. For the purposes of this study, the most useful estimates of home range were obtained by studies that tracked adults from their denning sites with radio-telemetry in areas with abundant populations of prey species.

Table 2-1 *Home ranges of kit foxes reported in literature.*

Author	Year	Subspecies	Home range estimator	Home range (km²)	n
Knapp	1978	*V. v. mutica*	Planimetry analysis	2.5 (min = 0.5; max = 7.5)	n = 9
Daneke and Sunquist	1984	*V. m. nevadensis*	Minimum area	min = 1.4; max = 4.2	n = 9
Hardenbrook	1986	*V. m. nevadensis*	Modified minimum area	9.7 ± 3.2 (SD)	n = 11
Zoellick and Smith	1992	*V. v. macrotis*	Grid-cell	11.2 ± 0.94 (SE)	n = 7
White and Ralls	1993	*V. v. mutica*	Minimum convex polygon	11.6 ± 0.9 (SE)	n = 21

Home ranges of kit foxes overlap appreciably with one another, especially among mated pairs (75%, in Zoellick and Smith, 1992) or other members of a family group (Morrell, 1972). Dens occur in aggregations (Egoscue, 1962; Hardenbrook, 1987), but it is not known if this due to a behavioral adaptation or because of resource constraints, such as soil characteristics. Egoscue (1962) found 31 dens in a 64 km^2 study site, but only five were occupied by mated pairs at any one time. The others were occupied sporadically by unmated residents and transients. Many were never occupied and were in a state of disrepair. The presence of many unused dens is reported consistently throughout the literature, and is most often regarded as a mechanism for avoiding attacks by predators and parasitic infestations.

2.3.5 Diet

Kit foxes are carnivores; the staple of their diet consists of small, nocturnal and crepuscular mammals, particularly heteromyid rodents and lagomorphs, although in desert areas scorpions also comprise a large proportion of the diet. V. m. arsipus in Arizona selectively feeds on Dipodomys (the frequency of occurrence of Dipodomys in scat samples was significantly greater than the frequency of capture of Dipodomys in the wild); lagomorphs were taken opportunistically as evidenced by a lower frequency of occurrence in scat samples than in the wild (Fisher, 1981). The diet of the San Joaquin kit fox (V. m. mutica) has a very high occurrence of lagomorphs (Scrivner *et al.*, 1987) in some years, yet very low in others (Laughrin, 1970). Seasonality, prey abundance, or geographic differences could account for the differences in prey utilization. There are also likely to be differences in detectability of some prey items, particularly lagomorphs, in scat samples (Golightly, pers. comm.).

Diurnal rodents are taken occasionally, suggesting that foxes hunt opportunistically when preferred prey abundances are low (Fisher, 1981). Ground nesting birds, such as horned larks and meadowlarks, lizards and insects are secondary food sources (Laughrin, 1970; Morrell, 1972; Egoscue, 1975; Scrivner, 1987). While insects are taken often, they are only a small fraction of the biomass ingested (Morrell, 1972). Kit fox also feed on road kills and other carrion, but the importance of this dietary source is unknown.

2.3.6 Parasites

Table 2-2 summarizes the ectoparasites of the kit fox. Egoscue (1956 and 1962) hypothesizes that the large number of ectoparasites found on kit foxes may explain why den changes are so frequent.

Up to four species of helminths have been found in a single fox (Bjotvedt *et al.*, 1980). The cestode, Dipylidium canium, and the nematode, Toxascaria leonina, have been found in a number of kit foxes in Arizona (Bjotvedt *et al.*, 1980). Toxocarid nematodes were identified in the feces of foxes captured near the study area on the BMGAFR (Botzler, Humboldt State University, pers. comm.).

Table 2-2 *Ectoparasites of kit foxes reported in literature.*

AUTHOR	LOCATION	FOX	PARASITE
Egoscue, 1956	Tooele Co., Utah	V. m. nevadensis	Flea: Pulex irritans Tick: Dermacentor parumapertus, Ixodus texanus
Hubbard, 1947	Arizona and California	not reported	Flea: Echidnophaga gallinacea
Egoscue, 1962	Tooele Co., Utah	V. m. nevadensis	Flea: Pulex irritans Tick: Ixodes texanus, I. kingi, and Dermacentor parumapertus

2.3.7 Predators and Mortality

Coyotes are thought to be the principal natural predators of adult kit foxes, although there has been no comprehensive work on the interactions of kit foxes and coyotes. Bobcats (Felis rufus) also take kit foxes that venture into heavy scrub or hilly areas, and grey foxes (Urocyon cinereoargenteus) may take weak or unwary individuals. On the BMGAFR, coyotes and bobcats are likely to be the predominant natural enemies of the kit fox. Raptors (great horned owls and golden eagles) prey on pups during the period of emergence, when pups may be found above ground during the daylight hours (Egoscue, 1962).

Humans kill many kit foxes, primarily through road kills and "varmint" hunting (Egoscue, 1956 and 1962; Laughrin, 1970; Morrell, 1972; O'Farrell and Gilbertson, 1986). Kit foxes scavenge at roadside kills and are thus vulnerable to being hit by automobiles. Road kills are a factor on the BMGAFR because the area is bisected by a highway (State Route 85). Hunting and trapping also occur on the BMGAFR. Cyanide guns and "1080" traps used to control coyote populations also potentially threaten kit foxes (Egoscue, 1956; Robinson, 1953) in areas where they are still used. Poisoned bait used to kill rodents may increase kit fox mortality as well (Laughrin, 1970; Swick, 1973). The effects of off-road vehicles on V. m. arsipus were found to be negligible, yet the potential to collapse dens, thus rendering an area uninhabitable, is great (O'Farrell and Gilbertson 1986).

2.3.8 Auditory Abilities of Foxes

The kit fox has large ears and a larger auditory bulla than its nearest congener, the swift fox (Thornton and Creel, 1975). This invites speculation that its auditory capacities at low frequencies could be enhanced. Unfortunately, essentially nothing is known about the auditory capacities of canids other than the domestic dog, and the hearing of the dog has not been examined often (Heffner, 1983; Lipman and Grassi, 1942; Fay, 1988). The auditory sensitivity of dogs at best frequency is equal to or better than that of humans (0 to -5 dB in Heffner, 1983; -24 dB in Lipman and Grassi, 1942). They are more sensitive at high frequencies

20-25 kHz) than humans. Their best frequency lies between 3 and 15 kHz, with significant sensitivity to bout 25 kHz. Their threshold at 1 kHz is 30-50 dB, so their low frequency sensitivity may be characterized s mediocre. There appears to be no scaling of best sensitivity or best frequency with body size in the omestic dog, based on examinations of dogs ranging from the Chihuahua to the Saint Bernard (Heffner, 983), but scaling in wild canids is likely based on data from other taxa.

he hearing of the kit fox is expected to be adapted to its predominantly nocturnal habit, so its hearing may e more like that of nocturnal cats. Cats hear extremely well at their best frequencies (-20 to -25 dB in the ange from 1-6 kHz; Fay, 1988), and they hear somewhat better at low frequencies than dogs (10-20 dB etter at 100 Hz; Fay, 1988). If the sensitivity of the cat is the result of a nocturnal lifestyle, then it is ossible that foxes will be sensitive at low frequencies as well. Other small nocturnal carnivores, particularly he least weasel (Heffner and Heffner, 1985), appear to have equal or greater sensitivity at low frequencies han the cat.

he differences between best sensitivities of dogs in the two studies available are large (on the order of 20 B; Heffner, 1983 *vs.* Lipman and Grassi, 1942), apparently due to methodological differences. This range comparable to differences found in studies of humans with similar methodological differences. Studies of ats have typically used negative reinforcement (shock avoidance, for example; McGill, 1959), which appears be a more sensitive measure of hearing capacity than positive conditioning techniques (Fay, 1988). The tartle-inhibition method being used by this study is likely to yield responses more like the negative einforcement method.

othing is known about the vulnerability of dog hearing to auditory damage, although they appear to abituate to very intense noise, including aircraft noise, easily (Treptow, 1966; Thalken, 1971; Gamble, 1982). at hearing is more susceptible than human hearing to continuous noise (Miller *et al.*, 1963) from 1 to 8 kHz, articularly in the range from 1-2 kHz. Miller *et al.* documented threshold shifts in cats of 40-50 dB after xposures to sounds of 103-105 dB for 15 minutes. Recovery from these exposures took up to 32 hours. is thus conceivable that aircraft noise on the BMGAFR could produce measurable temporary threshold hifts in foxes.

.3.9 Population Parameters and Life History

it fox breeding begins in late December or early January. Kit foxes are thought to be monogamous within reeding seasons, but there has been little or no research into the validity of this assumption. It is unknown hether they mate for life. Morrell (1972) noted that, of seven mated pairs studied over a two-year period, nly one pair remained together the following year. Egoscue (1962), on the other hand, considered them to e perennially monogamous. The discrepancy may be due to social differences between populations in ifferent habitats and the limited longevity of these small animals.

Litters of four to five young are born by mid April. Both the male and the female provide food and care for the young. Although nearly all adult activity is performed at night, pups are often seen playing outside the den during daylight hours. During the whelping season, a family of kit foxes may move its den site four or five times to avoid predators and reduce ectoparasite load. Dens may contain three or four entrances, and are easily recognizable by the accumulation of scat and prey remains at the entrances and by a characteristic dirt ramp that is formed during excavation.

The family unit remains together until late August or September, at which time the family disbands and its members live solitarily. Males and juveniles may disperse over relatively large distances at this time (10 to 30 km), but females are more sedentary, often remaining in the established territory and preparing the denning site for the new breeding season. Juveniles reach adult size by autumn.

2.4 INTRODUCTION TO DESERT HETEROMYIDS

The anatomy, physiology, and community ecology of small mammals in desert areas have been studied extensively in an effort to understand their specialized adaptations to the stresses of arid environments. The majority of this effort has concentrated on the heteromyids, which include the kangaroo rats (Dipodomys) and pocket mice (Perognathus and Chaetodipus). All members of this group, but particularly the kangaroo rat, possess an enlarged auditory bulla that enables them to hear predator sounds at what are relatively low frequencies for rodents (around 500 Hz). The heteromyids are thus of primary interest to this study. Other species of small mammals on the Luke Air Force Range include several harvest mice of the genus (Peromyscus spp. and Reithrodontomys spp.), woodrats (Neotoma spp.), the southern grasshopper mouse (Onychomys torridus), ground squirrels (Spermophilus and Ammospermophilus) and rabbits (predominantly the black-tailed jackrabbit, Lepus californicus and desert cottontails, Sylvilagus audubonii). A list of the mammals found on the Luke Range is given in Appendix A, taken from Tunnicliff *et al.* (1986).

What follows is a general introduction to the biology of the heteromyids, emphasizing the aspects important for this study.

2.4.1 Taxonomy

The Heteromyidae belong to a large superfamily, the Geomyiodea, or "pocket gophers," a reference to the fur-lined cheek pouch characteristic of the whole group. The heteromyids are a morphologically and ecologically diverse group of 66 species; their systematics are still in a state of transition (Hafner and Hafner, 1983). Currently they are broken into three subfamilies that differentiated during the Eocene epoch—the Perognathinae (pocket mice, Perognathus and Chaetodipus), the Dipodomyinae (kangaroo rats and mice, Dipodomys; kangaroo mice, Microdypodops) and the Heteromyinae (spiny pocket mice, Heteromys and Liomys).

Until recently, the pocket mice Perognathus and Chaetodipus were lumped into the genus Perognathus. There are 25 species of pocket mice spanning the North American continent, with nine of these now classed as Perognathus. These rodents are small (100-300 mm), quadrupedal, and fossorial.

The spiny pocket mice are the least studied of the heteromyids, represented by ten species of Heteromys and six species of Liomys. They are very closely allied. These small, quadrupedal rodents are not common, and none is expected in the study area (Hall and Kelson, 1959).

Kangaroo rats form a large and speciose group, with 24 species recognized in North America (U.S., Canada, and Mexico). It has been suggested that they should be separated into a family of their own, as they share few morphological characteristics with their allies (Hafner and Hafner, 1983; Hafner, 1978). They are lumped within the group based on phyletic evidence. All are relatively large and mobile, having adopted a bipedal, hopping form of locomotion that enables them to escape predators even on open ground. They are specialized both physically and biochemically to tolerate extremely arid climates and are ubiquitous in desert areas. Three species are listed in the LAFB management plan, D. merriami, D. spectabilis, and D. deserti (D. deserti has not been identified in trapping surveys in the study area).

Kangaroo mice are similar to kangaroo rats, but are much smaller in size. There are only two species, M. megacephalus and M. pallidus. Both are restricted to the Great Basin. Like the kangaroo rats, their affinity with other heteromyids is in question.

2.4.2 Natural History

Heteromyids are primarily granivorous (Brown *et al.*, 1979), but several species of Dipodomys require herbaceous vegetation to initiate breeding, although they can complete lactation without it (Munger *et al.*, 1983). Thus, rainy seasons and the blooms of annuals associated with them regulate the onset of the breeding season (Chew and Butterworth, 1964; Van de Graaff and Balda, 1973). There is some speculation that plants provide Dipodomys with the steroid hormones that trigger breeding (Chew and Butterworth, 1964; Reichman, 1975). Insects can comprise up to 15% of the diet of D. merriami (Reichman, 1975).

The heteromyids are all fossorial. Although they are largely nocturnal (Lockard, 1978), some occasional diurnal activity occurs. When the temperature or food supply drops to low levels, long periods of torpor occur in smaller species (Kenagy, 1973; Reichman, 1979) such as Perognathus, but apparently not in the larger species, like kangaroo rats. Large species, however, may become very inactive and avoid the surface during periods of high heat (Reichman and Van de Graaff, 1973).

Outside of breeding and rearing the young, heteromyids are solitary (Martin, 1977; Monson and Kessler, 1940). They maintain 5-7 burrows within their home ranges (Chapman and Packard, 1974). Home range size does not appear to be related to average body size (Chew and Butterworth, 1964; Schroder, 1979), but rather to the particular foraging strategy of a species. Dipodomys travels an average of 68 m per foraging trip and a total of 350 m per night. Home ranges of males and females overlap, with the larger territories possessed by males (Schroder, 1979; Maza *et al.*, 1973; O'Farrell, 1980). Dispersal occurs at the end of the breeding season, but juveniles generally establish burrows as near to the natal burrow as possible (Munger *et al.*, 1983).

Some species of Dipodomys advertise their presence in a territory by foot drumming (Kenagy, 1976) or by scent-marking. They defend their territories from conspecifics with teeth-chattering displays, and males may fight (Congdon, 1974). Females approach drumming males during courtship. Courtship and copulation are brief and the male does not participate in the care of the young.

Burrows are dug usually in wind-blown piles of dirt at the base of bushes. They vary tremendously in size and shape between sexes and species. Mounds are formed in the process of digging the burrow; in the larger species, these mounds may reach 2-3 m in diameter and 0.5-1 m in height. Burrows consist of sleeping areas and flask-shaped food caches, and may extend to a depth of 0.76 m. It takes from 23-30 months to build a large mound, work that is done by several generations of occupants. Some individuals, particularly females with young, plug the burrow entrance with dirt to keep out intruders.

Desert heteromyids generally have two litters per year. Females are in estrus only during the rainy season, but males may be capable of breeding all year (Reichman and Van de Graaff, 1973). Females show the first signs of sexual maturity at six weeks of age and can conceive at twelve weeks.

Gestation is short (18-30 days). Most births occur during the day and the young are relatively precocial (Eisenberg, 1963a). Females are not known to eat their young, except for dead neonates. The mother may move the young among the burrows during growth to avoid predators and parasites. They begin to take solid food at two weeks. The mother begins to ignore the young and to reject their attempts to nurse near weaning. The young disperse at that point.

2.4.3 Community Ecology

The community structure of heteromyid rodents has several unique features. Up to six species of heteromyid rodents have been reported on a study site (Brown,1973), and four to five species on a site is not unusual (Rosenzweig and Winakur, 1969; Reichman, 1975; Hallett, 1982). All species of heteromyids are predominantly granivorous, and thus rely on the same resource for survival. The exact mechanism of microhabitat partitioning is not clear. Foliage coverage appears to be positively correlated with the number of heteromyid species present in an area. The slower moving, quadrupedal Perognathus is more exclusive in its use of coverage (Thompson, 1982a) than the bipedal Dipodomys, which has the ability to move swiftly from one bush to another. In foliage manipulation experiments, the number of Perognathus species increased as more cover was added. The new species were larger in size than the original Perognathus occupants and appeared to exclude smaller kangaroo rats (Dipodomys merriami). There was also an increase in Peromyscus and Onchyomys (Thompson, 1982b). This suggests that cover and availability of seeds are the most important predictors of species diversity, and possibly of biomass.

2.4.4 Auditory Abilities of Heteromyids and the Anticipated Effects of Noise

The auditory capacities of heteromyids, particularly the kangaroo rat, have been studied (Heffner and Masterton, 1980; Webster and Webster, 1971, 1972, 1980; see summary in Fay, 1988). They have an enlarged auditory bulla anatomically, which apparently endows them with excellent hearing at relatively low frequencies (around 500 Hz). Most rodents hear better at high frequencies than at low, with best frequencies between 5 and 30 kHz. Merriam's kangaroo rat hears well in the range from 100 Hz-30 kHz (Fay, 1988), and localizes well, even at low frequencies (Heffner and Masterton, 1980). Figure 2-3 shows the auditory hreshold function of the Merriam's kangaroo rat along with the human auditory threshold curve, as determined both by minimum auditory field (MAF) and ANSI standard (MAP) methods, overlaid for comparison.

Kangaroo rats are particularly sensitive to scratching sounds (Reichman, 1979). This sensitivity allows hem to avoid predators, which produce scratching sounds in the 200-1,000 Hz range (Webster, 1962). Webster and Webster (1971) have shown in field tests that ablation of the auditory bulla makes kangaroo ats vulnerable to snakes, particularly on dark nights. The hearing of other heteromyids has not been studied and the costs of minor auditory deficits are unknown.

n humans and laboratory animals, exposures to sounds with levels greater than 80 dB result in a degree of threshold shift that is correlated with exposure level and duration. Temporary threshold shift (TTS) s proportional to the logarithm of the duration of the stimulus, and intermittent noise produces TTS in proportion to the duty cycle of the sound (Kryter, 1985). High-frequency components of noise produce more TTS than low-frequency components (Ward, 1960). The range of frequencies affected by TTS is elated to sound level, becoming broader with higher sound levels. The affected range of hearing is generally one-third to one octave higher than the affecting stimulus. Recovery is complex within two minutes of exposure. After that, recovery time is proportional to the logarithm of the total time since xposure. This means that recovery time is largely a function of the degree of threshold shift (Ward *et al.*, 1958).

The noise from low-altitude aircraft overflights on the BMGAFR is not expected to cause permanent uditory damage in the kangaroo rat, assuming that studies of laboratory rodents provide a reasonable model. However, overflights do intermittently produce amplitudes from 70-100 dB above the typical

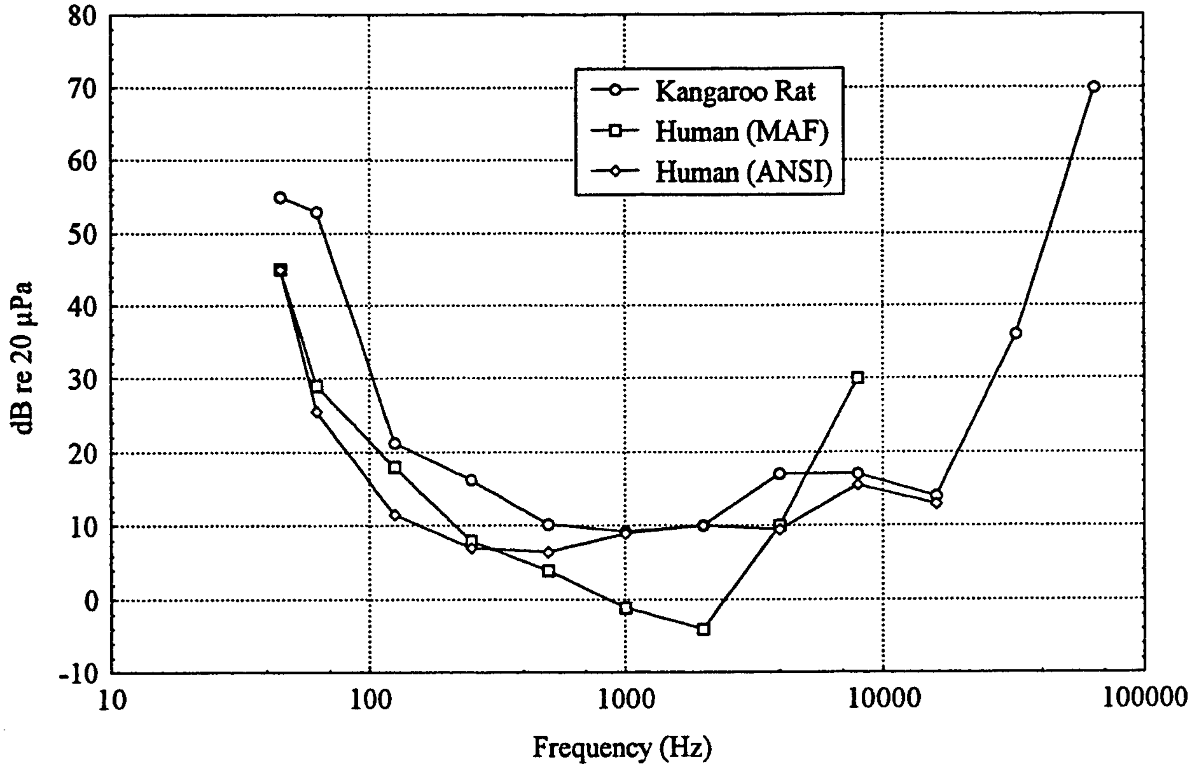


Figure 2-3 *Plot of the auditory threshold function curve for Merriam's kangaroo rat. Human curves determined by minimum auditory field (MAF) and ANSI headphone standard are plotted for comparison.*

ambient for periods of 20-40 minutes, and these exposures may occur up to six times per day. Kangaroo rats sleep in their burrows in the daytime, where levels would be slightly attenuated (see Section 3.4), and nighttime operations expose foraging individuals at the surface. Individuals could experience post-stimulatory fatigue or temporary threshold shift (Gelfand, 1990).

2.4.5 Foraging and Predator Avoidance

Kangaroo rats travel with the characteristic bipedal jumping that gives rise to their common name. They travel at average speeds from 3 to over 6 kph (Reichman and Kaufman, 1983). They can hop at 32 kph when fleeing a predator, traveling in an erratic path (Bartholomew and Caswell, 1951) and can jump to heights over 1 m. Perognathus are quadrupedal and travel more slowly (1.76 kph for P. longimembris).

Although heteromyid foraging ecology has been studied extensively, less is known about their predator-prey relations. Feeding and predator avoidance are intimately linked because desert rodents are most vulnerable when emerging from their burrows to feed. As a result, they spend as little time as possible foraging above ground. Total foraging times per night can reach five hours in the larger kangaroo rats, but pocket mice spend only about one hour above ground each night (Kenagy, 1973).

Olfaction is used predominantly in identifying food, followed by tactile cues, with little reliance on vision (Reichman and Oberstein, 1977; Lawhon and Hafner, 1981; Eisenberg, 1963a; Bartholomew and Caswell, 1951). Kangaroo rats in the laboratory can detect food in loose soil to depths of almost 8 cm (Reichman and Oberstein, 1977). Once identified, a packet of food is dug up and either eaten or stored in fur-lined cheek pouches for transport. Heteromyids can fulfill their total daily requirements for food with one full load in cheek pouches, allowing them to minimize foraging time and to separate eating and handling time from foraging time. Dipodomys merriami and Perognathus amplus, the most common species in the study areas, do not differ significantly in the types of seeds they ingest or their frequency of ingestion (Reichman,1975), but they do differ in the manner in which they forage for seeds. Pocket mice "filter feed" continuously, methodically searching a small area for individual seeds. Kangaroo rats move quickly from seed clump to seed clump, ignoring areas of low seed density (Reichman and Oberstein, 1977; Thompson, 1982a, 1982b). Both prefer to forage under the shelter of foliage, presumably to avoid predators. Thompson observed that Perognathus utilizes only one or two bushes in a foraging session, continuously gleaning individual seeds. Dipodomys utilize a larger area by searching for clumps of seeds beneath bushes then dashing across the open habitat to continue under another bush. Thompson has suggested that the hopping specialization of kangaroo rats has been an evolutionary response to predation risk during intershrub transit, as opposed to an adaptation to risk incurred during collection of seeds under shrubs.

Heteromyids cache seeds for long periods, for consumption between growing seasons. Dipodomys merriami hoards by scattering small caches at many sites within its home range (Jenkins and Peters, 1992). The benefit of this behavior is that other rodents, including conspecifics, will be less likely to plunder their entire cachement. Scatter hoarding may also reduce the amount of time in transit to a cache.

The most important predators of heteromyids are owls, snakes, foxes, and coyotes, in that order. Except for snakes, these predators must capture their prey above ground, so the burrow is the most important predator avoidance mechanism. Heteromyids are very sensitive to unusual smells and sounds in their environment (Eisenberg, 1963a), racing back to the burrow when anything unusual is detected. High winds and rain can decrease or halt their nocturnal activities (Kenagy, 1973; Lockard, 1978). Some authors believe that heteromyids reduce their activity on moonlit nights to avoid being seen by predators, although this contention is controversial (Kenagy, 1976; Schroder, 1979; Kaufman, 1982; Lockard and

Owing, 1974). Audition plays a critical role in predator avoidance in the dark (Webster and Webster, 1971).

2.5 OTHER FAUNA OF INTEREST FOUND ON THE BMGAFR

The Sonoran Desert supports an abundance of large mammals. The most abundant of these in the vicinity of the study area are desert bighorn sheep (Ovis canadensis mexicana); two species of deer (Odocoileus virginianus and O. hemionus); the collared peccary (javelina, Tayassu tajacu); the mountain lion (Felis concolor); the gray fox (Urocyon cinereoargenteus); the coyote (Canis latrans) and the bobcat (Felis rufus). There are also coatis (Nasua nasua) and ringtails (Bassariscus astutus). Some of these are game species and are hunted by special permit in areas of the BMGAFR. The Arizona Game and Fish Department has built artificial water cachements in the Sauceda and Sand Tank mountains to allow game to use the BMGAFR throughout the year.

The endangered Sonoran pronghorn antelope (Antilocapra americana sonoriensis) occurs on the Luke Air Force Base Range, but only to the southwest of the air training ranges and in the Cabeza Prieta Wildlife Refuge. Feral horses (mustangs) and burros are common in the washes at the southern end of the study area, where water can be found for longer periods during the summer. They did not occur in the study area.

Birds are common in the study areas at most times of year. Appendix A lists the species of birds found on the BMGAFR based on the LAFB Management Plan (Tunnicliff *et al.*, 1986), and those that were seen in the study area during conduct of this study. A few species of raptors that prey on foxes and/or small mammals can be found year round: the Golden Eagle (Aquila chrysaetos); the Red-tailed Hawk (Buteo jamaicensis); the Great Horned Owl (Bubo virginianus); and Harris' Hawk (Parabuteo unicinctus). Swainson's Hawk (Buteo swainsoni) is also found occasionally. Prairie Falcons (Falco mexicanus) and Cooper's Hawks (Accipiter cooperii) are important avian predators, and Turkey Vultures (Cathartes aura) are ubiquitous scavengers. The Sharp-shinned Hawk (Accipiter striatus), Kestrel (Falco sparverius), and Road Runner (Geococcyx californianus) prey on insects, lizards, and occasionally small rodents throughout the area. These species compete with foxes for food.

Reptiles are diverse in the area (Appendix A). The threatened desert tortoise occurs in the study area, *as does the protected Gila Monster. Several* species of snakes are found, including the Sonoran whipsnake (Masticophis bilineatus), the Sonoran shovel-nosed snake (Chionactis palarostris), and a number of species of rattlesnakes (Crotalus spp.). Zebra-tailed lizards (Callisaurus draconoides), whip-tailed lizards (Cnemidophorus spp.), and horned lizards (Phrynosoma spp.) are abundant. Of these lizards, nocturnal species and species that do not hide in burrows are vulnerable to predation by foxes.

The abundance of insects is highly seasonal, with large numbers emerging and breeding during the rainy seasons in late summer and late winter. Few of the small mammals in the area are insectivores, but foxes eat insects when other prey become scarce, particularly locusts and other beetles. These species are also the prey of predatory arthropods, particularly scorpions and solipugids, which are abundant in the study area. The scorpions found in the study area are *Hydrurus asutus*, *Vejovus veliger* and the dangerous bark scorpion, *Centroides sculpturatus*.

Scorpions burrow in the daytime, but they may be found at the surface at night during the warm months. Scorpions often have very high biomass in desert areas (Polis, 1990), composing an important source of food for other scorpions and for hematherm predators like kit foxes. Forty-six individuals were counted at the surface in a 29-m^2 area in a habitat similar to that found on the BMGAFR, for a density of 1.6/m^2 (Cornett, 1987).

3 ACOUSTIC MONITORING

To determine the potential for damage to the species in each area, it was first necessary to determine evels of noise exposure.

3.1 DESCRIPTION OF STUDY SITE

The study areas are located under the left and right "racetracks" (target approach routes) on Range 2 of he BMGAFR (Figure 3-1). The racetracks straddle Arizona State Highway 85, in an area characterized by creosote scrub and mixed Sonoran Desert scrub. Range 2 is bisected by a branch of the Sauceda Mountains, with the right racetrack to the north and the left racetrack to the south. The left racetrack s used almost exclusively, with the right used occasionally by relatively quiet A-10 "Warthog" aircraft. Thus, the portion of Range 2 immediately to the north of the range constituted a reasonable candidate control area. The entire southern end of the Range running along Hat Mountain Road from State Highway 85 at milepost 20 to Hat Mountain is exposed frequently to aircraft noise exceeding sound evels of 90 dB (maximum sound level [MXFA]); it therefore constituted an excellent exposed site. Preliminary measurements indicated that the northern area receives occasional distant aircraft noise from sorties traveling to Range 2, bombing runs on Range 3 to the north, and sorties headed towards Range 4 to the east, all at levels of 80 dB MXFA and below. Averaged levels are an order of magnitude less ntense than in the exposed area and the habitat is very similar to that in the exposed area. Therefore, he area was selected as the control site. There are good jeep tracks running through both areas.

Range 2 is used for air-to-ground training sorties, in which the pilot follows one of several prescribed acetracks (Figure 3-2), dropping a small charge over a marked target. These sorties originate out of several Air Force bases, but primarily Luke or Davis-Monthan. Flight scheduling for the ranges is made at LAFB and can be obtained at 1500 hrs for the following day. These schedules were collected for comparison with the acoustic records of overflights.

The principal types of aircraft flown on BMGAFR are the F-15 "Eagle," the F-16 "Falcon," and the A-10 Warthog," attack aircraft. Sound levels from the F-15 can exceed 120 dB directly under the flight path and from F-16s can exceed 110 dB (Berry *et al.*, 1991). These levels meet or exceed those produced by overflights along very low-altitude legs of MTRs (Bradley *et al.*, 1990) and occur with much greater frequency.

nformation was obtained from the Airspace Management Office at LAFB and the Chief of Range Operations, GBAFAF. Based on these discussions and the briefing manual for pilots, a detailed description of the flight patterns was obtained.

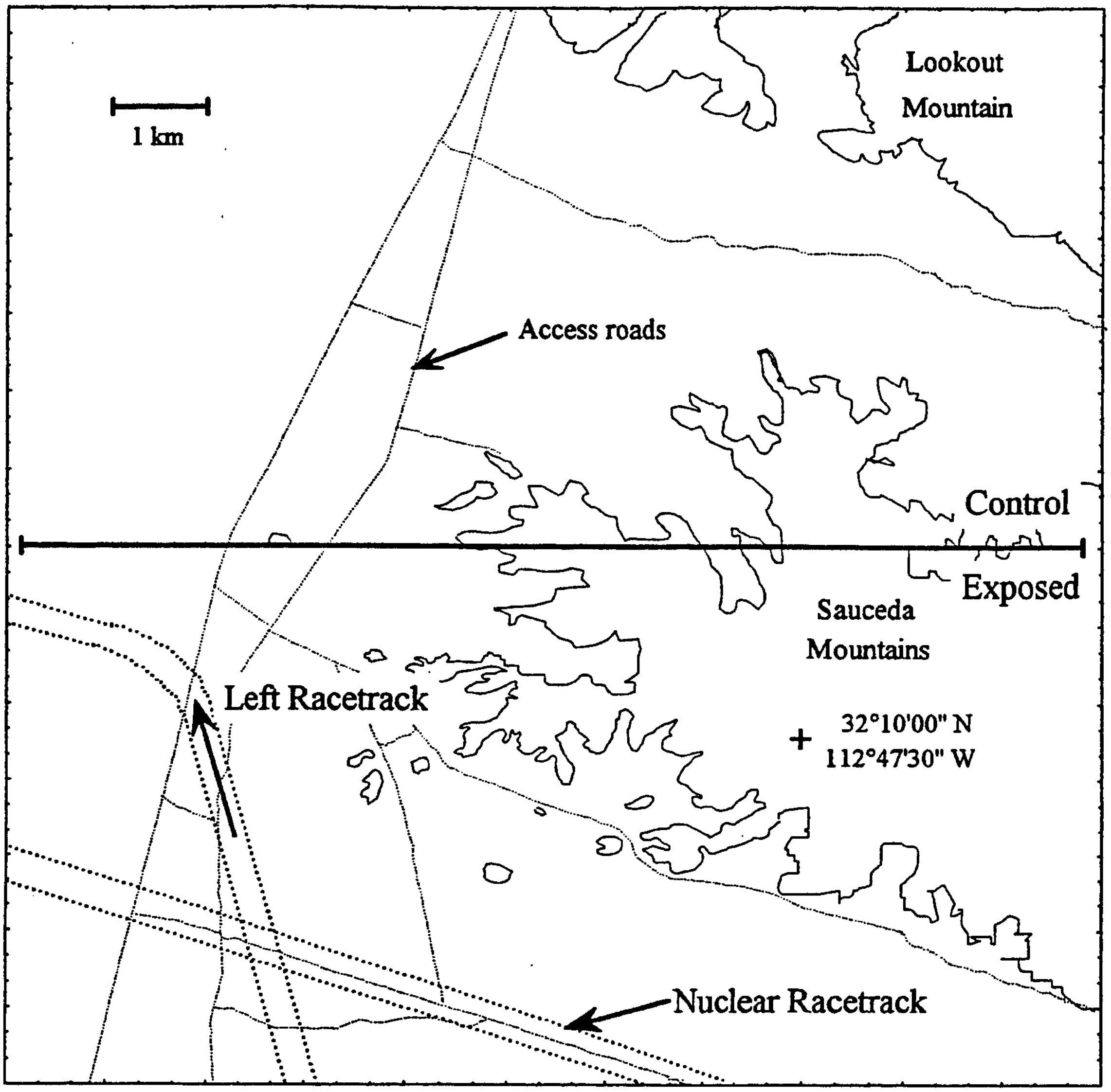


Figure 3-1 *Map of the study site showing the target approach routes flown at low-levels by F-15, F-16 and A-10 aircraft over the study area.*

The racetracks are not flown with great precision, insuring variety in the pilots' experience. Pilots enter Range 2 along a long, straight path dubbed the "Nuclear Racetrack," at altitudes of 500-1,000 ft, coming across the Sauceda and Sikort Chuapo Mountains from an MTR turning point on Cimarron Peak. From this leg, they enter the racetracks of Range 2. Flights around the left conventional racetrack oriented at 330° and 324° are the most common and noisiest. The aircraft may fly several circuits around the Nuclear Racetrack, or they may divert immediately upon entering the range to make practice bombing runs around the left racetrack. Once they enter this racetrack, the aircraft travel up the southern and eastern end at 200-500 ft, pop up to 5,000 ft, then drop to 2,500 ft over a target on the other side of

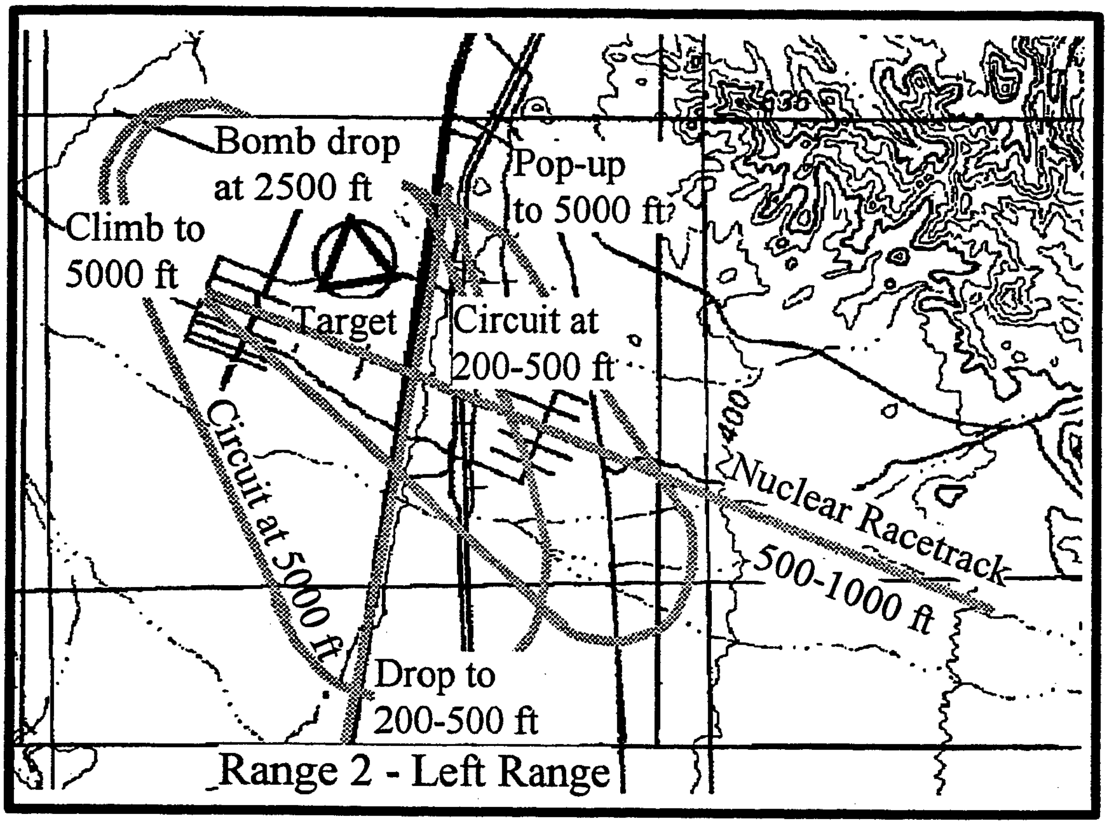


Figure 3-2 Map of Range 2 at Barry M. Goldwater Air Force Range showing the flight tracks used during low-level training flights.

Highway 85. During the pop-up maneuver, the tail of the jet is aimed downwards, increasing sound evels on the ground. They then return to 5,000 ft on the other side of the target, swing around over the highway, and drop down to begin the next circuit. This means that the areas that should receive the greatest sound levels lie along the Nuclear Racetrack and along the conventional racetracks just to the ast of State Highway 85.

.2 ACOUSTIC MONITORING

To determine whether there was any correlation between exposure to aircraft and the biological arameters being studied, it was important to develop an accurate characterization of the sound exposure n the study area. Because the flight path of the training aircraft was variable, exposures could not be alculated using a predictive program and knowledge of the flight path and topography; instead, they ad to be measured empirically. Because it was not at all clear from the data in previous studies which arameters were the most important predictors of animal response, a variety of acoustic measures were ollected.

3.2.1 Methods

3.2.1.1 Definitions of Acoustic Parameters

The acoustic measures collected fell into three categories, sound exposure level, maximum sound pressure level, and time-averaged or equivalent continuous sound levels. Sound exposure level is defined as the squared instantaneous sound pressure (generally A-weighted) over a stated time (Harris, 1991). Sound exposure levels account for all the sound energy contained in a transient sound event, given by the equation

$$L_{AE} = 10 \log_{10} \left(\frac{E_A}{E_O}\right) \qquad \textbf{(Eq. 1)}$$

where E_A is the A-weighted sound exposure level in pascal squared seconds and $E_O = p^2_0 t_0$ is the reference sound exposure with a reference sound pressure (p_0) of 20 micropascals (μPa) and a reference time (t_0) of 1 second (Harris, 1991). Maximum sound levels are defined as the highest exponential-time-averaged sound level (sound level = A-weighted sound pressure level) that occurs within a stated time interval. Maximum sound levels use exponential time-weighting; for this study fast time-weighting (0.125s) was used exclusively. Time-averaged or equivalent-continuous sound levels are defined as the sound level of a time-varying sound that is equal to the level of an equivalent steady sound. Time-averaged measures are specified for a given interval, typically 1 or 24 hour(s). One-hour average sound level is given by,

$$L_{1h} = 10 \log_{10} \left[\left(\left(\frac{1}{3600}\right) \int_0^{3600} p_A^2(t)\, dt \right] / p_A^2 \right) \qquad \textbf{(Eq. 2)}$$

where $p_A^2(t)$ is the square of the instantaneous A-weighted sound pressure, in pascals (Pa), as a function of time t. For L_{1h}, time is in seconds and the integration interval is one hour (3,600 s).

To obtain an empirical "noise map," monitoring stations were established on a 500-m grid across the exposed area and on a 2-km grid across the control area. Sites were monitored for 1-2 weeks at a stretch, long enough to average daily and weekly variability in noise exposure. Several noise monitors were tested, but most of the data were collected either with a Larson-Davis model 820 (LD820) Community Noise Monitor (CNM) equipped with a field case and solar-powered external batteries, or a custom-designed animal noise monitor (ANM). ANMs were developed for NSBIT by Dr. Roger Hill of Wildlife Computers and were designed for direct placement on free-ranging animals to monitor exposure to sound (Kugler and Barber, 1993). Six ANMs were used to make the majority of the sound measurements on the exposed site. A Computer Engineering Limited (CEL) 493 integrating sound level meter feeding into a CEL 438 secondary processor was used to monitor a few stations during the first year, but this system required a 12V car battery to operate for the desired two weeks, making remote placement very difficult; its use was discontinued. Both the ANMs and the CNMs were deployed twice a month and left to run until their memories were full or until the battery supply ran low.

The ANMs were designed to measure acoustic parameters of transients and, as such, they did not measure long-time equivalent average sound levels. However, because high sound levels contribute most of the sound energy to these parameters, a good approximation could be obtained by using the A-weighted sound exposure levels from the ANMs to calculate 1HL and 24HL with the following equations

$$1\mathrm{HL} = 10 * \log_{10}\left[\left(1/3{,}600\,\mathrm{s}\right) 10^{0.1(\mathrm{ASEL})}\right] \qquad \textbf{(Eq. 3)}$$

$$24\mathrm{HL} = 10 * \log_{10}\left[\left(1/86{,}400\,\mathrm{s}\right) 10^{0.1(\mathrm{ASEL})}\right] \qquad \textbf{(Eq. 4)}$$

where 3,600 is the number of seconds in an hour, and 86,400 the number of seconds in a day.

3.2.1.2 Calibration of Community Noise Monitors and ANMs

Calibration measurements between systems were made by deploying two devices at the same site for several weeks and by making detailed observations at a few sites in the most heavily exposed areas. Different systems were used on several occasions to monitor the same sampling site, providing a measurement of the repeatability of the results. After calibration measurements, individual units were deployed separately.

The CNMs and ANMs were not expected to yield precisely analogous measurements, because of differences both in the way they were triggered at the onset of a sound and in the way they terminated a measurement at the offset. The LD820 was set to trigger at MXFA 75 dB. Once triggered, it integrated the incoming sound until the level fell below 69 dB (hysteresis value of 6 dB) and then stored an assortment of acoustic parameters in memory. The CEL was also set to trigger at a sound level of 75 dB, but this system integrated the sound until the level dropped and remained below 75 dB for more than 5 seconds before storing the measurements. The ANMs were set to trigger when a sound event exceeded 80 dB. Their minimum setting was 78 dB in order to insure sufficient dynamic range to measure levels up to 130 dB. They stopped integrating when the sound level dropped below 75 dB for 2 seconds.

Since high winds are sometimes present in the desert environment, 18-cm windballs were used on the 1/2" CNM microphones to reduce wind-triggered events. The ANMs were mounted in a custom-designed nylon holder fitted with a 3.8-cm hemispherical windball. All microphones were mounted 1.2 meters high.

Events shorter than 100 milliseconds and with sound exposures less than 55 dB were characteristic of wind-related triggers and these were removed from the data before analysis. Throughout the study period, records of the sorties scheduled and weather were obtained from GBAFAF. These data were used to determine when storms were present and when the wind speed was high enough to trigger the monitors accidentally (about 25 kph). These data were used to check the estimates of wind-related events.

The CEL 493/438 and the LD 820 were calibrated using steady sine waves and 1-cycle tone pips presented at one-third octave center frequencies (Young, 1993). The test signals were generated using a Stanford Research Systems DS345 Synthesized Function Generator feeding a 50-ohm load and a 18-pf dummy microphone installed on the preamplifiers. Young's technique presents a steady sine wave and then a single sine wave to the device at the same frequency. The theoretical sound level is known for the single sine wave. If the SLM functions perfectly, the level it reports for the sine wave equals the theoretical calculation. The results for both the CEL 493 and the Larson-Davis 820 are shown in Appendix B. Both systems performed well from 12 Hz to over 5 kHz, covering the frequency range of most jet overflight noise. The LD820 had a mean error relative to the theoretical level of -0.48 dB over the range of 12 Hz to 5 kHz (n = 26, s.e. = 0.14). The same error for the CEL was -0.86 dB (n = 26, s.e. = 0.31).

The LD820 and the CEL system were calibrated in the field with either a General Radio Omnical 1986 sound level calibrator or a Brüel & Kjær type 4220 pistonphone. The ANMs were equipped with flush-mounted, non-standard size microphones, making field calibrations impossible. These systems were calibrated by staff at BBN Systems and Technologies, Canoga Park, California, prior to the field work.

3.2.1.3 Detailed Observations of Sorties

During March 1992, observers made tape recordings of several sorties and took still photographs of the aircraft at the same time to estimate slant distance. Black and white photographs were taken using high speed film in a 35 mm Nikon 8008 camera with a 300 mm Nikon lens equipped with a motor drive. A series of photographs was taken at a rate of two per second as the aircraft approached and passed over. The photograph with the largest aircraft image was used to estimate closest approach.

A derivation of the lensmaker's equation (Sears *et al.*, 1987) was used to calculate the distance from the camera to the aircraft. The image height, x', was the length of the aircraft on the film negative. This measurement was taken by measuring the length of the aircraft, y, on 4" x 6" black and white prints with calipers. The length of the print frame, p, and the negative, n, were also measured. The image height on the negative, x', was calculated using the relation

$$x' = \frac{y * n}{p} \qquad \textbf{(Eq. 5)}$$

The object distance, d, the desired unknown, was calculated knowing the image distance (the focal length of the camera), d', the actual length of the aircraft, x, and the image height. The object distance was calculated with the equation

$$d = \frac{d' * x}{x'} \qquad \textbf{(Eq. 6)}$$

During the sorties, the CNMs saved the following parameters for each event recorded: date, time, duration, A-weighted maximum sound pressure level (MXFA), fast A-weighed peak sound pressure level (PKA), A-weighted sound exposure level (ASEL), and A-weighted hourly and daily average levels. A-weighted levels were preferred over C-weighted levels because instruments on C-weighted settings are much more likely to trigger spuriously when exposed to wind. For humans, A-weighted levels are robust estimators of response (Kryter 1985). However, because the spectral characteristics of noise from the aircraft that fly on the BMGAFR are known, if C-weighted levels later prove to be better estimators of response they can be estimated from A-weighted levels.

The ANMs collected date, time, duration, MXFA, ASEL, PKA, onset rate, and octave band spectral characteristics of the overflight events.

3.2.2 Results

3.2.2.1 Distribution of Sound Exposures

The repeatability of the measurements taken at each sampling site was estimated by sampling simultaneously or resampling the same site using a different type of sound meter. Table 3-1 shows the results of these comparisons. Generally, there was good agreement between the different systems used in this study and between different sampling periods. However, on three occasions, resampling the same site with different ANMs led to differences between the means of the ASELs of 7-9 dB. These differences were most likely due to variations in the flight patterns, or the types of jets used during the sampling period. The final values used for that site included both sampling efforts.

Table 3-1 *Comparison of sound monitoring results taken from different meters and at the same grid location.*

System	Easting	Northing	Mean of MXFA	Mean of Max 30 ASELs	Hours Monitored	Largest 24HL	Largest 1HL
ANM	326230	3614620	93.1	107.2	236.0	69.2	81.7
CEL 438	326230	3614620.	90.8	107.5	90.0	71.1	83.3
ANM	326820	3615620	91.3	100.4	884.0	62.3	73.8
Larson Davis 820	326820	3615620	88.9	104.4	151.3	64.7	73.0
ANM	327230	3614120	91.5	100.0	176.0	65.1	78.5
Larson Davis 820	327230	3614120	88.4	100.4	279.0	63.1	75.0
ANM	327230	3615620	90.9	102.0	169.0	65.0	74.6
Larson Davis 820	327230	3615620	89.1	102.9	117.0	67.9	78.1

Easting and Northing are coordinates in Universal Transverse Mercator units. Mean of Max 30 ASELs is the mean of the 30 largest A-weighted sound exposure levels measured by each system.

The different sound event measuring methods and threshold settings used by each type of system led to differences in the number of sound events they collected. The ANMs, with their highest trigger threshold recorded the fewest number of sound events. The CEL, with a lower threshold but relatively long five or six second "minimum event duration," recorded more events than the ANMs, but fewer than the LD820. The extra events recorded by the CEL and the LD820 were below 80-85 dB.

Figure 3-3 compares the distribution of ASELs greater than 80 dB recorded by the LD820 and the ANMs. The only substantial difference between the distributions is in the 80 to 85 dB range. This discrepancy may either reflect the differences in the triggering techniques of each system, or differences in the sound events occurring at remote monitoring sites. The ANMs, being easier to deploy, were more often used to collect measurements at the least accessible sites, which included some of the noisier locations. Whatever the cause, the similarity in the distribution for the majority of the events allowed for direct comparison of the sounds measured by the two systems.

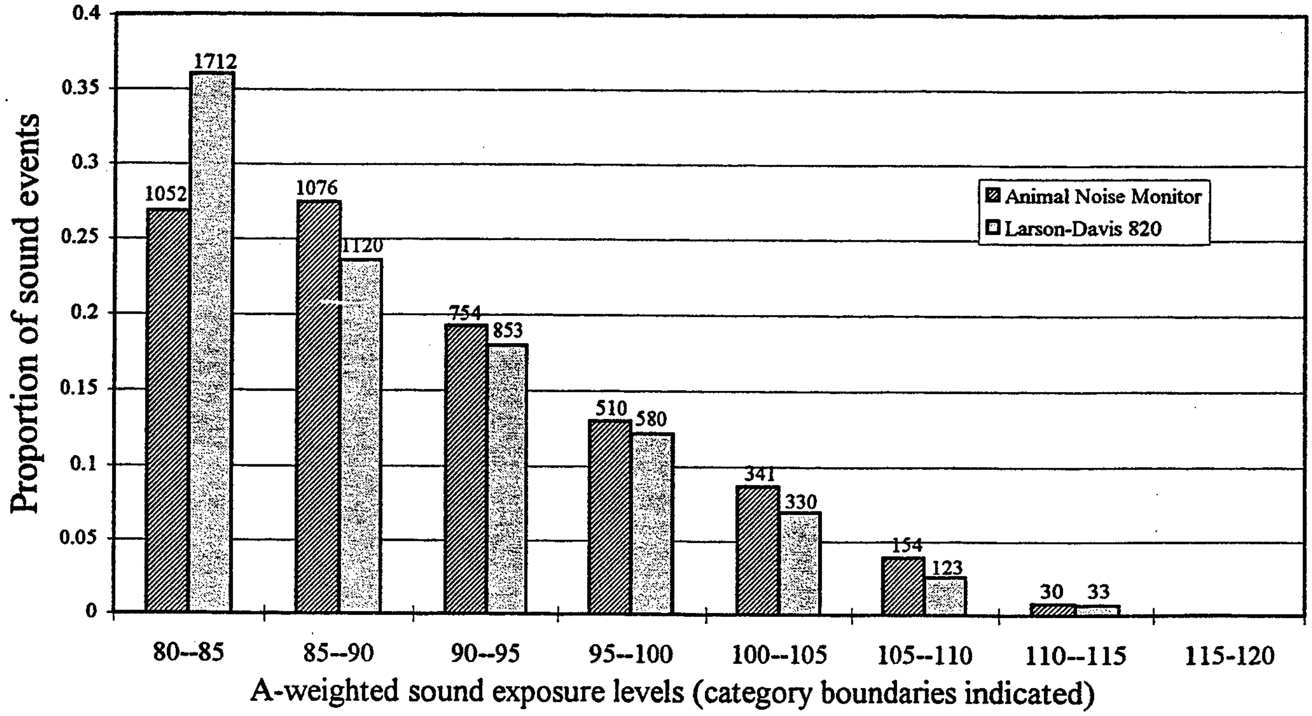


Figure 3-3 Distribution of sound exposure level collected by the Larson Davis 820 and the animal noise monitors. Sample sizes are the numbers above the columns.

3.2.2.2 Acoustic Parameters by Grid Site

Sorties were rarely flown on weekends, so the following analysis treats data from weekdays (Monday o Friday) only. Weekend days were treated separately. Appendix C summarizes the following nformation from the sound sampling grids for both the control and exposure sites: location in Universal Transverse Mercator (UTM) coordinates; the type of sound meter used; total flight days monitored on weekdays; total flight hours monitored; number of flights per day; mean, minimum and maximum; median, upper and lower quartiles; range; standard deviation; and the mean of the 30 largest events for he ASELs and MXFAs at each site.

Figure 3-4 shows the sites on the grid (small open circles) with the sampling effort in total flight hours monitored for each site. Each of the 59 sites was sampled for a minimum of 144 flight hours. Fifty-nine total sites were monitored for a total of 19,035 hours and recorded 19,171 sound events over 80 dB. The median sampling time for all locations was 254 hrs. Fifty-three of the sites were in the exposed area; six were in the control area.

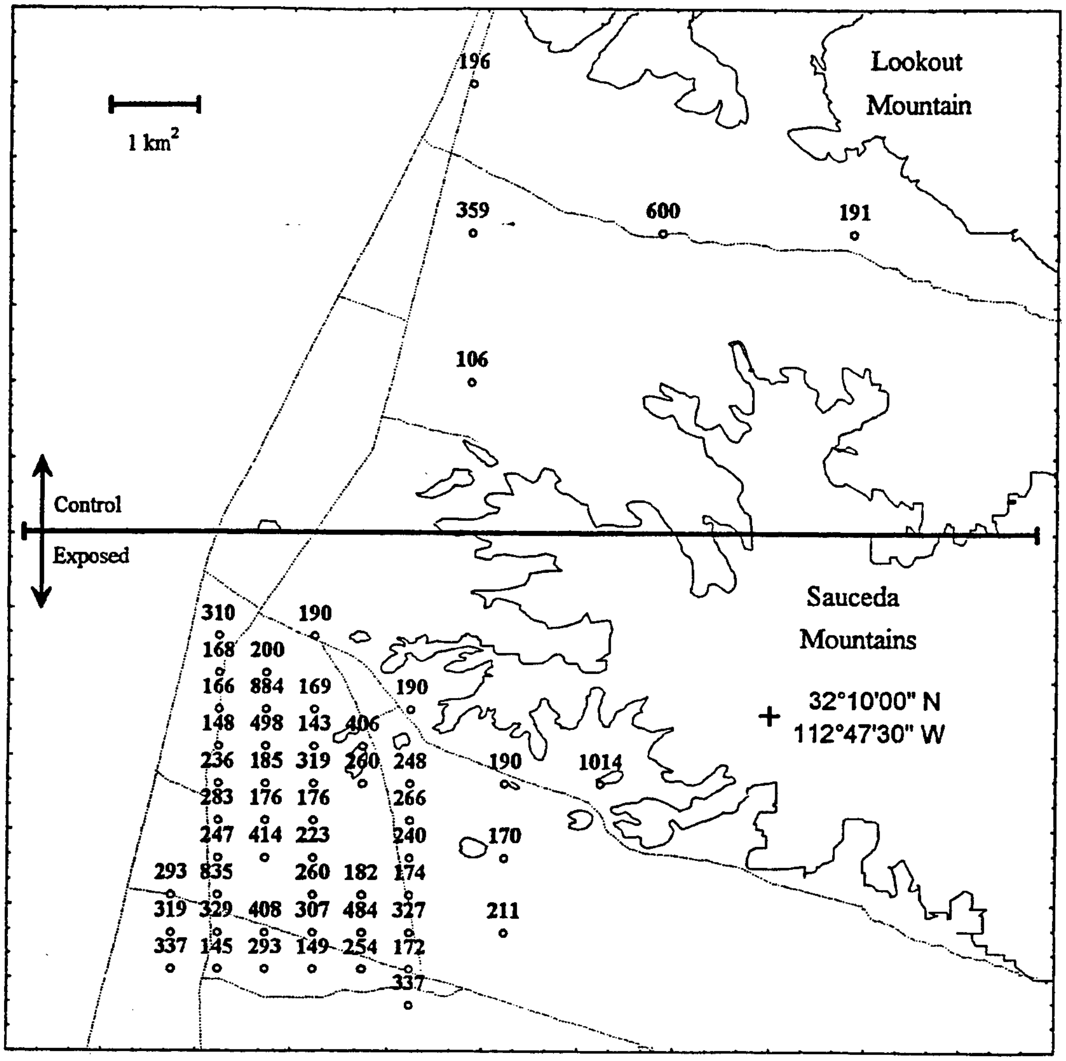


Figure 3-4 *Map of the study site showing the locations where sound monitors were used (small open circles) with the corresponding numbers showing the Monday through Friday hours monitored at each site.*

Figure 3-5 shows the largest 24HL recorded at each monitoring site. As predicted, there were two areas exposed to high noise levels. One area is near the southern part of the exposed site, under the run-up line (Nuclear Racetrack). The second is near the western side of the site, under the pop-up zone.

Figure 3-5 also shows that the control site received much lower sound levels. The quietest sampling station on the exposed site, located near the Sauceda mountains, is noisier (as measured by maximum 24HL) than any point measured on the control site. The average of the maximum 24HLs for the control site was 51.4 dB (n = 6 stations) and 68.8 dB for the exposed site (n = 53 stations). This amounts to an 17.4-dB difference in exposure between the two areas.

To compare the most intense events recorded at each site, the mean of the 30 loudest ASELs was calculated. Figure 3-6 shows this mean for each sampling site. This measurement indicated that the two oudest areas on the exposed site were along the nuclear run-up line and under the pop-up point. A few of the sampling grid locations had all 30 of their highest events greater than 110 dB. As was the case for the 24HL measurements, the sampling points on the control site were much quieter than the exposed. The mean sound level for the loudest 30 events at all stations over the entire exposed site was 103.4 dB; for the control site it was 87.3 dB. This is consistent with an order-of-magnitude difference in exposure levels between the two areas.

Figure 3-7 shows the number of overflights greater than 80 dB that occurred per flight day for each sampling point. The mean number of overflights greater than 80 dB recorded on the exposed site per day was 30.22 flights. For the control site, the mean was only 0.99 flights. Thus, both the sound levels and the rate of exposure were over an order of magnitude lower in the control area.

The highest 1HL measured was 86.7 dB and this occurred on 30 April 1993. Between 1104 hr and 1112 hr, 19 events greater than 80 dB, including five sound exposures greater than 110 dB, impacted a site ocated just north of the nuclear run-up line. This is the path most often flown by F-15s. A 24HL of 76.4 dB was measured on the western edge of the exposed site on 8 October 1993. During this day, 207 events greater than 80 dB occurred, including 35 sound events greater than 105 dB.

3.2.2.3 *Detailed Observations of Sorties*

The results of the sorties monitored by a CNM, ANM, and observer in March 1992 have been analyzed. The aircraft traveled around the racetrack many times during each sortie. The exact time each aircraft passed over the monitors was measured from a cassette recording used to collect notes. Eighty-five overflights were observed from seven F-15 sorties in three separate exercises lasting a total of two hours. Eighty-one were recorded on high-speed black and white film. Distances were calculated from these photographs.

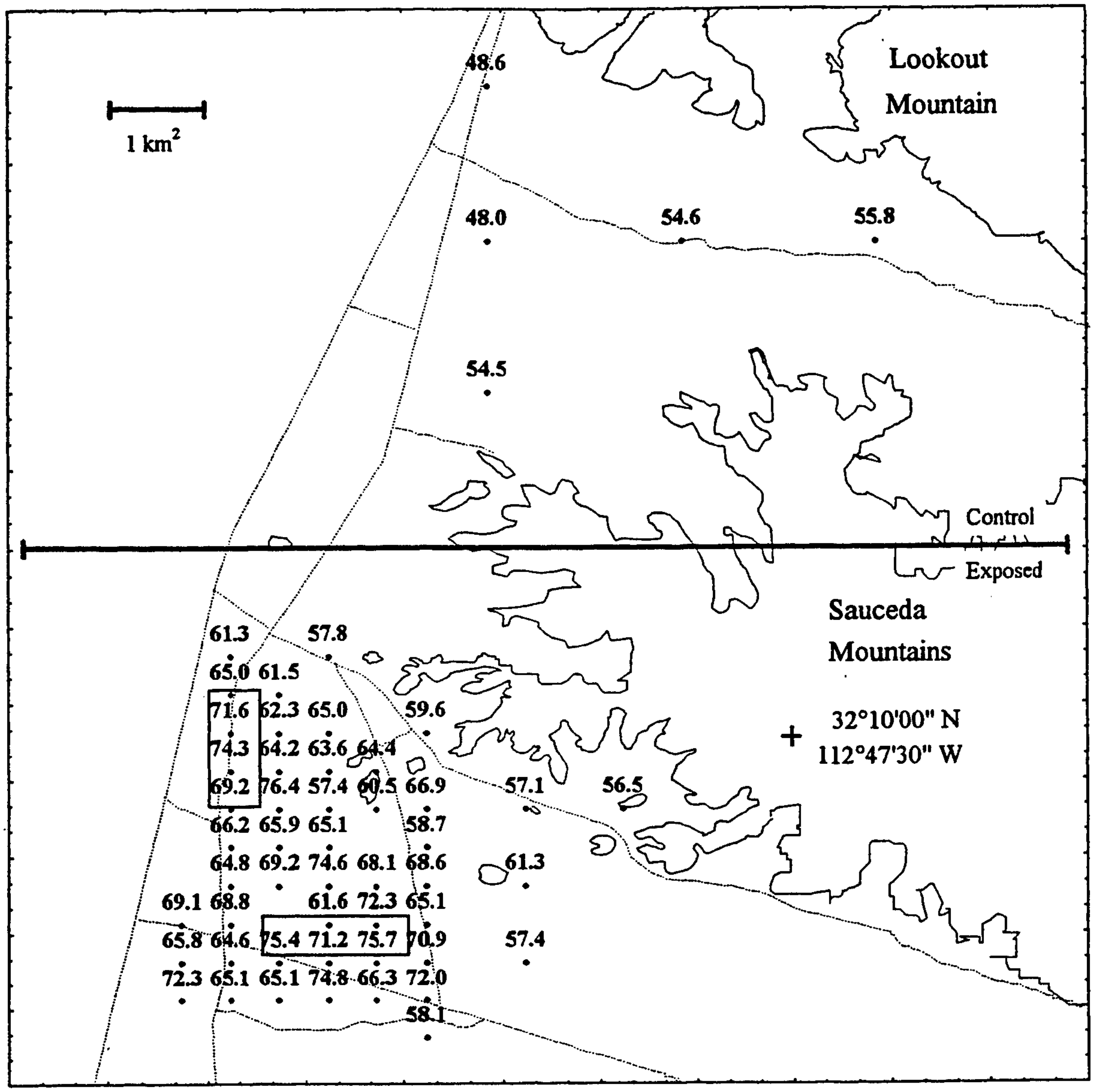
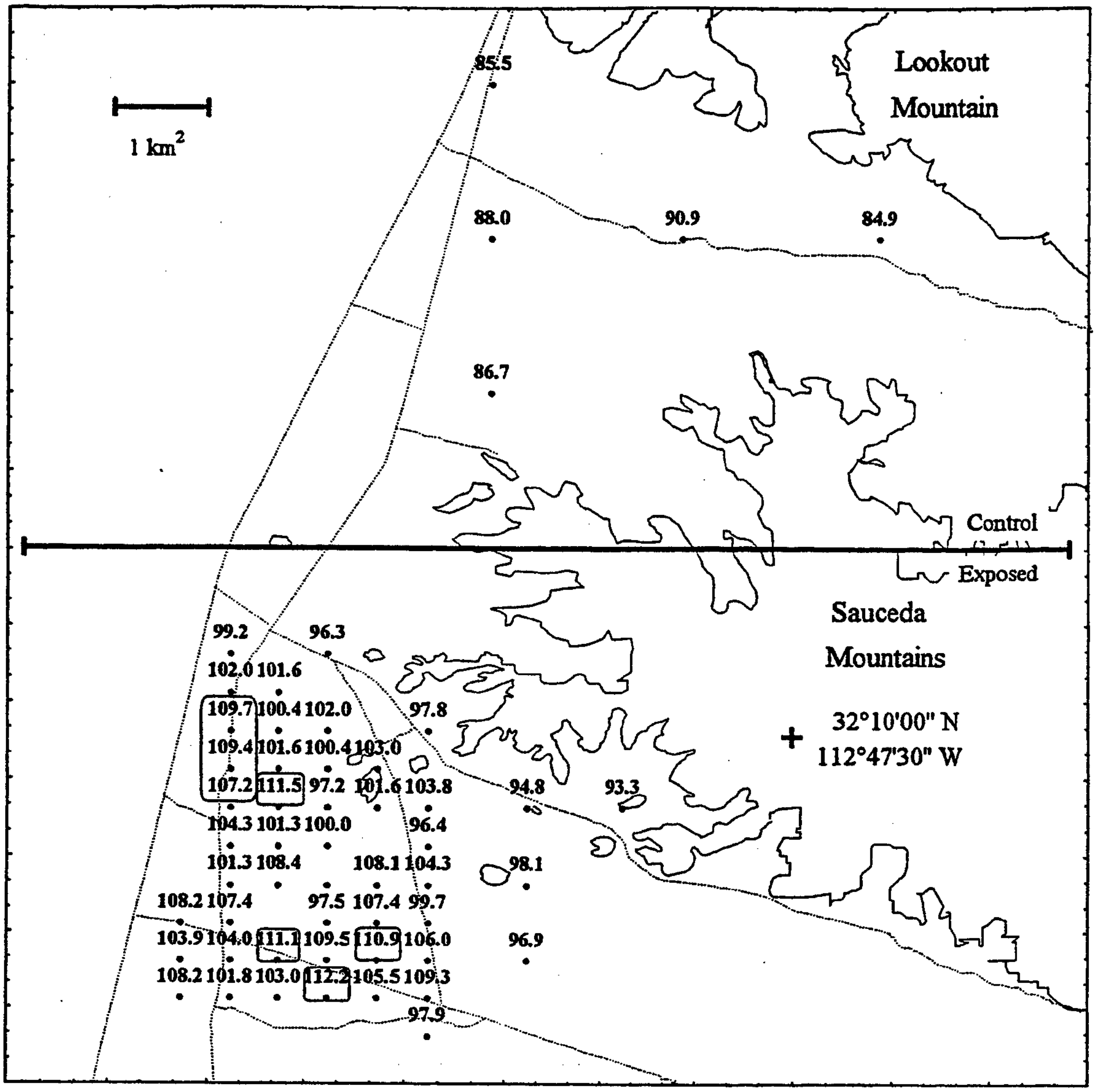


Figure 3-5 Map of the study site showing the largest 24-hour average sound level measured at each sampling grid location.

The sequence of observed overflights was compared to the events triggered on the LD820 CNM. Sixty-four of the 81 possible overflights were recorded as events. Thirteen overflights did not trigger the CNM because the levels were too low: Either the aircraft was at a slant distance of 3 km or greater or was too close to the ground. Four did not trigger the CNM because they followed upon the previous overflight too closely and the CNM was still integrating the previous sound event. Two overflights triggered the device twice; in both cases, the level (MXFA) was close to the trigger threshold.



igure 3-6 ***Map of the study site showing the mean of the 30 largest A-weighted sound exposure level measured at each sampling grid location.***

ifty-eight (91%) of the events recorded by the CNM exceeded MXFA of 80 dB, nine (14%) of 95 dB, nd two (3%) of 100 dB. The highest MXFA recorded during these overflights was 105 dB; the highest ıst, A-weighted peak SPL was 119 dB; and the highest ASEL was 105.7 dB (all the same overflight). he point of closest approach of this overflight was 718 m and it was nearly directly overhead relative) the observer (Bowles).

ı an attempt to estimate the worst exposure possible on the range, a controlled overflight was measured sing a CNM and DAT tape recorder in August 1992. During this observation, the pilot overflew the

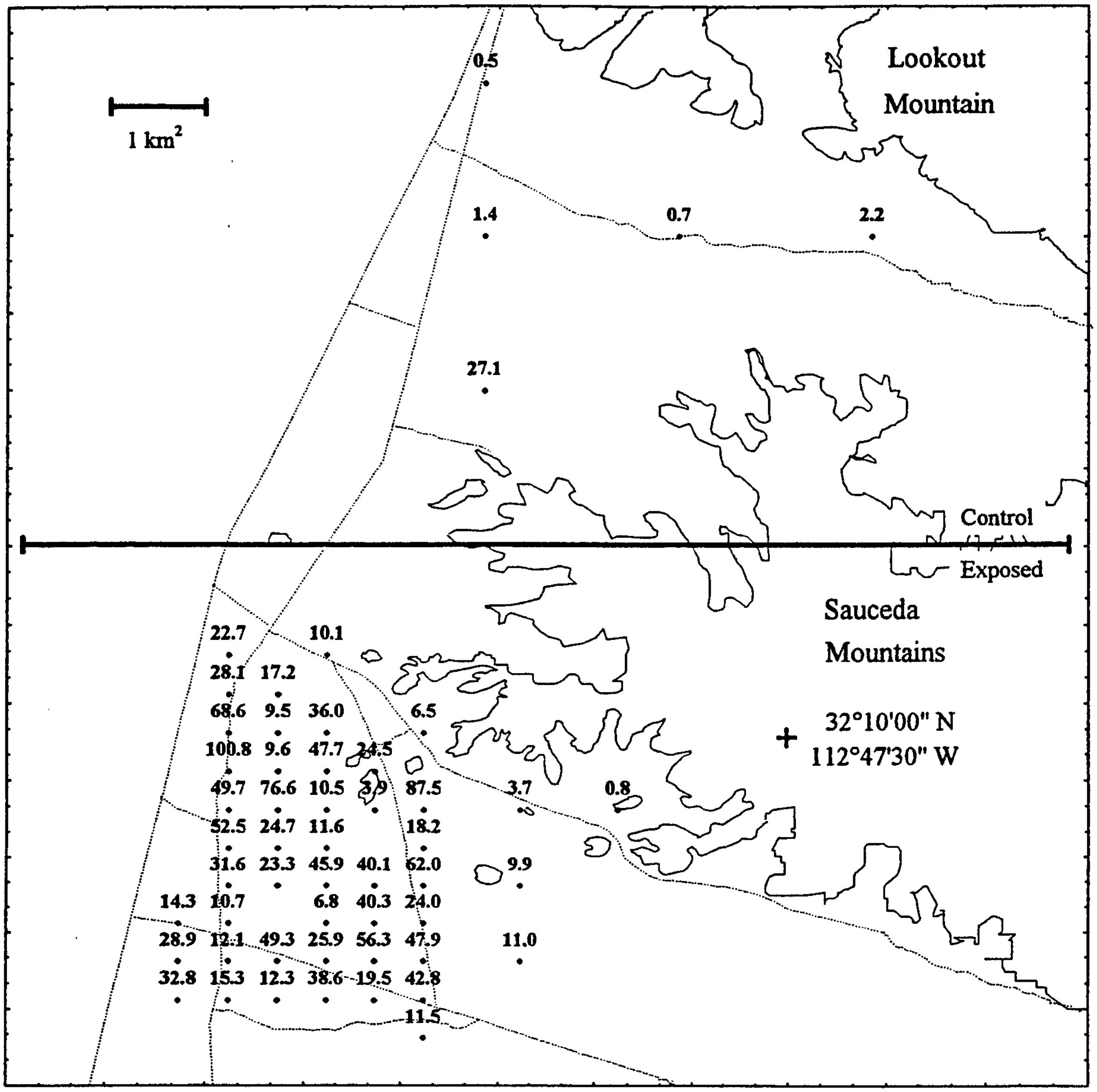


Figure 3-7 *Map of the study site showing the number of flights, greater than 80 dB, per day for each sampling grid location.*

recording site at the highest speed and lowest altitude that could be used in training. The aircraft was an F-16 that was 47.6 ft (15.6 m) in length. The altimeter reading at the time it crossed over the recording site was approximately 100 ft (33 m) and the pilot had the engines at the highest thrust he considered safe. The speed was estimated in excess of 500 mph, with the aircraft flying in a straight line.

The overflight exceeded MXFA of 127 dB, the upper limit of the CNM at the time. Based on the observer account (Francine) and the data from the monitoring systems, this was an experience unequaled by any of the other overflights monitored, either on the Luke Range or at Broadwell Lake (Bradley *et al.* 1990). The observer felt the overflight as pressure in his lungs and sinuses and had difficulty with his motor function. The overflight produced a substantial but not dangerous wind at the recording station. This wind could not have damaged eggs on the ground, but could have tossed nests in trees or bushes about.

3.2.2.4 3.2.2.4 Results of Sound Measurements in Animal Dens

One-hour average sound levels plotted against hours of the day (Figure 3-8) show that the majority of the overflights on Range 2 occur during the daylight hours. Since most desert animals are nocturnal and stay in burrows during the day, they can be insulated from this noise by the ground. Recordings were made inside both kangaroo rat burrows and kit fox dens to measure attenuation of jet overflights by the ground. On 19 March 1993, the CEL 493 CNM was placed in a small rodent burrow beneath the run-up line on Range 4. The signal from an ACO Model 7013 Type 1 microphone powered by an ACO PS9200 power supply was fed simultaneously onto a Casio model DA-7 digital audio tape recorder (DAT). The ACO microphone was covered with a 5.5-cm windball and attached to the end of a 100-cm long, 2-cm diameter aluminum pole. The microphone was then gently placed as far down the burrow as possible. Both the ACO microphone and the microphone for the CEL system were calibrated with a Gen Rad Omnical 1986 calibrator. The results of these measurements are shown in Table 3-2. For overflights 1-5, the microphone was mounted on the pole aiming downward, *i.e.*, with the angle of incidence away from the microphone. The A-weighted sound exposure levels were measured for F-16 overflights during bombing runs, except for tests 4 and 5, which were sounds generated by cannon fire from the F-16. For tests 6-11, the microphone was remounted on the pole so it was pointing towards he mouth of the hole, with the angle of incidence directly toward the microphone. The mean attenuation for overflights 6-11, as measured by ASEL, was 2.38 dB (n = 6, s.e. = 0.38).

Since there was little overall sound loss in the rodent dens, frequency-dependent attenuation was examined by placing one microphone 1.2 m above the den and a second microphone down in the den. The signals from the microphones were recorded onto the Casio DA-7 DAT. A calibration signal from a Gen Rad 1982 Omnical calibrator was recorded onto the tape before and after the overflights. As with he previous experiment, the underground microphone was placed in a small windball for protection and mounted on a pole with the grid cap of the microphone pointing towards the mouth of the hole outwards). During these recordings, the underground microphone was 42 cm inside the hole, with 33-45 m of soil above the microphone. The opening to the hole was roughly oval-shaped, measuring 10 cm vertically and 8 cm across. The recorded overflights were analyzed using a Spectral Dynamics model SD380 2-channel signal analyzer. Each overflight was averaged for 10-15 seconds, covering the majority of the overflight sound.

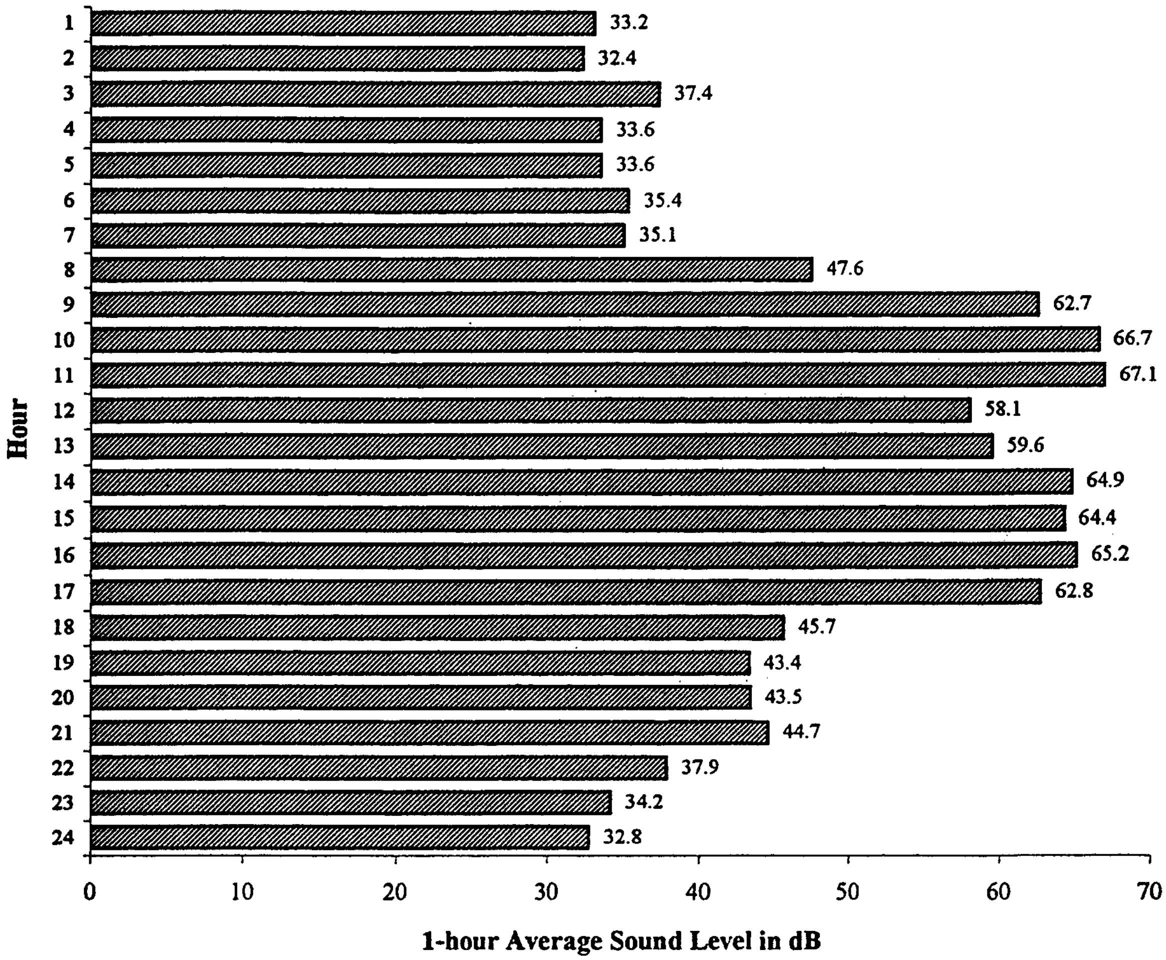


Figure 3-8 *One-hour average sound level plotted against the hours of the day. Measured on the exposed site during 1991-1992.*

Sound exposure levels were then obtained by adding 10 $\log_{10}$ (T), where T is the averaging time, to the averaged sound pressure level. The results of these tests are shown in Table 3-3. The mean wideband attenuation for all overflights measured using a dual channel recording system was 0.57 dB.

Figure 3-9 shows the spectra recorded by both microphones of overflight 8 from Table 3-3. Both spectra display sound pressure levels averaged for approximately 10 s. The jet producing this noise was an F-16 flying 200-400 m AGL and about 200 m offset from the center of the trackline and the recording station (slant distance of 280-450 m). The closest point of approach (CPA) was southwest of the recording site, the direction the burrow hole was pointing.

able 3-2 ***Difference in A-weighted sound exposure levels for jet overflight noise as measured simultaneously in-air with an integrating sound level meter, and recorded in a small rodent burrow.***

Number	ASEL (CEL 493)	ASEL (ACO microphone)	Soil above microphone	Depth in burrow	Difference
1	83.6	76.0	30 cm	80 cm	-7.6
2	83.6	75.8	30 cm	80 cm	-7.8
3	85.4	82.3	30 cm	80 cm	-3.1
4	113.2	104.9	30 cm	80 cm	-8.3
5	117.2	107.9	30 cm	80 cm	-9.3
6	99.0	95.9	60 cm	70 cm	-3.1
7	101.8	99.7	60 cm	70 cm	-2.1
8	101.3	98.0	60 cm	70 cm	-3.3
9	99.8	96.8	60 cm	70 cm	-3.0
10	97.1	96.2	28 cm	43 cm	-0.9
11	100.2	98.4	28 cm	43 cm	-1.8

s shown in Table 3-3, both ASEL and TSEL were separated by less than 1 dB for overflight 8. Figure -9 shows that, up to about 1,300 Hz, the sound levels are very similar. However, above about 1,300 z, the sound level in the rodent burrow was increasingly attenuated.

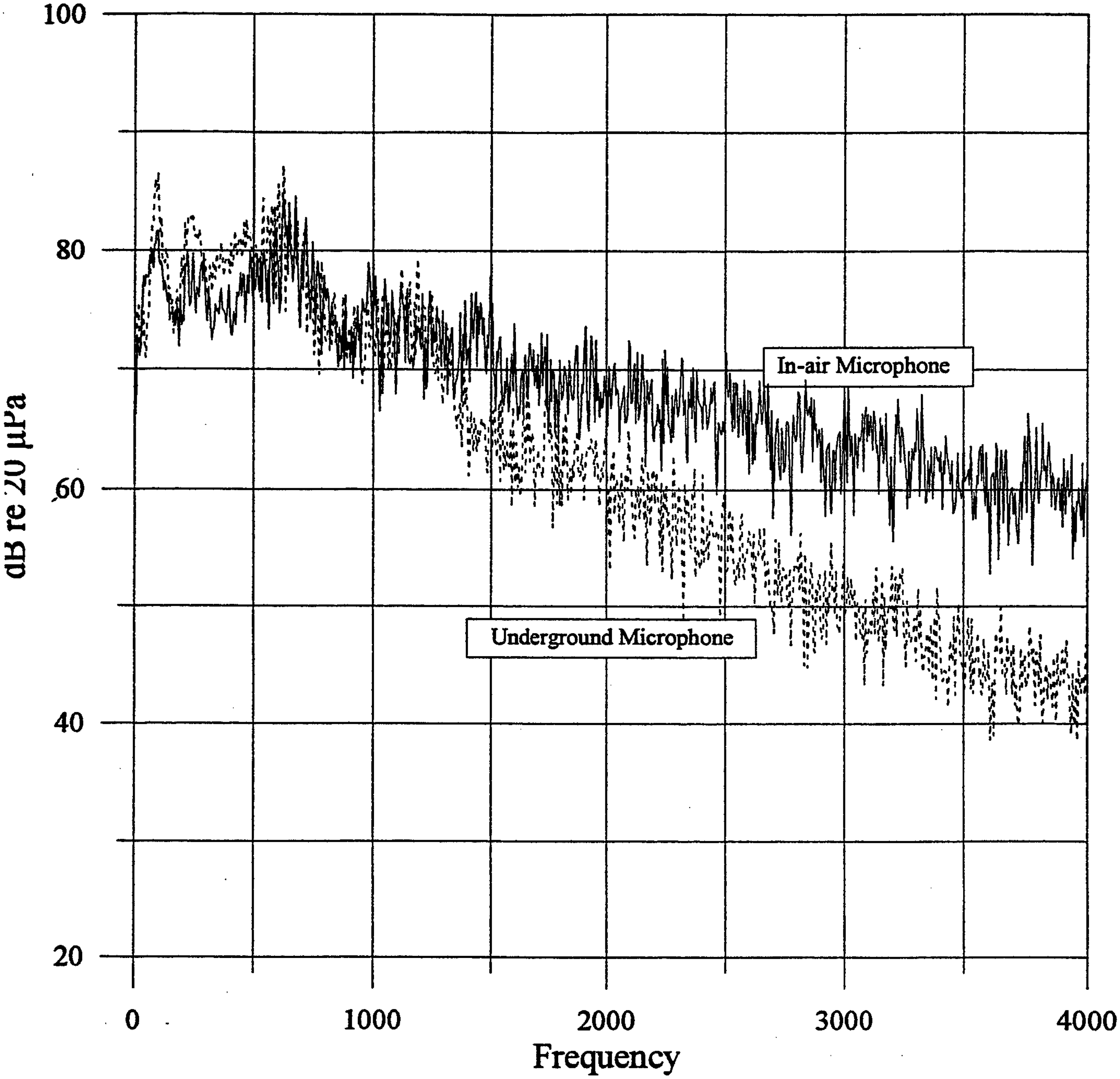
igure 2-3 shows the auditory threshold function of the Merriam's kangaroo rat (from Fay, 1988) with ts exceptional low-frequency sensitivity. Figure 3-9 shows that burrows probably do not provide much eduction in jet overflight noise to kangaroo rats because they hear well in the range from 125 Hz to ,500 Hz. However, at ranges of 1,500 Hz and higher, burrows probably provide a reduction of 10-15 B of jet noise. Equal loudness contours have not been measured for this species, so it is difficult to redict what frequencies would be most likely to cause irritation and waking.

igure 3-10 shows the sound spectra of an A-10 overflight measured with the same parameters as those n Figure 3-10. The A-10 was approximately 500 m AGL and within 100 m of 0° slant angle. Again, ound levels above and below ground were similar up to around 1,300 Hz, with attenuation below round at higher frequencies. The tonal information between 3,300 and 3,700 Hz in Figure 3-10 is the haracteristic "whine" produced by A-10s.

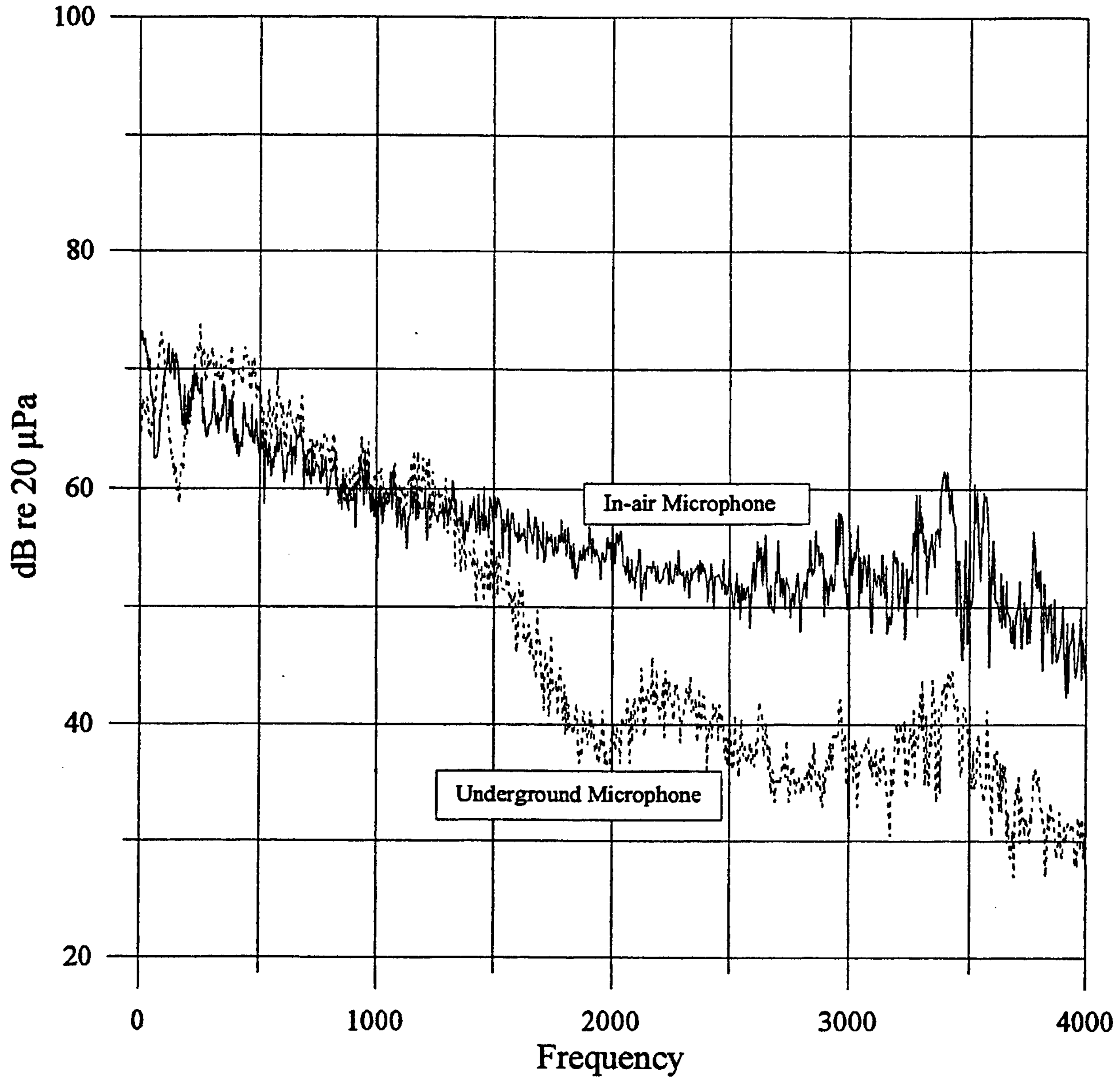
Table 3-3 Difference in A-weighted and unweighted sound exposure levels (ASEL and TSEL) for jet overflight noise recorded simultaneously in-air and down a small rodent burrow.

Number	Aircraft	TSEL (in-air)	ASEL (in-air)	TSEL (in burrow)	ASEL (in burrow)	ASEL difference	TSEL difference
1	A-10	92.9	87.7	94.5	89.5	-1.8	-1.6
2	A-10	92.1	85.8	92.7	86.5	-0.7	-0.6
3	A-10	89.3	76.7	85.2	77.0	-0.3	4.1
4	A-10	96.7	92.4	99.2	94.7	-2.3	-2.5
5	A-10	94.1	90.5	94.8	90.6	-0.1	-0.7
6	F-16	94.3	86.9	93.6	85.4	1.5	0.7
7	F-16	105.1	101.3	105.9	100.0	1.3	-0.8
8	F-16	111.6	110.0	112.3	109.3	0.7	-0.7
9	F-16	105.4	102.3	108.0	104.3	-2.0	-2.6
10	F-16	104.1	100.7	106.2	102.7	-2.0	-2.1

Similar recordings were made in a kit fox den in August 1994. The underground microphone was approximately 2.3 m down a kit fox hole for these recordings. Figure 3-11 shows the spectra of both the underground and in-air recordings of an overflight by two F-16s flying side by side. The attenuation deep in the den was much more pronounced than in shorter and shallower rodent burrows. The fox den attenuated sound down to 500 Hz, with 20 to 40 dB of sound loss between 1,000 and 4,000 Hz. The relationship between the auditory threshold function of the kit fox and these levels will be discussed in later sections.



igure 3-9 *Spectra of an F-16 jet overflight simultaneously recorded above and in a small rodent burrow. Sound begins to attenuate above about 1,300 Hz.*



Sound begins to attenuate above about 1,300 Hz. Tonal information around 3,500 Hz is the characteristic "whine" of an A-10.

Figure 3-10 *Spectra of an A-10 jet overflight simultaneously recorded above and in a small rodent burrow.*

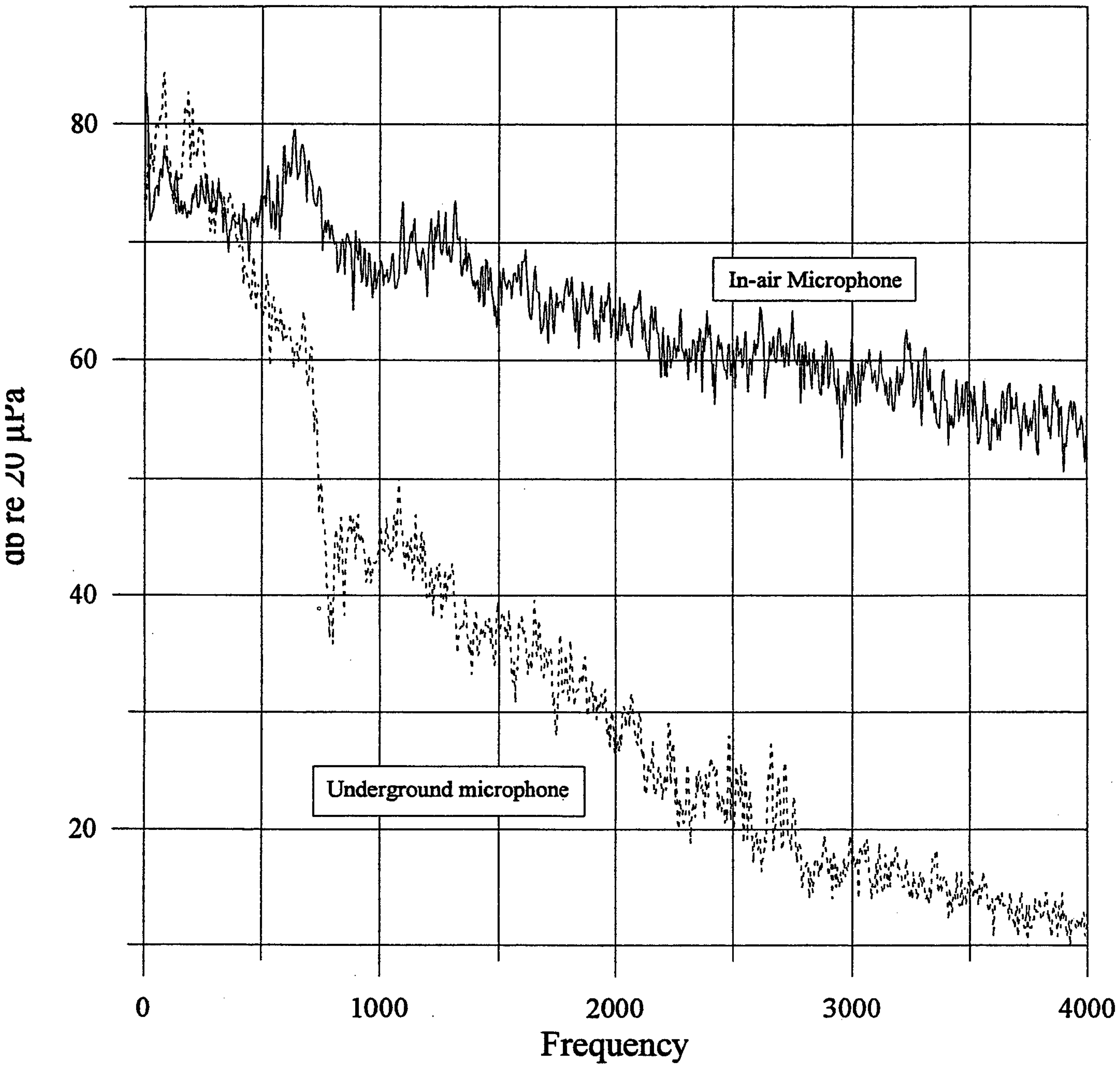


Figure 3-11 *Spectra of an F-16 overflight recorded simultaneously above and in a kit fox burrow. Overflight noise begins to attenuate at around 500 Hz, reducing the sound by 20-40 dB above 1,000 Hz.*

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4 LABORATORY STUDIES

These studies consisted of a series of laboratory and field experiments designed to measure fox and kangaroo rat hearing and the ability of foxes to function in tasks requiring detection of sounds made by prey and a stalking predator. These were specifically:

- Experiment 1: Fox hearing thresholds.
- Experiment 2: Fox prey detection of simulated prey and predators sounds in the presence of simulated jet noise.
- Experiment 3: Fox prey detection of simulated prey and predators sounds after exposure to simulated jet noise during the day.
- Experiment 4: Measurement of hearing thresholds of exposed and unexposed kangaroo rats *in situ.*

The laboratory experiments (1-3) were conducted at the Wildlife Research Center at Humboldt State University (HSU) in Arcata, California. The site at Arcata was chosen for the experience of its senior investigator (Golightly) in handling kit foxes and the presence of a USDA-approved holding facility for foxes. Permits were obtained from Arizona Game and Fish to collect four foxes (two males and two females) from an area to the west of State Highway 85 and to the north of Range 3 (dubbed "Area C"), transport them to Arcata, and conduct the tests (Permit #GLHT000247). The HSWRI Institutional Animal Use Committee approved the research protocol, based on standards of the Animal Behavior Society and American Veterinary Medical Association. Transport and holding in California was approved by the California Department of Fish and Game. None of the foxes was seriously injured or impaired during these or the following experiments; they are currently being used for ecological research by the HSU Wildlife Research Center.

The foxes were housed in same-sex pairs in runs at HSU and maintained by assistants experienced in caring for foxes. They were in good health at capture. On arrival, they were weighed, measured, and examined by Dr. Golightly. They were found to have ear mites and internal parasites (ascarid nematodes, Toxocara spp., per Botzler, HSU, pers. comm.). They were treated for mites and given two doses of an anthelminthic. They acclimated rapidly to the presence of humans (under seven days). They were found to interact with one another using vocalizations that have not been reported in wild foxes. They were fed mice the first two days of captivity, and were shifted to a high protein diet consisting of mink chow and dead chicks. All four acclimated to the diet without difficulty.

4.1 METHODS

4.1.1 Laboratory Studies of Fox Hearing

There have been no audiometric evaluations of foxes. Foxes were not expected to be easy to condition using classical stimulus reinforcement techniques (Golightly, pers. comm.), hence a somewhat more passive method was chosen. Startle inhibition audiometry (SI audiometry) has been used successfully on a number of small to mid-sized mammals, and yields measurements of auditory capacity comparable to or better than stimulus-reinforcement techniques. The system used was developed by San Diego Instruments, Inc. (SDI) and Dr. Mark Geyer at the University of California, San Diego. The system consists of a "lunchbox" (portable) 386/25 MHz minicomputer running under MS-DOS, a Rapid Systems Waveform Generator, and an SDI Startle Recording System. The recording system consists of a fox holding tube mounted on a piezoelectric acceleration sensor, an amplifier, an air puff generator developed by one of the authors (Francine), a speaker to generate a startling white noise pulse, and a stage to support all the equipment. A calibrator was provided by SDI to insure that the response of the acceleration sensor remained constant.

Foxes were tested in a house on the campus of HSU. The holding tube for the fox was mounted in a specially-constructed wooden box lined with sound absorbing foam to reduce background noise as much as possible. The tube was designed to minimize standing waves (HSWRI design). The playback computer and receiving system were quiet enough to permit thresholds at approximately 0 dB to be determined. A modified step-up, step-down procedure was used for the testing.

Startle-inhibition (SI) audiometry is possible because any sound heard by a mammal within approximately 150 ms of the presentation of a startling stimulus inhibits the muscular twitch associated with the startle. The startling stimulus must have the lowest possible level needed to produce an adequate startle, to reduce the chances of temporary threshold shifts induced by the experimental paradigm itself. Both air puffs and white noise bursts were used as startling stimuli during these experiments. The air puffs were originally intended as a control, to insure that the startling noise did not introduce threshold shifts; they later proved to be more reliable as startling stimuli.

Startle inhibition (SI) occurs if an animal receives a "warning" pre-stimulus before a loud noise-burst or an air puff. The pre-stimulus alters the latency of a startle and reduces the intensity of startled movements. Therefore, by observing the latency and magnitude of the startle, it can be determined whether the animal heard the pre-stimulus sound. All four experimental foxes were tested by this method using pre-stimulus tones at octave intervals beginning at 125 Hz and ending at 40 kHz (well above the upper limit of hearing in dogs). Stimuli were 300 ms in duration with shaped onsets and ffsets, and were separated from the startling stimulus by 100 ms. Measurements stepped up and down cross the estimated detection threshold in 3-dB increments and an average threshold was calculated for oth the upward and downward limits of detection.

.1.2 Detection of Simulated Prey and Predator Noise in the Presence of Simulated Jet Noise

BBN Sound Simulation System was transported to Arcata in July, 1992 and set up at the Simpson imber Mills, approximately four miles from the Wildlife Research Center. These inoperative mills are cated in rural Humboldt county. The warehouse dedicated to these experiments was over 1 km from e nearest road, which was narrow and lightly-traveled. This area was chosen for the experiments ecause noise and disturbance was too great at the Wildlife Research Center.

he BBN Sound Simulation System was designed to simulate the aircraft noise generated by low-altitude verflights (Chavez *et al.*, 1990). It consisted of a Panasonic Digital Audio Tape recorder (DAT) producing pre-recorded jet noise through a loudspeaker cluster. The speaker was set up on a caffolding 5.8 m from the ground in a vacant yard adjacent to the large mill warehouse. A fenced area .8 x 9.2 m was built to hold the foxes during the experiments. The yard had lights and a room from hich the experiments were monitored. The setup is shown in Figure 4-1 and a map of the sound field roduced by the simulation system is shown in Figure 4-2.

ive weatherproof surface-mounted speakers were laid out at varying distances from the jet playback eaker, but with constant angular separation (17°) from the fox staging area (Figure 4-1). Each prey eaker stand was equipped with a food cup covered by a trap door controlled by an electronic solenoid; e door was opened by an operator when a fox approached the speaker during tests. Food dispensing d sound playbacks were controlled from a booth invisible to the foxes (Figure 4-1). Sound levels of e playback stimuli and simulated aircraft were measured using either a type 1 microphone recorded nto a DAT tape, or with an integrating sound level meter.

t the start of each experiment, the focal fox sat or stood ("staged") on a small box in the corner of the perimental pen. The course it traveled and the time it took to identify the source of the sound was easured using videotaped images of the experiment. Food rewards were dispensed only if the fox proached the speaker producing the noise. Food cups were refilled at the end of blocks of five trials minimize disturbance and to maximize the number of trials per night. Hence, during the course of ch five-trial block, the number of speakers with food available decreased from 5 to 1. There was no parent evidence that foxes remembered which speaker boxes they had already visited, ***but possible fects of trial order will be examined during analysis.***

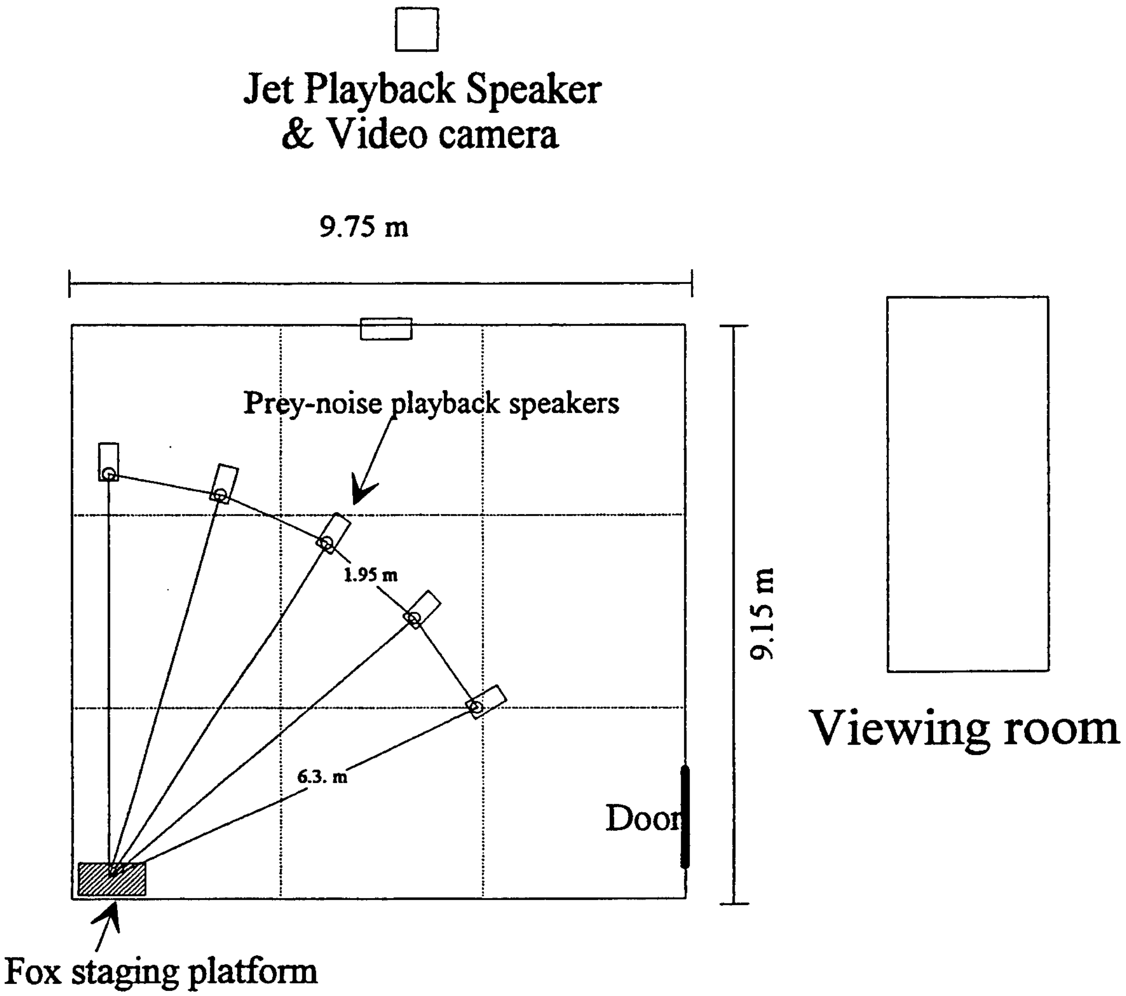
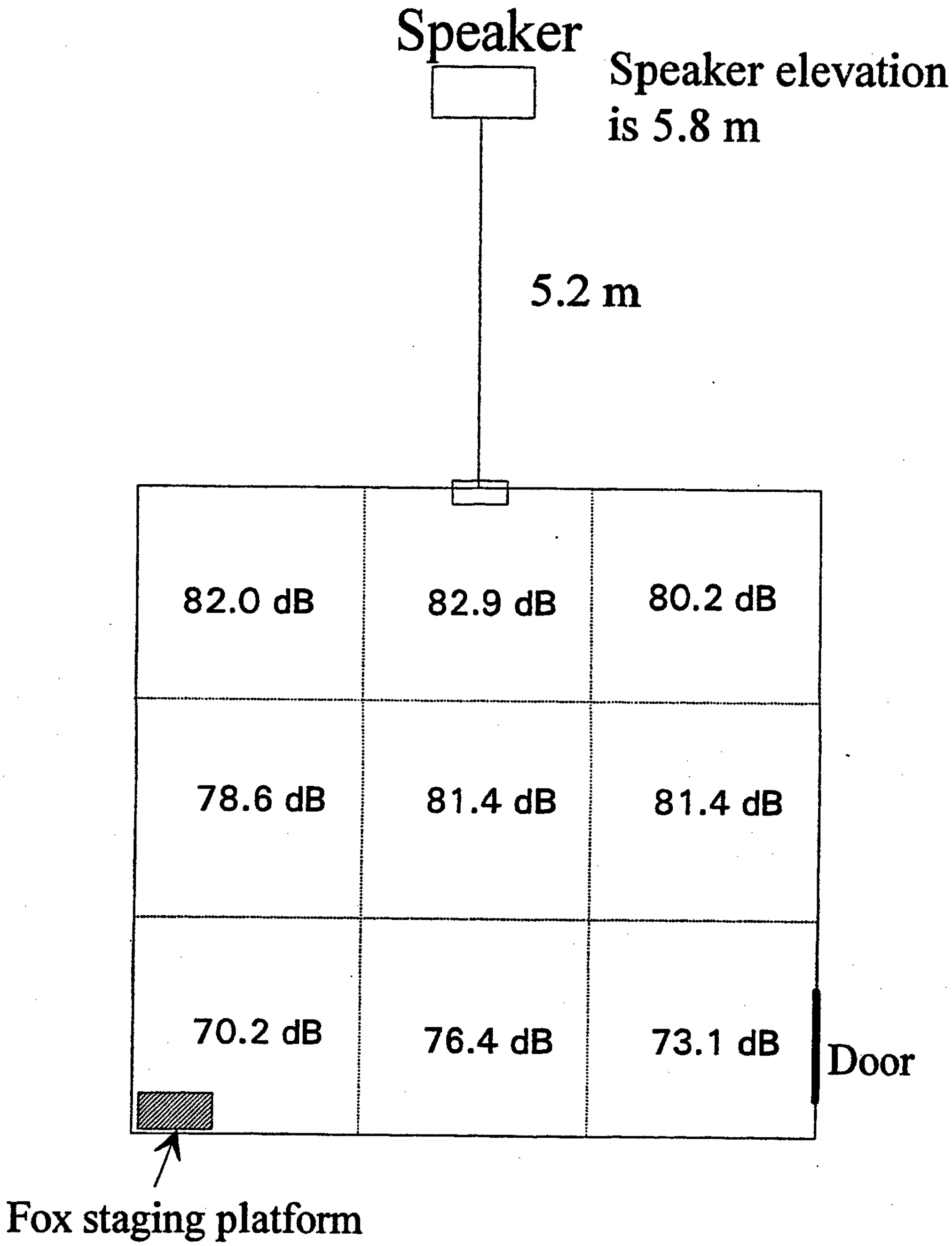


Figure 4-1 *Set-up for kit fox predator-prey experiment at Simpson Timber Mill in Arcata, CA.*

Experiments took place at night, when the foxes were most alert. After initial tests, all the experiments were conducted in the dark, a more natural setting for the animals. Video images were amplified during nighttime trials with a Dark Invader light-intensifying lens.

The sound level of prey noise produced by each speaker was held constant at approximately natural levels (a few dB above ambient at the source). Animal responses were measured by ear-pricking, orientation on the sound source, latency to leave the staging box, latency to approach the speaker and directness of approach.



igure 4-2 *Sound calibration levels (MXFA) in the predator-prey experiment enclosure from the jet overflight simulation playback system.*

hen the fox approached the correct speaker, it was rewarded by opening the trap door and allowing to eat the food. Food was not dispensed unless the fox oriented on the speaker and came within a body length of it. If the animal did not approach the correct speaker within 15-45 seconds, the prey sound ceased and no reward was given. Care was taken to insure that the fox could not tell which cup was to be opened prior to each trial by putting food in all cups at one time before the start of the trial block.

The nightly ration of food was dispensed completely using this protocol whenever possible, and the fox was not fed for six hours before the start of trials. Any food that was not dispensed by the end of the session was left for the animal in its holding area after the end of the trials.

Trials were also conducted with the sound of footsteps approaching stealthily. These sounds were also delivered at levels a few dB above ambient at the source. Foxes responded to human approach by freezing alert oriented on the sound, or by dropping into a defensive posture with the body and ears flattened close to the ground (Figure 4-3). The latency to these behaviors and the duration of the response was measured.

Figure 4-3 ***Kit fox response to an approaching human. Foxes flatten their bodies and often lower their ears at the sound of an approaching human.***

Using this setup, the following experiments were conducted:

Experiment 1: Exposure to aircraft noise during the day. Foxes were exposed to 330 simulated aircraft overflights broken into "sorties" during the daytime. Exposures were at levels up to 94 dB ASEL directly over the staging area and consisted of five bouts of playbacks with sixty-six "passes" by aircraft during each bout. Sorties consisted of F-16, A-10, F-4 and B-1B aircraft. Figure 4-4 shows the ASEL level of the overflights played during each sortie. Each sortie lasted approximately 40 minutes, with a one-hour average sound level of 70.5 dB at the staging box. The loudest overflight playback at the fox staging area had an MXFA of 96.2 dB and an ASEL of 93.9 dB. The interval between bouts was assigned randomly, but the interval between passes was fixed. The rate at which foxes correctly identified prey noise at night was then measured. Responses of sleeping foxes to the simulated overflights was also measured with a time-lapse video camera mounted above the sleeping area.

Experiment 2: Exposure to aircraft noise at night. Foxes were exposed to simulated overflights during the sound identification trials at night. Real-time video records of the experiments were used to determine how the foxes modified their behavior in the presence of noise and whether the time to prey detection changed. Two hundred to three hundred simulated overflights were emitted during the course of the experiments at random intervals. The strategy for identifying the active speaker, the initial direction of travel to the speaker, the latency to detection and the detection threshold (sound level) were measured. By the time these experiments were conducted, the foxes were accustomed to aircraft noise, so startle responses were not expected or observed.

4.1.3 Laboratory Experiments on Small Mammals

The laboratory work on small mammals consisted of measuring small mammal hearing in the study area on Merriam's kangaroo rats from both exposed and control areas. Measurements were made using startle audiometry and later using auditory brainstem responses (ABR). There are no studies involving measurements of hearing sensitivity in wild populations of animals, with or without exposure to man-made noise. Therefore, it was unclear how rapidly the measurements could be made or what sensitivities would be obtained. Kangaroo rats on the BMGAFR were expected to be good subjects for such a study because they are a population with particularly good hearing at low-frequencies; because small mammals are to some extent more prone to auditory damage than humans; and because, in the BMGAFR, they are exposed to levels of noise just under maximum levels that would be considered safe for lifetime exposure in humans.

Although the jet noise occurring in the most heavily exposed areas of Range 2 was loud and frequent, based on laboratory studies it was not likely to cause permanent hearing loss in small mammals (see Section 2.4.4). However, most laboratory rodents do not hear well at low frequencies, nor have they been exposed throughout their lifetimes in most studies. It was therefore unknown how protracted exposure would affect them. It was certainly possible that temporary threshold shifts lasting for hours or days would be detectable.

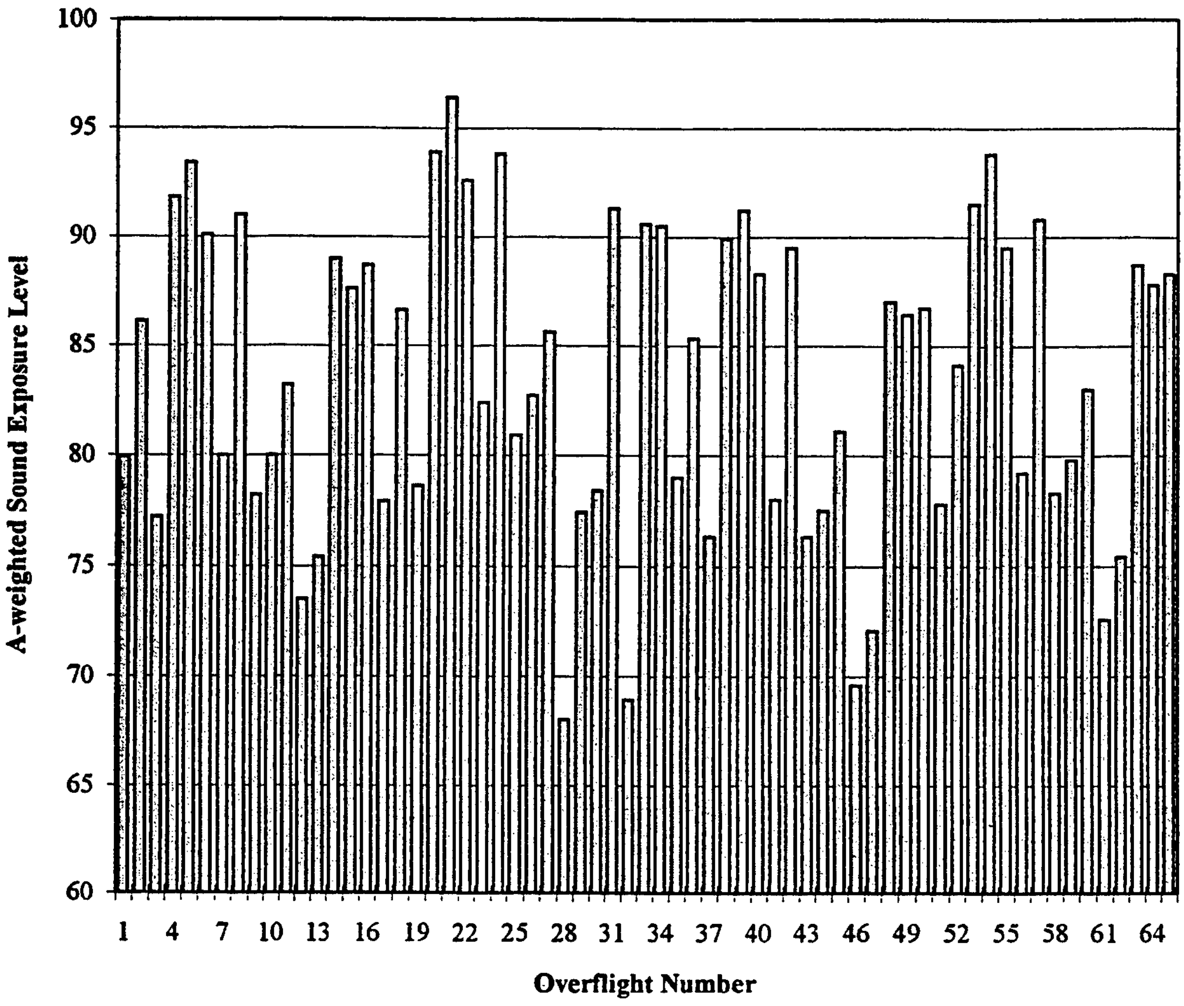


Figure 4-4 Sound exposure levels of the overflight playback used for kit fox foraging experiments.

Two methods were used to estimate hearing thresholds: startle inhibition audiometry (which has already been described) and auditory brainstem responses (ABRs). ABRs are very *precise* measures of function (coefficients of variation in estimates on the order of 5%) and hearing loss correlates directly with increased ABR latencies and decreased ABR amplitudes. However, they are not as *sensitive* as behavioral measures. Therefore, the bulk of the measurements were collected using ABRs, and some measurements of function were collected using startle audiometry.

4.1.3.1 Hearing Tests (Startle Audiometry)

Hearing of kangaroo rats from both the exposed and control areas was measured using the startle-inhibition audiometric system. This method has been used previously to measure aspects of the hearing capacities of kangaroo rats (Foss, 1984). The startle-inhibition method produces thresholds similar to those measured using negative reinforcement techniques. Negative reinforcement is used routinely to measure auditory thresholds in rodents because it provides a sensitive estimate of the threshold of detection of an intact animal and does not require extensive training (Webster and Webster, 1972).

The sound level of the startling stimulus and the interval between pre-stimulus and startling stimulus was adjusted during initial tests. All study subjects were taken from study sites, tested, and returned within 24 hours to the site where they were captured. Four kangaroo rats from the most intensely noise-exposed area and from the matching control site were tested. Auditory thresholds were measured at selected frequencies using a pre-stimulus tone 300 msec in duration. Because the auditory threshold function of the species is already known (Figure 2-3), effort was concentrated on a few selected frequencies (0.125, 1, 4, 10, and 20 kHz). A step-up, step-down protocol was used to measure the thresholds at each of these frequencies. No individual animal was exposed to more than one series of trials.

4.1.3.2 Hearing Tests (Auditory Brainstem Response)

In addition to startle audiometry, auditory-evoked brainstem responses (ABRs) were used to measure hearing thresholds in kangaroo rats. ABRs are electrical potentials generated by the brainstem when the ear is stimulated by sound (Hall, 1992). They appear at medium latencies after exposure to a stimulus, after cochlear microphonics but before cortical-evoked potentials. Stimuli may be clicks, which are used to measure broadband hearing sensitivity, or shaped tone-bursts, which are used to measure frequency-specific sensitivity. The potentials are measured as voltage differences between electrodes located over the cochlea, at the vertex of the head, and on the body (ground). Potentials are averaged during several hundred successive presentations to increase the signal-to-noise ratio. ABR is a popular method in hearing research because:

1) In most cases it is not affected by subject state;

2) The response is strongly correlated with changes in the stimulus;

3) Estimates of thresholds can be obtained in a few hours; and

4) It is found in a wide variety of animals (Burkard and Voigt, 1989).

The hearing of 18 Merriam's kangaroo rats was measured using this method. Nine of the rats were captured from the control site and nine from the exposed site. ABR testing was conducted in the field, using a battery operated, portable system consisting of a Bio-Logic model Traveler II computer and a Heart Interface voltage inverter powered by a pair of 12VDC deep cycle car batteries.

Testing was done in September 1994, during the cool, early morning hours. On the night before testing, 15 to 20 Sherman livetraps were baited with commercial birdseed and set out in appropriate areas. Traps were cleared before sunrise, with the largest and healthiest kangaroo rats kept for testing. Therefore, the samples collected do not represent a random selection of individuals in the population. Although animals with auditory impairment might be most likely to have other health problems, it would have been impossible to differentiate between illness-induced hearing loss and noise-induced hearing loss without histological examination of the ears, which was outside the scope of the present study. The purpose of the present tests was to determine whether mild hearing deficits were widespread after exposure to aircraft overflights during the day.

After capture, all the rats were temporally marked on the leg with a felt-tipped pen. They were weighed prior to anaesthesia with a mixture of Ketamine and Xylazine. Since the anaesthesia was intended to immobilize rather than prevent pain (no significant pain was expected), the level of anaesthesia was kept as light as possible. Once immobilized, three subdermal platinum/iridium needle electrodes were implanted. The active electrode was placed at cz in the International 10/20 system (on the vertex of the cranium), the reference electrode just posterior to the pinna and the ground electrode on the animal's back. Electrode impedance was less than 6 kW and inter-electrode impedance was less than or equal to 4 kW. The drugged animal's body temperature was measured with a rectal thermometer and respiration was timed throughout to insure that the animal was not too deeply anaesthetized. Every effort was made to keep the animal's temperature stable and normal, to insure that threshold measurements were not affected by temperature. A small chemical hand warmer was used to warm any animal that showed a decrease in body temperature; animals with increasing body temperature were cooled with water mist. The study subject was then placed on a small foam pad on the ground and, if there was wind, covered with a custom windscreen. Prior to and during the ABR testing ambient air temperature, wind velocity and background noise levels were measured. Sound was conducted into the external auditory meatus through an Etymotic Research model ER-2 speaker using a modified ear insert. The modified ear insert fit snugly into the ear canal, with standard earplug foam to reduce external noise.

There was no difference in the background noise during the tests on the control site and the exposed site. The A-weighted ambient noise ranged from 13 to 22 dB, and averaged 19.3 dB on the control site and 19.1 dB on the exposed site. There was also no difference in ambient air temperature during the testing. The air temperatures ranged from 24.6°C to 30.8°C with the mean temperature during testing at 27.7°C on the control site and 27.5°C on the exposed site. The winds were never judged to be greater than 3-5 mph and for most of the testing there was no measurable wind. The modified ear insert was expected to produce attenuation of 10-15 dB; therefore, kangaroo rat sensitivity could be measured down to 5-10 dB, close to the best sensitivity of kangaroo rats measured in the laboratory.

The sound stimuli presented to the kangaroo rats were calibrated after testing. Signals from the Bio-Logic ABR computer were recorded through a Brüel & Kjær model dB0138 2cc coupler with a calibrated Type 1 microphone. The signal from the microphone was analyzed through a Spectral Dynamics SD380 signal analyzer.

The above analysis provided the sound pressure levels of the stimulus relative to an ear canal volume of 2 cc. The sound pressure of the stimuli presented to the rat (whose ear canal volume is substantially smaller than the 2 cc typical for humans) was calculated by the following means: The volume of the external auditory canal was measured for seven Merriam's kangaroo rat ears by injecting a two-part polyurethane resin (PDL Castmaster) into the ear canal and allowing it to harden. The solidified resin was then carefully removed from the skull and the volume determined by submersing the "plug" into a graduated tube. The kangaroo rats used for these measurements were collected for studies of body fat content in 1992 and had been frozen since they were collected.

The mean external auditory canal volume for seven Merriam's kangaroo rat ears was 0.081 cc (CV = 8.5%). This increased the SPL of the calibrated stimulus signal by $20*\log_{10}(2\text{ cc}/.081\text{ cc})$, or about 25 dB. The 60-dB click setting on the Biologic system produced a click measured through the 2-cc coupler at 64 dB, providing a signal of 89 dB SPL to the kangaroo rat.

Three different stimuli were used in the hearing tests. The first was a broadband click. This click had most of its sound energy between 1 and 4 kHz, but some energy up to around 5-6 kHz (Figure 4-5). The click was used to measure:

1) Typical ABR in the rats;

2) Changes in the ABR after changes in the presentation rate; and

3) The 40-Hz response.

The last test is used to determine responses at levels approaching threshold; it provides the best estimate of absolute sensitivity. To determine the 40-Hz response, clicks are presented to the subject at rate of 40 Hz. Instead of a 10-15 ms time window for recording the ABR, a 100-ms window is employed. The 40-Hz response is seen as peaks occurring approximately every 25 ms (1/40/s). Unlike other ABR tests, the 40-Hz response may be affected by anesthetizing agents. The second type of stimulus was a toneburst at 250 Hz. This shaped toneburst had a rise and fall time of 4 ms with 2 ms at the plateau. The third stimulus was a shaped tone-burst at 8 kHz. This stimulus had a 2-ms rise and fall time with 1 ms at the plateau.

For standard ABR testing, stimuli were presented at rates of 19.1/s. The amplified output of the electrodes was filtered from 100-3,000 Hz and sampled for 15 ms after the stimulus was presented (except for 40-Hz response testing). The ABR at each stimulus amplitude was replicated twice and the waveforms were saved on disk for further analysis. Each ABR represented 1,024 averaged waveforms collected after artifact rejection.

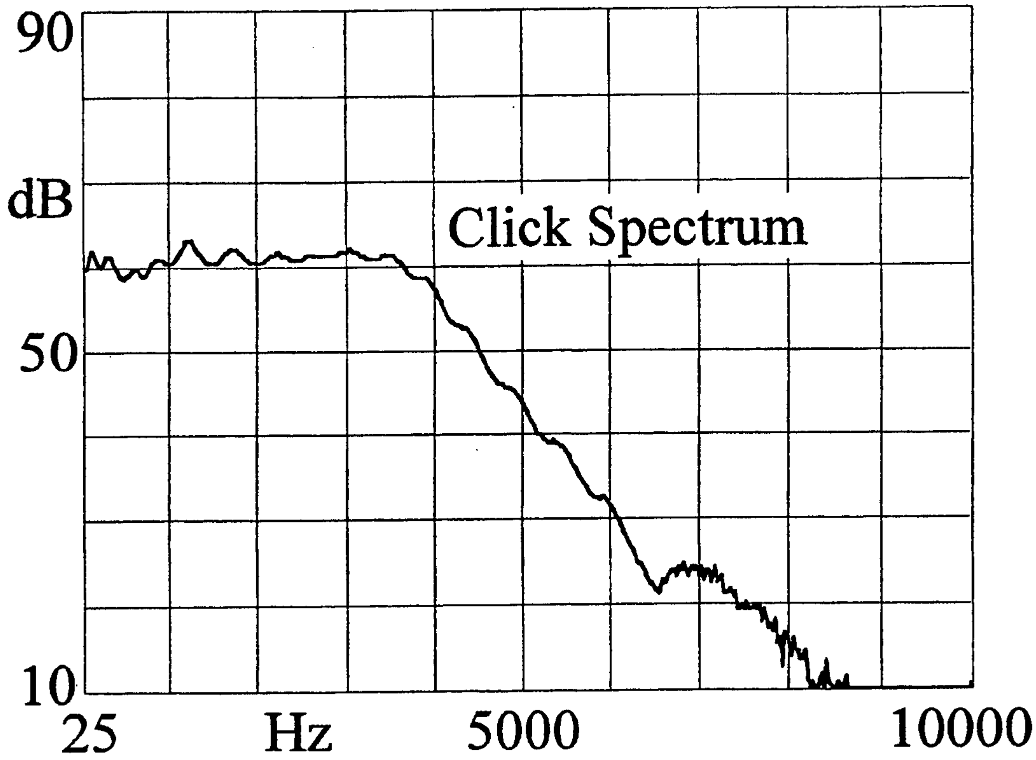


Figure 4-5 *Spectrum of clicks used for audiometric assessment of kangaroo rats with auditory brainstem responses.*

4.2 RESULTS

4.2.1 Hearing of Kit Foxes (Startle Audiometry)

4.2.1.1 Hearing of Kit Foxes After Exposure to Simulated Aircraft Noise

4.2.2 Responses of Kit Foxes to Simulated Aircraft Noise During the Daytime

4.2.3 Performance of Kit Foxes on Tasks in the Presence and Absence of Simulated Aircraft Noise

4.2.3.1 Hearing of Kangaroo Rats Exposed to Aircraft Noise on the BMGAFR (Startle Audiometry)

4.2.3.2 Hearing of Kangaroo Rats Exposed to Aircraft Noise on the BMGAFR (ABR Audiometry)

An artifact during ABR collection is defined as any electrical activity that is not part of the response and therefore should be excluded from the analysis (Hall, 1992) (*e.g.*, muscle movement). The Bio-Logic system automatically excludes from averaging any signal that is out of a specified voltage range. The amplifier gain was adjusted until the level of artifact rejection was around 10% of the collected waveform. For the click response tests, the mean percent of artifacts for all the trials was 9% (minimum = 6%, maximum = 13%). For the 250-Hz test, the mean was 8% (minimum = 5%, maximum = 14%). For the 8 kHz test, the mean was 9% (minimum = 6%, maximum = 14%).

The click stimulus alternated between compression (positive pressure) and rarefaction (negative pressure). Alternating clicks, rather than stimuli that consist of all compression or all rarefaction clicks, reduce stimulus artifacts during waveform averaging, giving a more accurate representation of neural response. The ABR waveforms from the kangaroo rats were remarkably consistent for each amplitude combination. Figure 4-6 shows a matched pair of kangaroo rat ABR waveforms generated by 89-dB SPL clicks. As seen in Figure 4-6, 5 major positive peaks result from the click stimuli. The numbers above and below the major waves are the labeling convention used in this analysis. Figure 4-7 shows the peaks generated by an 8-kHz click and Figure 4-8 shows the peaks generated by a 250-Hz stimulus.

The decrease in peak amplitudes and increase in peak latencies are clearly seen in Figure 4-9 as the amplitude of the click is reduced. At 29 dB SPL, only two small peaks (#3 and #5) remain. The mean peak latencies for control and exposed site animals are plotted in Figure 4-10 against stimulus amplitude. A two-way ANOVA tested for significant differences in peak latencies of Waves #4-#7 (Figure 4-6) between the two sites, and between the stimulus levels. Table 4-1 summarizes the results of this test.

Table 4-1 shows that there was a significant difference between the control site animals and the exposed site animals in latency. There was, not surprisingly, also a significant difference between responses at varying stimulus amplitudes, but no interaction effect.

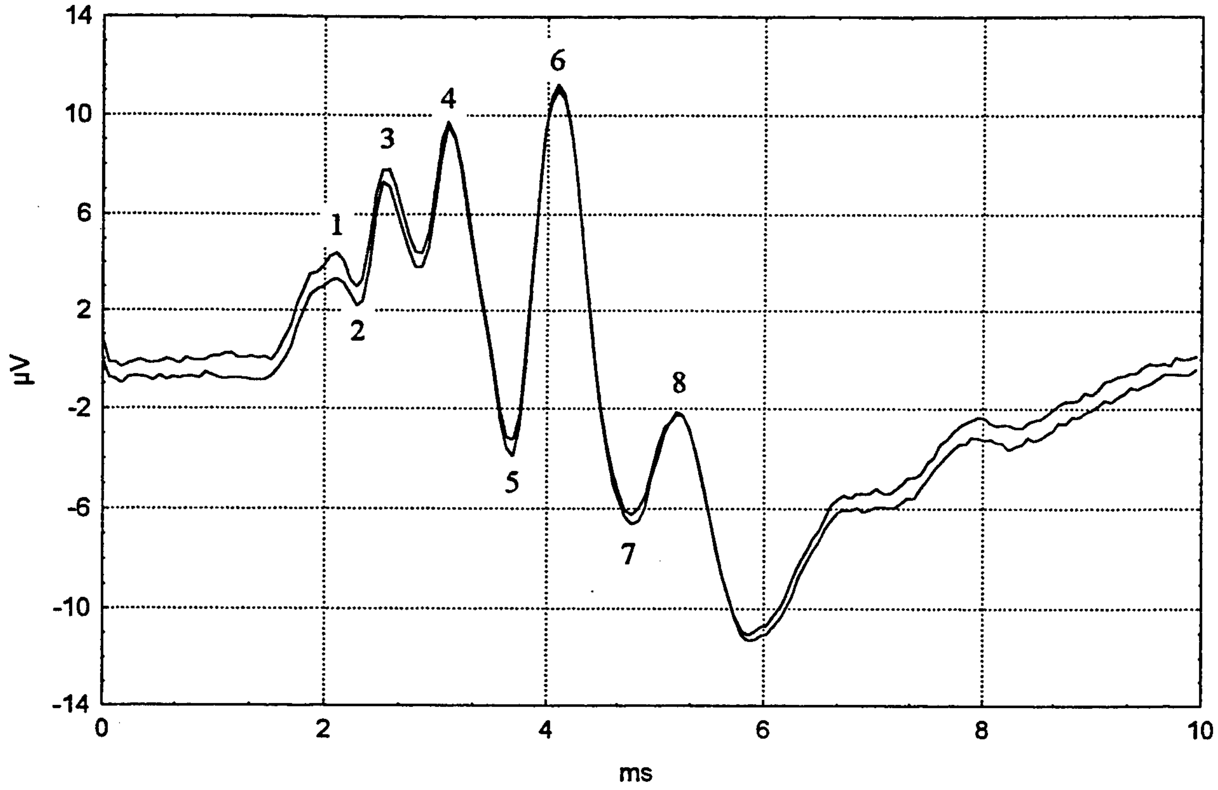


Figure 4-6 *Representative auditory-evoked brainstem response from a Merriam's kangaroo rat to click stimuli. Numbers are the labeling convention referred to in the text and the tables.*

Table 4-1 *Summary of two-way ANOVA for differences in latency to peaks between the control and exposed sites.*

Effect	Degrees of freedom	Stimulus degrees of freedom	p-level
Site	4	113	.0054
Stimulus level	12	299	.0000
Interaction	12	299	.2440

An animal was found with substantial hearing impairment on the exposed site. Figure 4-10 compares the ABR from this female generated with a 69-dB click to the ABR of a typical animal generated by a 29-dB stimulus. The normal kangaroo rat had lower peak latencies and higher peak amplitudes with

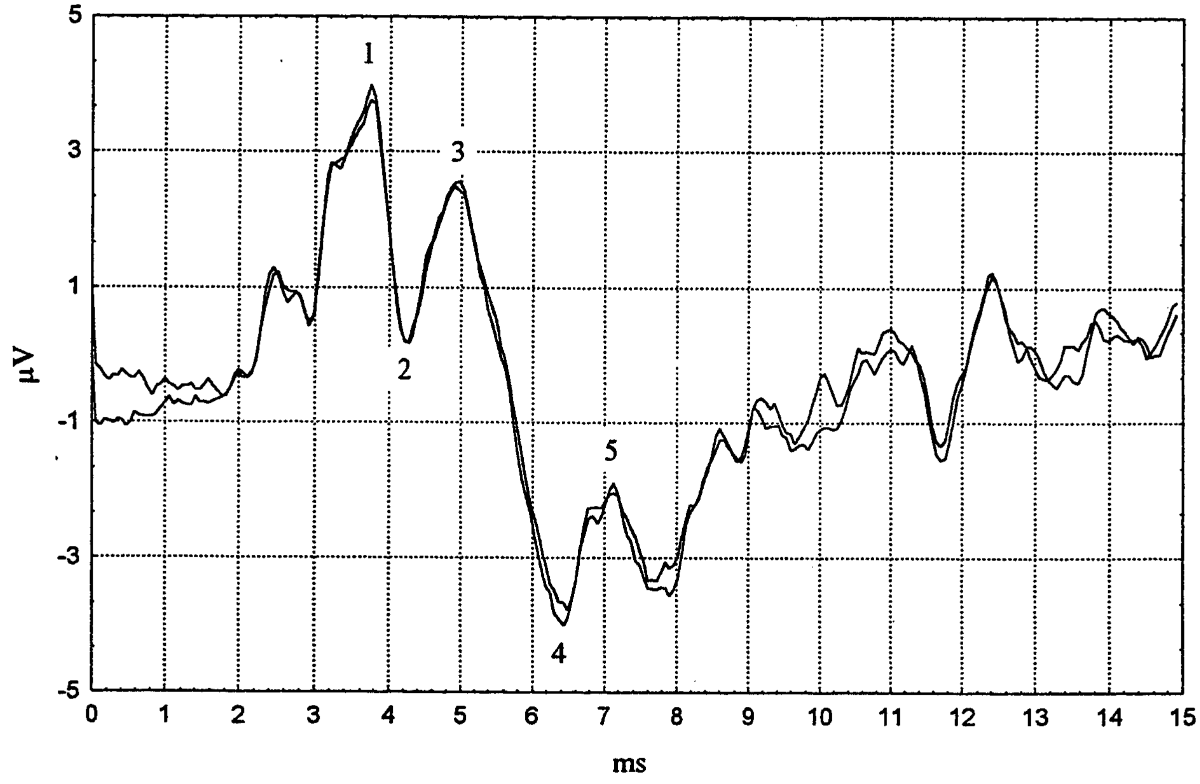


Figure 4-7 *Representative auditory-evoked brainstem response from a Merriam's kangaroo rat to an 8-kHz toneburst stimuli. Numbers are the labeling convention referred to in the text and the tables.*

40-dB quieter stimuli. The hearing impaired animal also had similar reductions in latencies and amplitudes to 250-Hz and 8-kHz tonebursts. At 250 Hz, the response of this animal to a 104-dB toneburst was similar in amplitude, but increased in latency, to a typical kangaroo rat's ABR at 74 dB. This animal appeared to have a 30-50 dB hearing loss over the range tested (250 Hz to 8 kHz). Remarkably, the animal appeared healthy in all other respects. It is not known whether the impairment was permanent, but the profoundness of the loss suggested illness or a congenital or genetic defect.

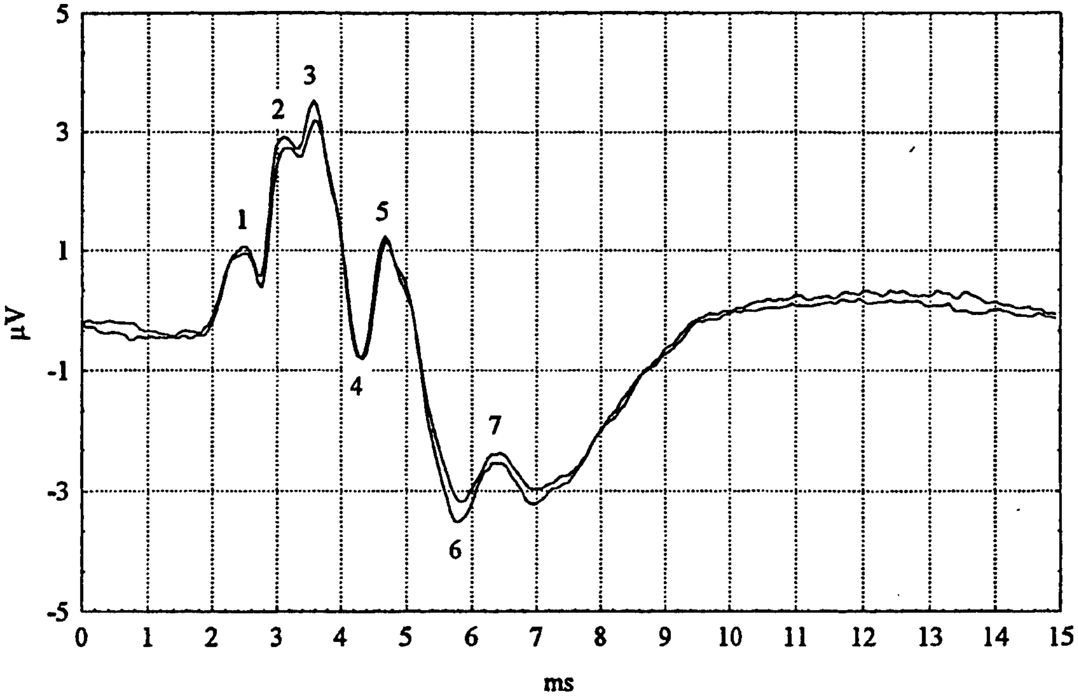


Figure 4-8 *Representative auditory-evoked brainstem response from a Merriam's kangaroo rat to a 250-Hz toneburst stimuli. Numbers are the labeling convention referred to in the text and the tables.*

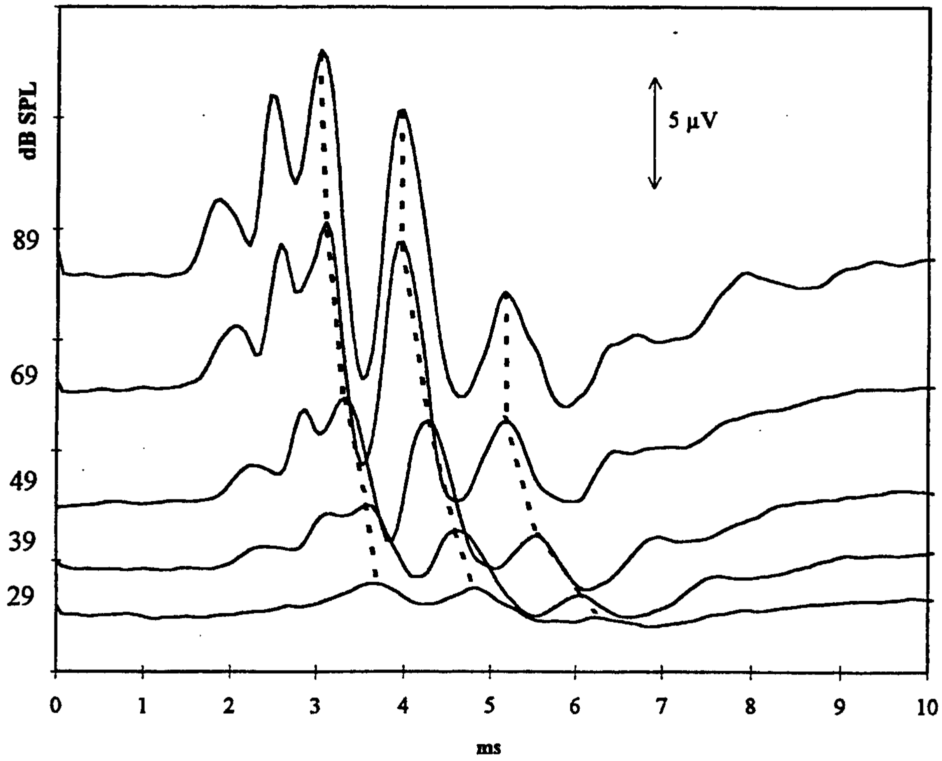
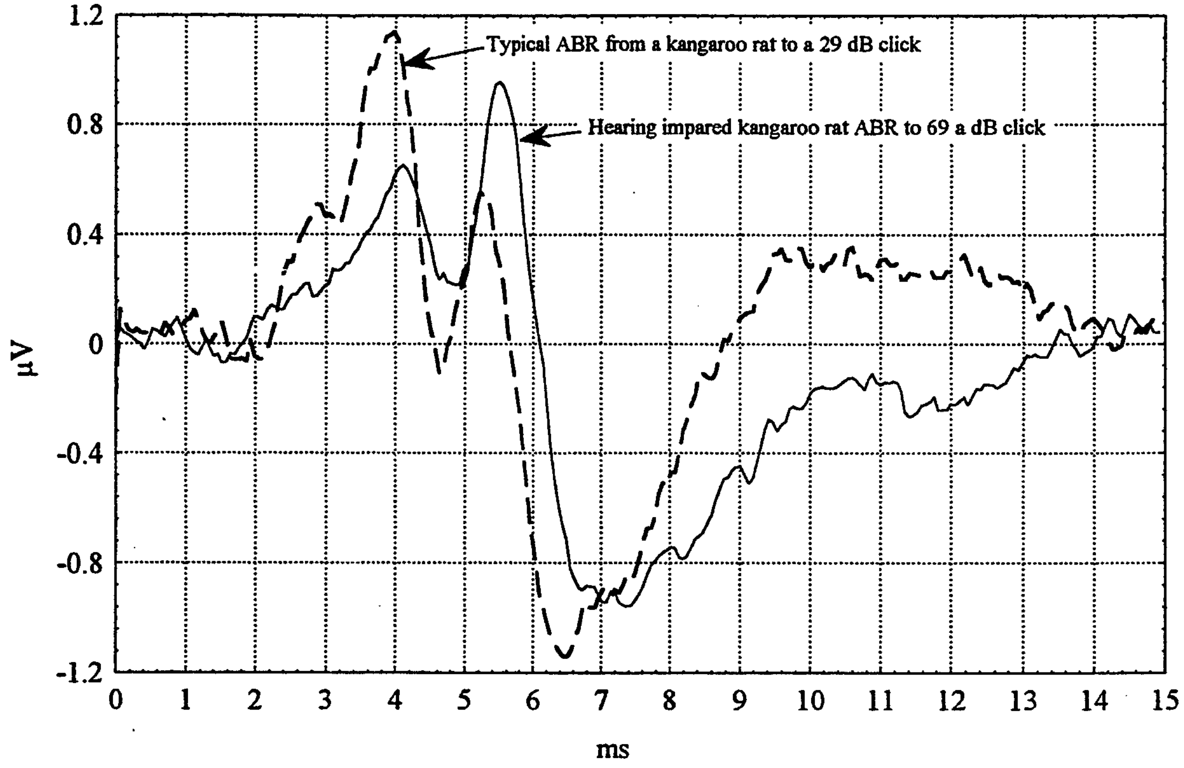


Figure 4-9 *Plot showing the increase in peak latencies and decrease in peak amplitudes as the click sound pressure level is reduced. Dotted lines follow the increase in latency for waves #4, #6 and #8.*



The stimulus amplitude for the normal hearing animals was 29 dB; for the hearing-impaired animal it was 69 dB. The response of the hearing-impaired animal shows increased peak latencies and reduced peak amplitudes to a 40-dB quieter stimulus.

Figure 4-10 *Plot of ABRs from both a hearing-impaired kangaroo rat and a normal-hearing kangaroo rat.*

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5 FIELD SURVEYS FOR SMALL MAMMALS

Surveys were conducted for small mammals in the two study areas to determine whether differences between exposed and unexposed individuals could be uncovered. Although survey grids were matched as much as possible for vegetation type and geographic features, small differences among plots were expected. Therefore, surveys included vegetation sampling to determine diversity and cover, good estimators of the capacity to support rodent populations.

5.1 MATERIALS AND METHODS

Monthly assessments of small mammal population and community dynamics were conducted on eight study plots (Figure 5-1) from December 1991 through August 1994. Five of the study plots (Grids A-C, H, and I), which were located under Range 2 racetracks, were subject to frequent low-altitude jet overflights and designated as exposed plots. Trapping on Grids A-C was initiated in December 1991 and discontinued in November 1992 because of predator attacks on the traps that decimated the rodent populations. It was apparent that an individual or a small number of individuals had learned that the traps were a good source of food. Trapping began on Grids H and I in January and March 1993. These plots were closer to the areas of most intense aircraft exposure, which by then had been established by acoustic monitoring. Grids D-F were located in the control area. The control plots were monitored monthly without interruption from February 1992 through August 1994.

5.1.1 Vegetation Sampling

Plant communities were sampled on Grids A-F in April 1992, and on Grids H and I in March 1994. Two 50-m transects were set up at each grid. Data were recorded at 100 points at 0.5-m intervals along the transects. A meter stick was placed vertically at each point with the tip touching the ground; all plant species intersecting the plane of the meter stick were recorded. Often more than one species was observed at any given point. If plants were not present at a sampling point, "bare ground" was recorded.

The two transects on each plot were set up in an "L" configuration. The first transect was laid down along the outer edge of the plot and the second transect ran through the center of the plot perpendicular to the endpoint of the first transect. Transect data were analyzed using the Simpson index of diversity (Simpson, 1949). This index takes into consideration the number of species, the total number of individuals and the proportion of the total contributed by each species. The Simpson index value (D_s) ranges from zero (low diversity) to one (high diversity). Transect data were pooled for Grids A-C, Grids D-F, and Grids H and I. D_s was calculated for each of these three groups. T-tests were performed to determine if the D_s values differed significantly between groups, as outlined by Browner *et al.* (1990).

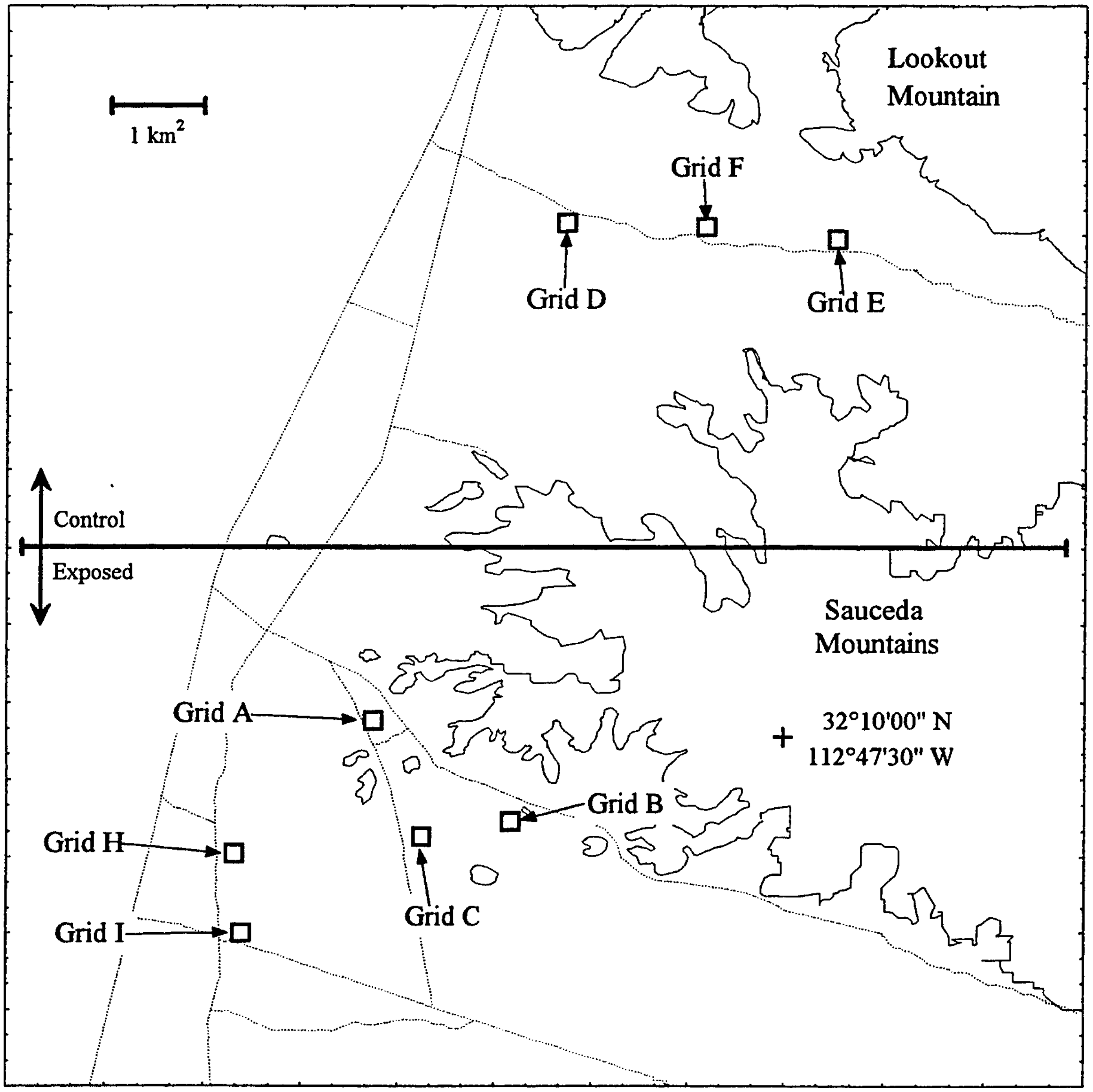


Figure 5-1 *Map of the study area showing locations of small trapping grids.*

5.1.2 Small Mammal Trapping

Each study plot consisted of a 7 x 7 live trapping grid. Traps were set at 15-m intervals in a square 105 m on a side and covering a 1.1-ha area. Each trap station was marked with a numbered wooden stake. All study plots were sampled two nights per month, weather permitting. The interval between trapping sessions was 4-5 weeks. Sherman live traps baited with mixed bird seed were set out before dark on the plots, one trap per station. Traps were checked before sunrise, closed, reopened again before dark and checked again before sunrise on the second day.

Each individual rodent captured was identified to species and given a uniquely numbered monel eartag for future identification. In the case of smaller species, such as Perognathus amplus, unique identification numbers were given by toe-clipping. Prior to release at the point of capture, the following information was recorded for each animal:

1. **identification number**
2. **sex**
3. **weight** to nearest gram
4. **location** of capture on grid
5. **external reproductive condition**
   a. males: testes scrotal or abdominal
   b. females: vagina perforate or nonperforate; nipples small or large; visibly pregnant or not pregnant
6. miscellaneous indicators of **condition,** such as general appearance, presence of wounds, and parasite load

Demographic parameters were estimated from these data monthly and seasonally for the rodent communities and for each species. These parameters were defined as follows:

1. **species diversity and biomass**—the number of species captured and the total mass of each species collected on each site
2. **species density**—the density of each species in individuals per hectare on each site
3. **trappability**—defined as the ratio of the number of individuals captured in a sampling period to the number known to be alive during the period
4. **estimated reproductive activity**—the proportion of individuals in reproductive condition
5. **recruitment rate**—the ratio between the number of individuals captured for the first time during the month and the number known to be alive at the time
6. **survival/emigration rate**—the number of individuals seen for the last time during the month divided by the total number known to be alive
7. **time of persistence**—the difference between the first and last month the individual was known to be alive
8. **body weight**

Statistical analyses were conducted using Statview (Brain Power, Inc.) on a Macintosh IIsi computer and the BMDP statistical package (Dixon *et al.*, 1988) on an SDSU Life Sciences Computing Center's Sun 4/330 computer. Statistical significance was assumed in all tests a level of $p \leq 0.05$.

5.2 RESULTS

5.2.1 Vegetation Sampling

Plant species present on each transect in order of decreasing dominance are presented in Appendix D. The two most common perennial and annual species for each transect are listed in each table. Schismus barbatus, an introduced annual grass from the Mediterranean, and the native perennial creosote bush, Larrea divaricata,, respectively, were the most common annual and perennial species on all the grids. D_s values were 0.821 for exposed Grids A-C, 0.722 for the control Grids (D-F), and 0.586 for exposed Grids H and I. The results of t-tests for these values indicate that plant diversity was significantly greater on Grids A-C than on Grids D-F ($t = 4.05$, $p < 0.001$, d.f. = **), significantly greater on Grids D-F than on Grids H and I ($t = 5.52$, $p < 0.001$, d.f. = **), and significantly greater on Grids A-C than on Grids H and I ($t = 11.75$, $p < 0.001$, d.f. = **). A total of 20 different plant species were recorded on Grids A-C, while 19 and 16 species were recorded on Grids D-F and Grids H and I, respectively.

Perennials accounted for seven of the species at the control sites (Grids D-F), while the exposed plots (Grids A-C, H and I) had only four species of perennials. D_s values using only data for perennial species were 0.596 for the control plots, 0.464 on Grids A-C, and 0.388 for Grids H and I. Perennial diversity was significantly greater on control sites than on exposed Grids A-C ($t = 5.73$, $p < 0.001$, d.f. = **) and Grids H and I ($t = 2.50$, $p < 0.05$, d.f. = **), but was not significantly different between Grids A-C and Grids H and I ($t = 0.92$, $p > 0.20$, d.f. = **).

5.2.2 Small Mammal Diversity and Biomass

Statistics summarizing trapping effort and success are provided in Table 5-1. A total of 14,455 trap-nights was spent monitoring the small mammal communities on the exposed and control plots over the course of the study. A total of 7,500 captures was made of 2,328 marked individuals. Trapping success (the proportion of traps capturing prey) ranged from a minimum of 23.3% on Grid C to a maximum of 67.3% on Grid I. When all plots were pooled, trapping success was 51.9%. Trapping success estimates are somewhat biased when Grids A-C are included in the analysis because these grids were subject to disturbances by predators, resulting in reduced trapping success. Excluding Grids A-C, trapping success for the remaining plots was 59.7%. Mean trapping success on exposed plots H and I was 66.2% ± 1.25%, while control plots D-F had mean trapping success of 56.9% ± 1.2%; this difference was statistically significant ($t = 7.77$; $p = 0.005$; d.f. = 3).

Nocturnal rodents present on the study plots in order of decreasing abundance included Merriam's kangaroo rat (Dipodomys merriami), the Arizona pocket mouse (Perognathus amplus), the desert pocket mouse (Chaetodipus penicillatus), the banner-tailed kangaroo rat (Dipodomys spectabilis), the white-

Table 5-1 *Summary trapping statistics for exposed (Grid A-C, H and I) and control (Grids D-F) study plots on the Barry M. Goldwater Air Force Range, Arizona.*

GRID	Trap-Nights	Animals Marked	Cumulative Captures	Trapping Success
Grid A	1,078	141	284	26.3%
Grid B	1,078	133	267	24.8%
Grid C	1,078	127	251	23.3%
Grid H	1,813	342	1,180	65.1%
Grid I	1,617	344	1,088	67.3%
Total Exposed	6,664	1,087	3,070	46.0%
Grid D	2,597	389	1,441	55.5%
Grid E	2,597	418	1,501	57.8%
Grid F	2,597	434	1,488	57.3%
Total Control	7,791	1,241	4,430	56.9%
Total All Plots	14,455	2,328	7,500	51.9%

throated wood rat (Neotoma albigula), and the southern grasshopper mouse (Onychomys torridus). The latter three species were not present on all plots and the number captured was small. As a result, they were not used in any statistical analysis. The diurnal round-tailed ground squirrel (Spermophilus tereticaudus) and antelope squirrel (Ammospermophilus harrisi) were also captured incidentally on several occasions; these two sciurid species have not been included in any of the analyses.

Monthly differences in mean number of species captured between control and exposed groups were assessed by an analysis of variance (ANOVA) with repeated measures; months before and after the disturbances on the exposed grids were considered separately. For the time period before the predator disturbance, mean species number was not significantly different between control and exposed plots (F = 2.20, p = 0.2122, d.f. = 1, 4). Likewise, species number did not significantly differ over months (F = 1.90, p = 0.1079, d.f. = 7, 7), nor was the change in species number over months different for exposed and control plots (F = 0.43, p = 0.8770, d.f. = 7, 28). After the predator disturbance, mean species number was not significantly different between control and exposed plots (F = 3.77, p = 0.1475, d.f. = 1, 3). However, species number among plots did differ significantly over months (F = 12.33, p = 0.0000, d.f. = 17, 17), but monthly changes were not significantly different for control and exposed plots (F = 0.68, p = 0.8064, d.f. = 17, 51).

Numbers of species were pooled by season and averaged for exposed and control grids to determine seasonal changes in species diversity (Figure 5-2). Two points emerge from Figure 5-2. First, species diversity varied seasonally on all the study plots and patterns of temporal change were similar among years. Second, levels of diversity and patterns of change were very similar when control and exposed plots were compared. Rodent species diversity was greatest on all plots from spring through fall. Diversity declined in the winter because the two pocket mouse species (Chaetodipus penicillatus and Perognathus amplus) hibernated during the winter and thus were not captured during those months.

Rodent biomass on each plot was assessed as the total weight of animals captured in each month. Means were calculated for exposed and control plots (Figure 5-3) and then compared by repeated measures ANOVA for the months before and after the disturbances on the exposed plots. Prior to the disturbance, biomass on control plots was significantly greater than on exposed plots (F = 9.68, p = 0.0358, d.f. = 1, 4). Biomass also varied significantly among plots over months (F = 7.11, p = 0.0002, d.f. = 6, 6), but the changes over months did not differ between control and exposed plots (F = 0.66, p = 0.6833, d.f. = 6, 24). Similarly, after the predator disturbance, biomass on control and exposed plots was not different (F = 4.16, p = 0.1341, d.f. = 1, 3), but varied significantly over months (F = 7.54, p = 0.0000, d.f. = 16, 16). Patterns of change with month did not differ for control and exposed plots (F = 0.67, p = 0.8058, d.f. = 16, 48). Biomass on all plots increased over the course of the study and reached peaks in the fall and winter of 1993; declining biomass was observed over the last five months of the study.

5.2.3 Trappability

Direct enumeration (Krebs, 1966) of live-trapped individuals was used to estimate population densities for the nocturnal rodent species on exposed and control study plots. The efficacy of enumeration as a census technique is largely a function of the trappability of the species being enumerated (Hilborn *et al.*, 1977). Monthly trappability estimates were pooled by species for each plot.

Seasonal trappabilities for Dipodomys merriami on the control and exposed plots are given in Table 5-2. Seasonal estimates varied between 0.61 and 1.00. Chi-square tests for heterogeneity revealed significant differences in trappability among seasons for Grid A (X^2 = 8.42, p = 0.0381, d.f. = 3), Grid C (X^2 = 9.04, p = 0.288, d.f. = 3), Grid D (X^2 = 21.10, p = 0.0122, d.f. = 9), Grid E (X^2 = 35.24, p = 0.0001, d.f. = 9) and Grid F (X^2 = 40.27, p = 0.0001, d.f. = 9). When trappabilities were pooled over seasons, no significant differences among control and exposed plots were observed. Overall trappability for D. merriami was 0.84 on control plots and 0.88 on exposed plots; these estimates were significantly different from one another (X^2 = 15.11, $p < 0.0001$, d.f. = 1), but the difference measured was small (5%).

Trappabilities for Perognathus amplus on the study plots are shown in Table 5-3. Because this species hibernates during the winter, seasonal trappabilities were computed only for spring, summer and fall.

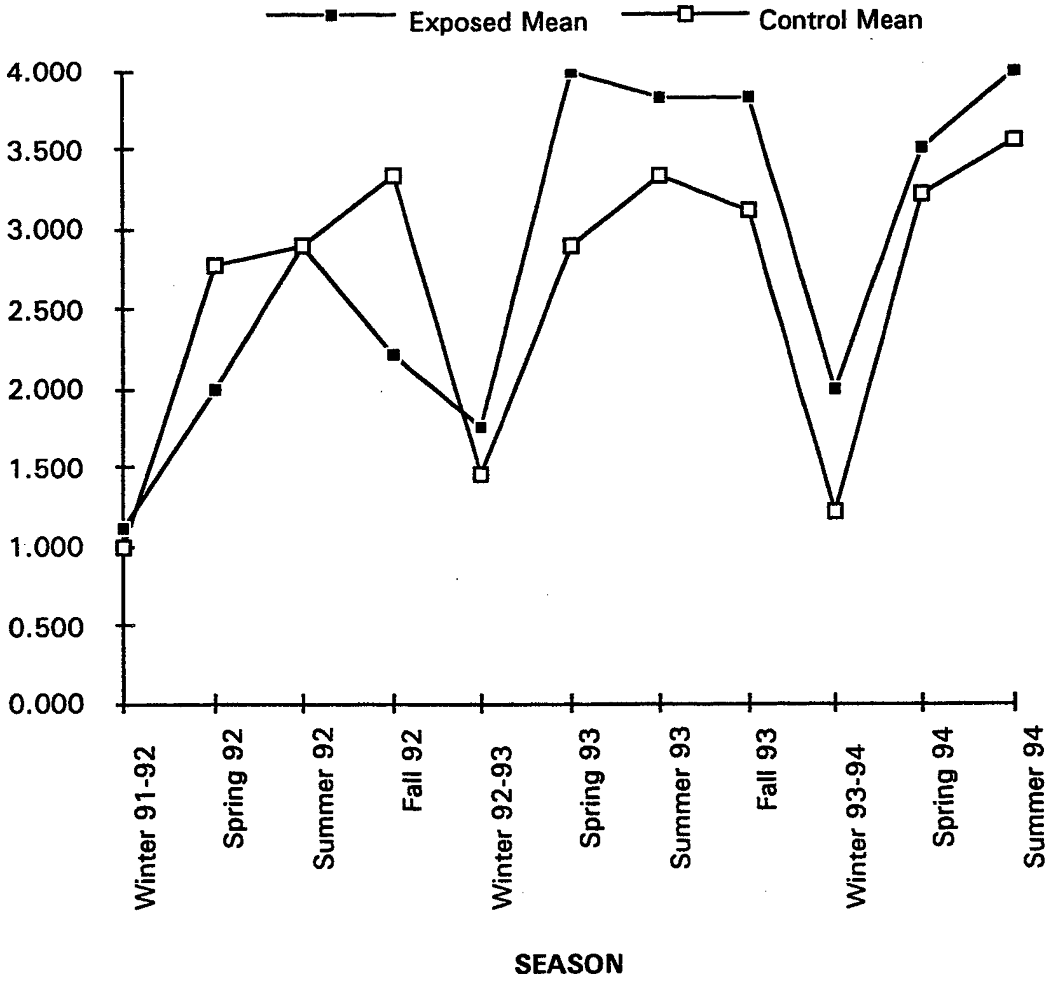


Figure 5-2 Mean number of species present on exposed and control study plots on the Barry M. Goldwater Air Force Range, Arizona.

Significant seasonal heterogeneity in trappability was observed for P. amplus on Grid B (X^2 = 17.43, p = 0.0002, d.f. = 2), Grid I (X^2 = 12.02, p = 0.0172, d.f. = 4), Grid D (X^2 = 23.27, p = 0.0015, d.f. = 7), Grid E (X^2 = 30.46, p = 0.0001, d.f. = 7) and Grid F (X^2 = 22.28, p = 0.0023, d.f. = 7). When seasons were pooled for each grid, no significant heterogeneity in trappability was observed for the three control grids; exposed plots were significantly heterogeneous (X^2 = 31.06, p = 0.0001, d.f. = 4). For P. amplus, overall trappability was 0.68 on the control plots and 0.86 for the exposed plots; the difference in these values was significant (X^2 = 87.50, p = 0.0001, d.f. = 1), a difference of 21% between the two areas.

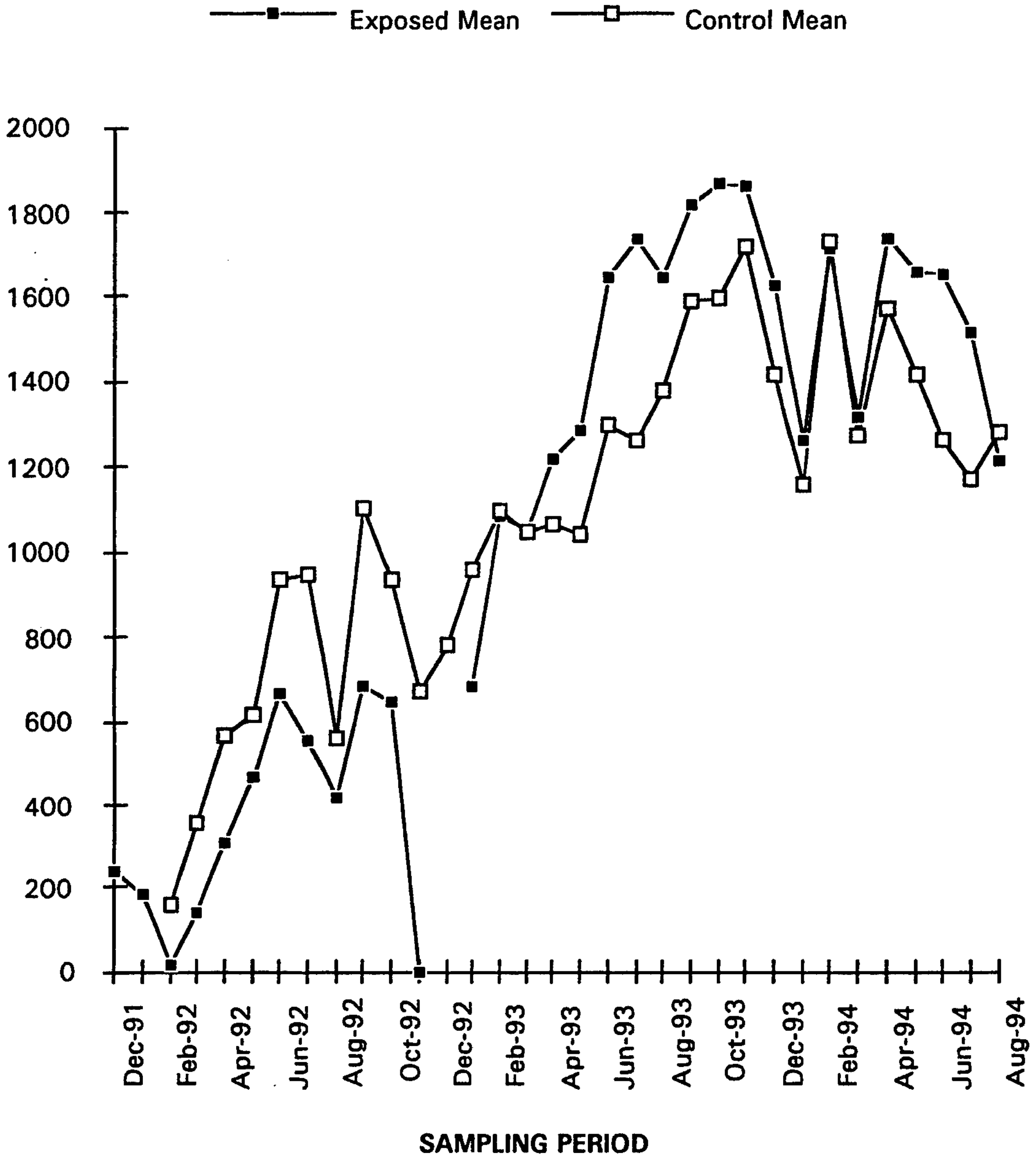


Figure 5-3 *Mean rodent biomass on exposed and control study plots on the Barry M. Goldwater Air Force Range, Arizona.*

Table 5-4 provides trappabilities for Chaetodipus penicillatus. This species also hibernates, so estimates were not available for all seasons. Sample sizes were small on Grids A-C and these plots were not included in the analysis. Significant differences in trappability among seasons were observed for C. penicillatus on Grid H (X^2 = 11.18, p = 0.0246, d.f. = 4), Grid I (X^2 = 13.67, p = 0.0084, d.f. = 4) and Grid D (X^2 = 18.88, p = 0.0044, d.f. = 6). With pooling over seasons, Grids D-F displayed no significant differences in trappability, but Grids H and I had different trappabilities (X^2 = 17.72, p =

Table 5-2 Trappability for populations of Dipodomys merriami on exposed and control study plots on the Barry M. Goldwater Air Force Range, Arizona. Monthly trappabilities were pooled by season.

Season	Exposed Grids					Control Grids		
	A	B	C	H	I	D	E	F
Winter 91-92	0.67	1.00	1.00					
Spring 92	0.71	1.00	1.00			0.83	0.85	0.88
Summer 92	1.00	0.78	0.71			0.81	0.67	0.61
Fall 92	1.00	0.88	0.96			0.94	0.78	0.82
Winter 92-93				1.00		0.98	0.91	0.93
Spring 93				0.89	0.97	0.88	0.82	0.82
Summer 93				0.84	0.85	0.73	0.77	0.71
Fall 93				0.86	0.90	0.86	0.82	0.88
Winter 93-94				0.94	0.90	0.83	0.93	0.86
Spring 94				0.91	0.91	0.79	0.88	0.78
Summer 94				0.87	0.95	0.87	0.93	0.90
Total **(N)**	**0.86** **(44)**	**0.86** **(56)**	**0.91** **(56)**	**0.87** **(622)**	**0.89** **(590)**	**0.84** **(792)**	**0.85** **(886)**	**0.82** **(904)**

0.0001, d.f. = 1). Overall trappability for C. penicillatus was 0.72 on the control plots and 0.67 on exposed plots H and I; these values were not significantly different.

5.2.4 Population Sizes

Monthly abundance for D. merriami, P. amplus, and C. penicillatus was estimated as the minimum number of individuals known to be alive in each month (Krebs, 1966). Mean abundance for these species on exposed and on control plots was calculated for each month (Figure 5-4). Differences in population size between mean control and exposed plots were assessed by repeated measures ANOVA, with time intervals before and after the predator disturbance considered separately.

Numbers of Merriam's kangaroo rats (D. merriami) increased steadily on all plots over the first two years of the study, with peak densities of approximately 50 individuals per plot occurring in the late fall of 1993 and winter of 1993-94; population sizes decreased during the spring and summer of 1994 (Figure 5-4). Patterns of change were generally similar on exposed and control plots.

Table 5-3 *Trappability for populations of <u>Perognathus</u> <u>amplus</u> on exposed and control study plots on the Barry M. Goldwater Air Force Range, Arizona. Monthly trappabilities were pooled by season.*

Season	Exposed Grids					Control Grids		
	A	B	C	H	I	D	E	F
Winter 91-92								
Spring 92	0.98	1.00	0.97			0.91	0.91	0.79
Summer 92	0.90	0.85	0.94			0.64	0.73	0.76
Fall 92	1.00	0.59	1.00			0.52	0.36	0.46
Winter 92-93								
Spring 93				0.90	0.96	0.57	0.58	0.58
Summer 93				0.74	0.80	0.75	0.75	0.68
Fall 93				0.68	0.76	0.76	0.64	0.75
Winter 93-94								
Spring 94				0.71	0.64	0.69	0.58	0.81
Summer 94				0.86	0.83	0.79	0.67	0.86
Total **(N)**	**0.94** **(185)**	**0.84** **(150)**	**0.95** **(122)**	**0.78** **(229)**	**0.82** **(215)**	**0.68** **(494)**	**0.67** **(407)**	**0.69** **(447)**

Densities on Grids A-C were significantly smaller than those on Grids D-F up to the predator disturbance (F = 40.57, p = 0.0031, d.f. = 1, 4). In addition, <u>D</u>. <u>merriami</u> abundance varied significantly over months on all plots (F = 8.82, p = 0.0000, d.f. = 10, 10) and the pattern of density change varied significantly between exposed and control plots (F = 4.30, p = 0.0004, d.f. = 10, 40). From March 1993 through August 1994, differences in densities on control and exposed plots were not significant (F = 3.95, p = 0.1411, d.f. = 1, 3). Densities varied significantly over months on the plots (F = 13.12, p = 0.0000, d.f. = 17, 17), but the patterns of change were not different between control and exposed plots (F = 0.45, p = 0.9635, d.f. = 17, 51).

Figure 5-5 illustrates changes in numbers for <u>Perognathus</u> <u>amplus</u> on exposed and control plots over the course of the study. Numbers increased rapidly to peaks of about 40 individuals per plot during the spring of 1992 and then declined during the summer and fall. Smaller spring peaks were again observed on all plots in 1993 and 1994. As with <u>D</u>. <u>merriami</u>, temporal patterns of changes in numbers for <u>P</u>. <u>amplus</u> were similar on exposed and control grids. Differences between densities on Grids A-C and Grids D-F were not significant until the predator disturbance (F = 2.52, p = 0.1875, d.f. = 1, 4).

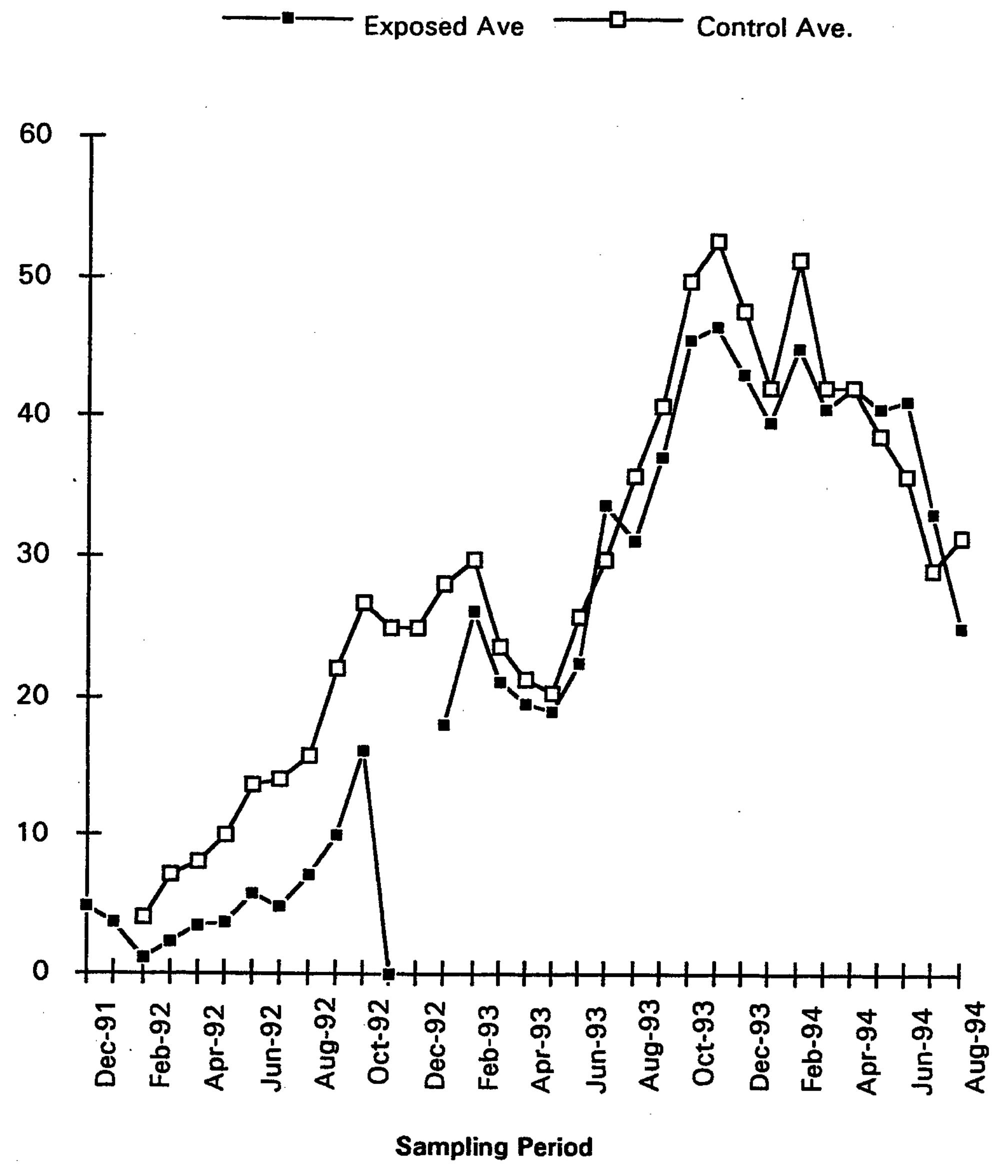


Figure 5-4 *Mean population densities for* *Dipodomys merriami* *on exposed and control study plots on the Barry M. Goldwater Air Force Range, Arizona.*

However, density did vary significantly over months (F = 61.34, p = 0.0000, d.f. = 6, 6) and the pattern of density change varied significantly between exposed and control plots (F = 4.68, p = 0.0028, d.f. = 6, 24). From March 1993 through August 1994, when Grids D-F were compared to Grids H-I, densities of P. amplus on control and exposed plots were not significantly different (F = 2.77, p = 0.1947, d.f. = 1, 3). In addition, densities did not vary significantly over months on the plots

(F = 1.49, p = 0.1297, d.f. = 17, 17) and patterns of density change were the same on control and exposed plots (F = 0.76, p = 0.7389, d.f. = 17, 51).

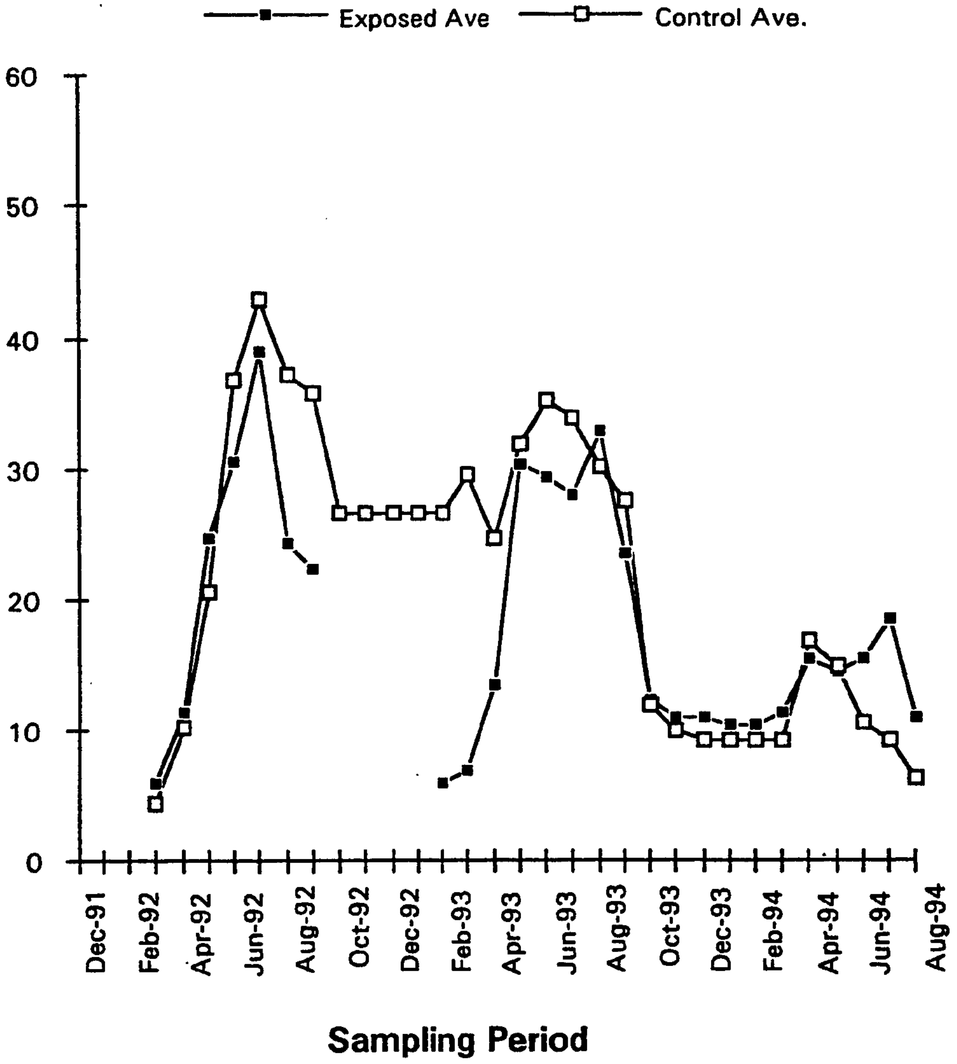


Figure 5-5 *Mean population densities for Perognathus amplus on exposed and control study plots on the Barry M. Goldwater Air Force Range, Arizona.*

Populations of Chaetodipus penicillatus were considerably smaller than those of D. merriami and P. amplus on the study plots (Figure 5-6). Fluctuations in numbers of C. penicillatus were of relatively low magnitude; peaks of 12-14 individuals per plot were observed in the summer and fall of 1993. Numbers of C. penicillatus were too low on exposed and control sites to allow analysis by ANOVA during the early part of the study.

Table 5-4 *Trappability for populations of Chaetodipus penicillatus on exposed and control study plots on the Barry M. Goldwater Air Force Range, Arizona. Monthly trappabilities were pooled by season.*

Season	Exposed Grids					Control Grids		
	A	B	C	H	I	D	E	F
Winter 91-92								
Spring 92							0.88	0.77
Summer 92	1.00	1.00	1.00			0.56	0.67	0.54
Fall 92		1.00	1.00			0.25	0.72	0.75
Winter 92-93								
Spring 93				0.71	1.00	0.46	0.73	0.63
Summer 93				0.64	0.94	0.88	0.79	0.79
Fall 93				0.36	0.62	1.00	0.60	0.67
Winter 93-94								
Spring 94				0.39	0.75	0.83	0.76	0.58
Summer 94				0.73	0.88	1.00	0.91	0.82
Total **(N)**	**1.00** **(2)**	**1.00** **(11)**	**1.00** **(7)**	**0.54** **(116)**	**0.82** **(90)**	**0.65** **(63)**	**0.74** **(133)**	**0.68** **(127)**

However, comparing abundance on Grids H-I to control Grids D-F, mean densities of C. penicillatus were not different on control and exposed plots (F = 0.76, p = 0.4470, d.f. = 1, 3), but densities did vary significantly among plots over months (F = 15.35, p = 0.0000, d.f. = 17, 17) and patterns of change differed significantly between control and exposed plots (F = 2.56, p = 0.0040, d.f. = 17, 54).

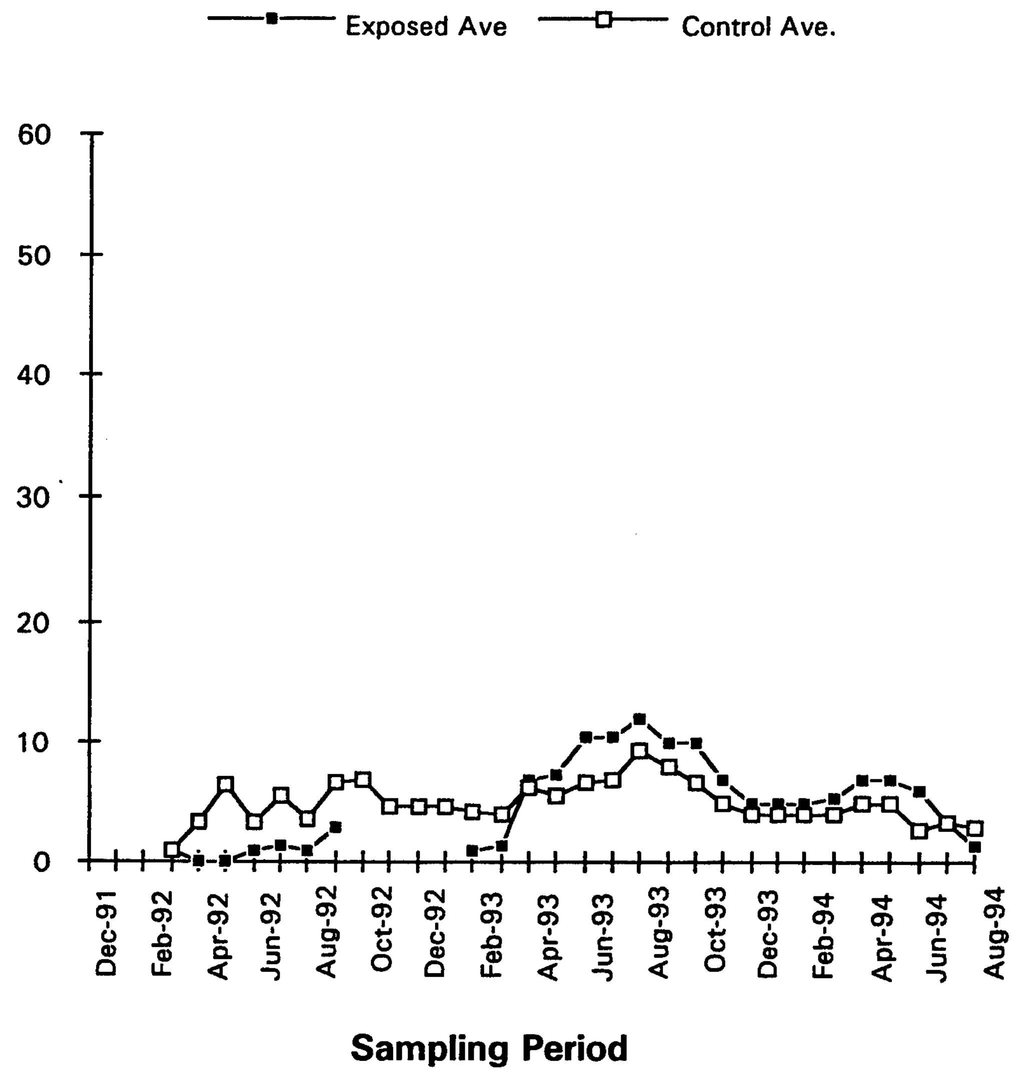


Figure 5-6 *Mean population densities for Chaetodipus penicillatus on exposed and control study plots on the Barry M. Goldwater Air Force Range, Arizona.*

5.2.5 Reproductive Activity

Temporal patterns in reproductive activity were investigated by determining the proportion of animals in reproductive condition by species for each month. Males with scrotal testes and females with medium or large mammae were designated as being in reproductive condition. Monthly proportions were then pooled by season. Seasonal levels of reproductive activity are shown in Figures 5-5, 5-6, and 5-7 for D. merriami, P. amplus, and C. penicillatus, respectively. For each species, differences in reproductive activity between control and exposed plots in each season were assessed by chi-square tests of heterogeneity. Lastly, chi-square tests were used to determine among-year heterogeneity in reproductive activity for each season (Tables 5-5 and 5-6).

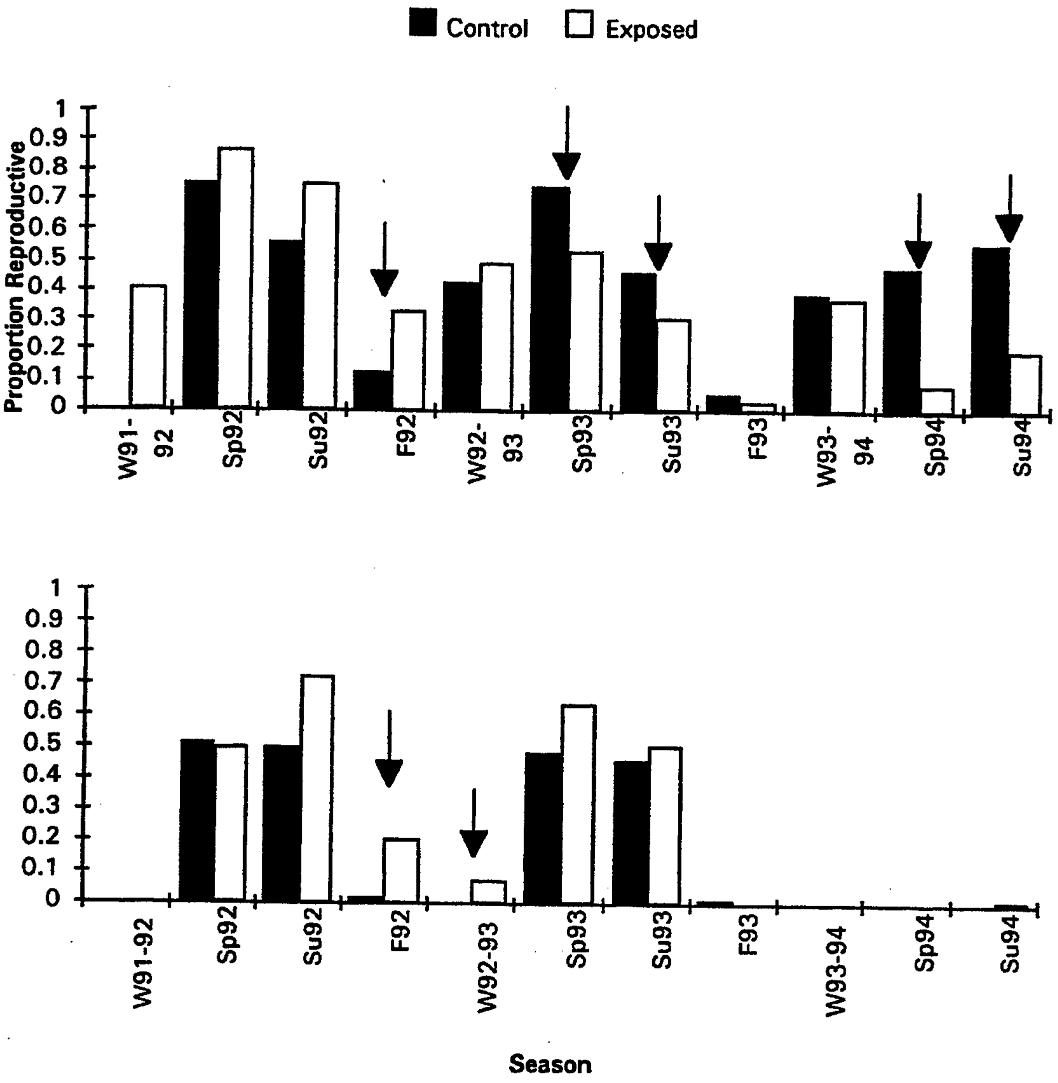


Figure 5-7 *Reproductive activity in male (top) and female (bottom) Dipodomys merriami on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.*

Table 5-5 *Results of heterogeneity chi-square tests for reproductive activity on control plots from the Barry M. Goldwater Air Force Range, Arizona.*

Species and Sex	**Season**				**Total**
	Spring	**Summer**	**Fall**	**Winter**	
D. merriami males	**18.45** (2)	2.19 (2)	**4.91** (1)	0.38 (1)	**196.70** (9)
D. merriami females	**118.83** (2)	**102.61** (2)	0.78 (1)	0.00 (1)	**500.92** (9)
P. amplus males	**11.26** (2)	**7.01** (2)	1.09 (1)	---	**63.77** (7)
P. amplus females	**12.11** (2)	**8.78** (2)	0.00 (1)	---	**35.16** (7)
C. penicillatus males	2.97 (2)	4.54 (2)	0.72 (1)	---	**41.16** (7)
C. penicillatus females	**15.29** (2)	4.81 (2)	0.00 (1)	---	**45.38** (7)

Individual seasons were compared for the total chi-square. Seasonal values assess among-year heterogeneity for each season. Significant X^2 values ($p < 0.05$) are given in bold and degrees of freedom are in parentheses. See text for determination of breeding condition in males and females.

Not unexpectedly, levels of reproductive activity varied greatly over seasons for D. merriami on all plots (Figure 5-7, Tables 5-5 and 5-6). Males with scrotal testes were found on exposed and control plots during all seasons, but were most numerous in spring and early summer. Breeding activity in females was much more constrained by season than in males; lactating females were lacking from several seasons. However, like males, breeding females were most abundant in spring and summer. Not only did reproductive activity vary significantly from season to season for both males and females, but there was also significant year-to-year variation within seasons for both sexes on control and exposed plots; reproductive activity for male and female D. merriami was generally reduced on all plots during the spring and summer of 1994. Comparisons of males on control and exposed plots revealed significant differences in breeding activity in five out of eleven seasons; reproductive activity was greater on control plots in four out of the five significant comparisons (Figure 5-7). For females, only two comparisons were significant and reproductive activity was greater on the exposed plots in both those comparisons.

Temporal patterns of breeding activity in P. amplus were generally similar to those for D. merriami, with reproductive males and females being most abundant in spring and summer (Figure 5-8); significant heterogeneity in reproductive activity over seasons was observed for both male and female P. amplus (Tables 5-5 and 5-6). Similarly, there was significant among-year heterogeneity for reproductive activity on all plots for both males and females in spring and summer; intensity of breeding activity was less during 1994 than in previous years (Figure 5-8).

Table 5-6 *Results of heterogeneity chi-square tests for reproductive activity on exposed plots from the Goldwater Air Force Range, Arizona.*

Species and Sex	Season				Total
	Spring	Summer	Fall	Winter	
D. merriami males	**59.97** (2)	**27.62** (2)	**27.56** (1)	1.05 (2)	**196.70** (10)
D. merriami females	**81.14** (2)	**169.97** (2)	**24.83** (1)	**9.20** (2)	**294.56** (10)
P. amplus males	**17.84** (2)	**10.51** (2)	0.00 (1)	---	**46.91** (7)
P. amplus females	**12.89** (2)	**23.73** (2)	1.40 (1)	---	**51.25** (7)
C. penicillatus males	**10.77** (2)	4.08 (2)	0.00 (1)	---	**31.79** (7)
C. penicillatus females	2.87 (1)	0.79 (2)	0.00 (1)	---	8.34 (6)

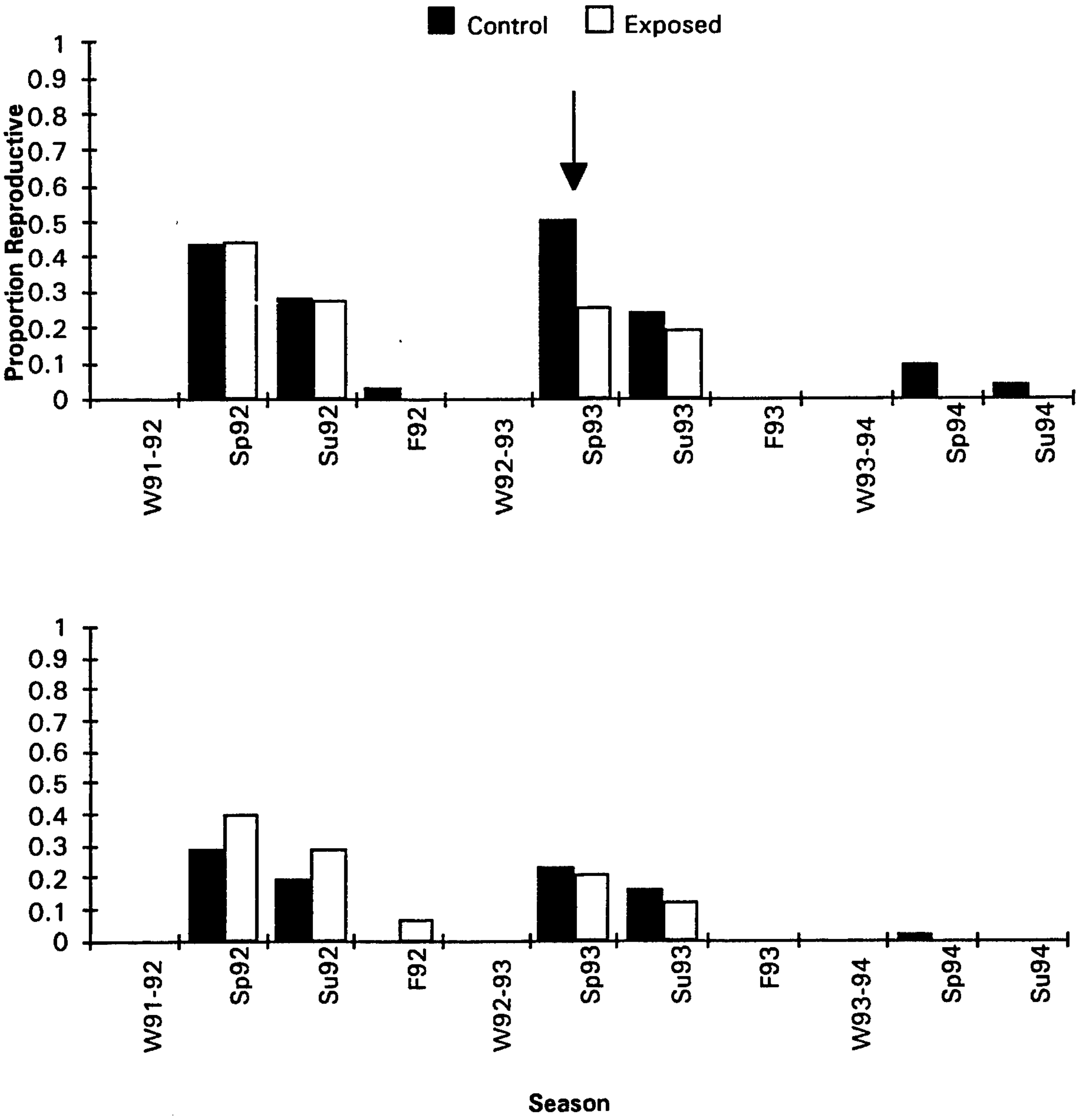
Individual seasons were compared for the total chi-square. Seasonal values assess among-year heterogeneity for each season. Significant values ($p<0.05$) are given in bold and degrees of freedom are in parentheses. See text for determination of breeding condition in males and females.

When control and exposed plots were compared, the proportion of reproductive males on control plots was greater than that on exposed plots during the spring of 1993; all other comparisons were not statistically significant.

In C. penicillatus, the presence of reproductive individuals of both sexes was restricted to spring and summer (Figure 5-9); seasonal heterogeneity in reproductive activity was significant for both sexes on all plots except for females on exposed plots (Tables 5-5 and 5-6). However, unlike the pattern for D. merriami and P. amplus, among-year heterogeneity was only observed for spring in females on the control plots and for spring in males on exposed plots. When control and exposed plots were compared, only the comparison involving males during the spring of 1994 was statistically significant, with more reproductive activity being observed on the control plots than on the exposed plots (Figure 5-9).

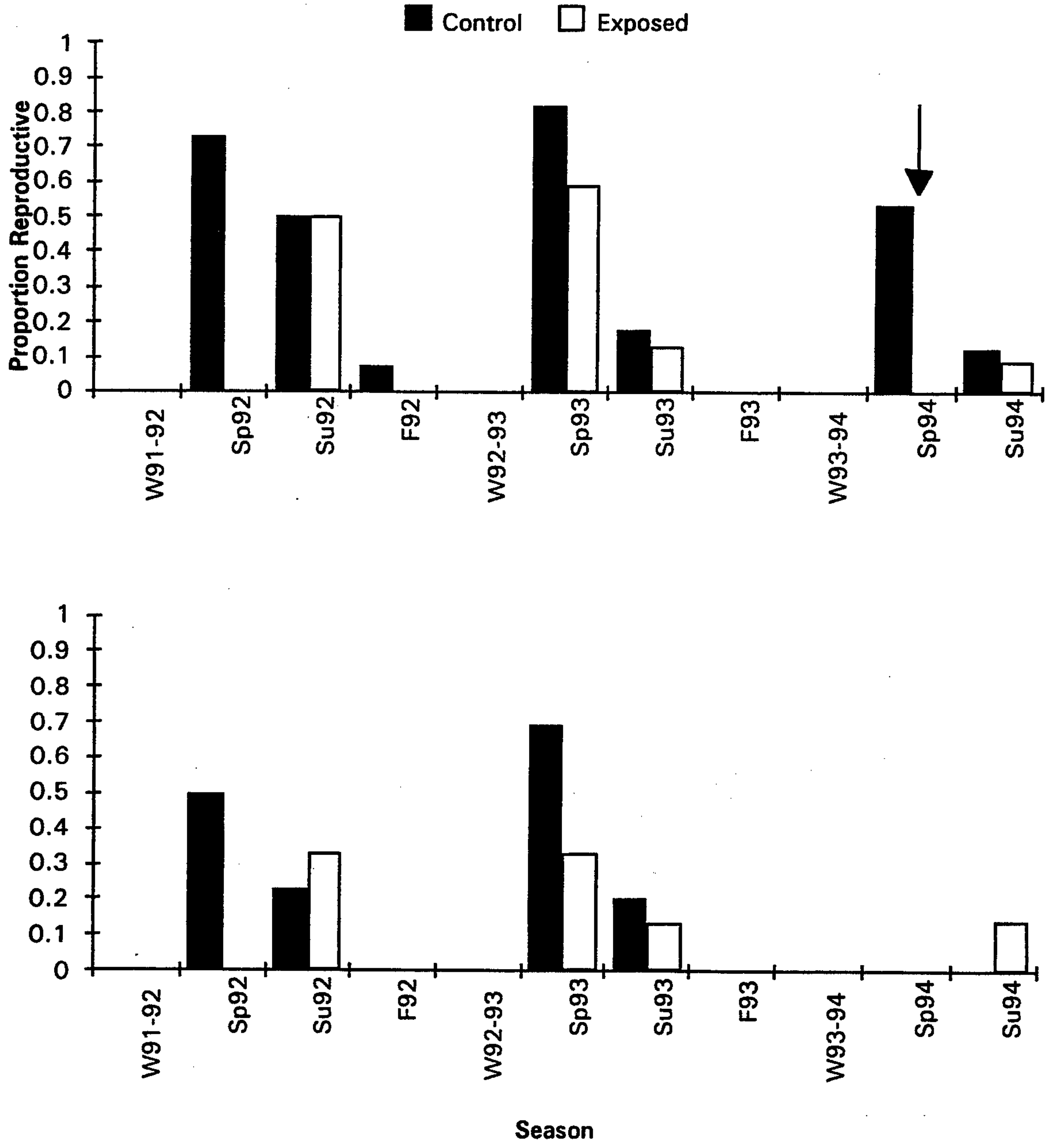
5.2.6 Recruitment

Recruitment on study plots for each species was measured as the proportion of the animals known to be alive in each month that were captured for the first time in that month. These estimates thus included individuals added to populations by immigration and by reproduction. Monthly rates were pooled by season. Temporal patterns of recruitment for D. merriami, P. amplus and C. penicillatus are shown in Figures 5-10, 5-11, and 5-12.



Arrows indicate seasons with significant differences in reproductive activity between control and exposed plots. See text for determination of breeding condition in males and females.

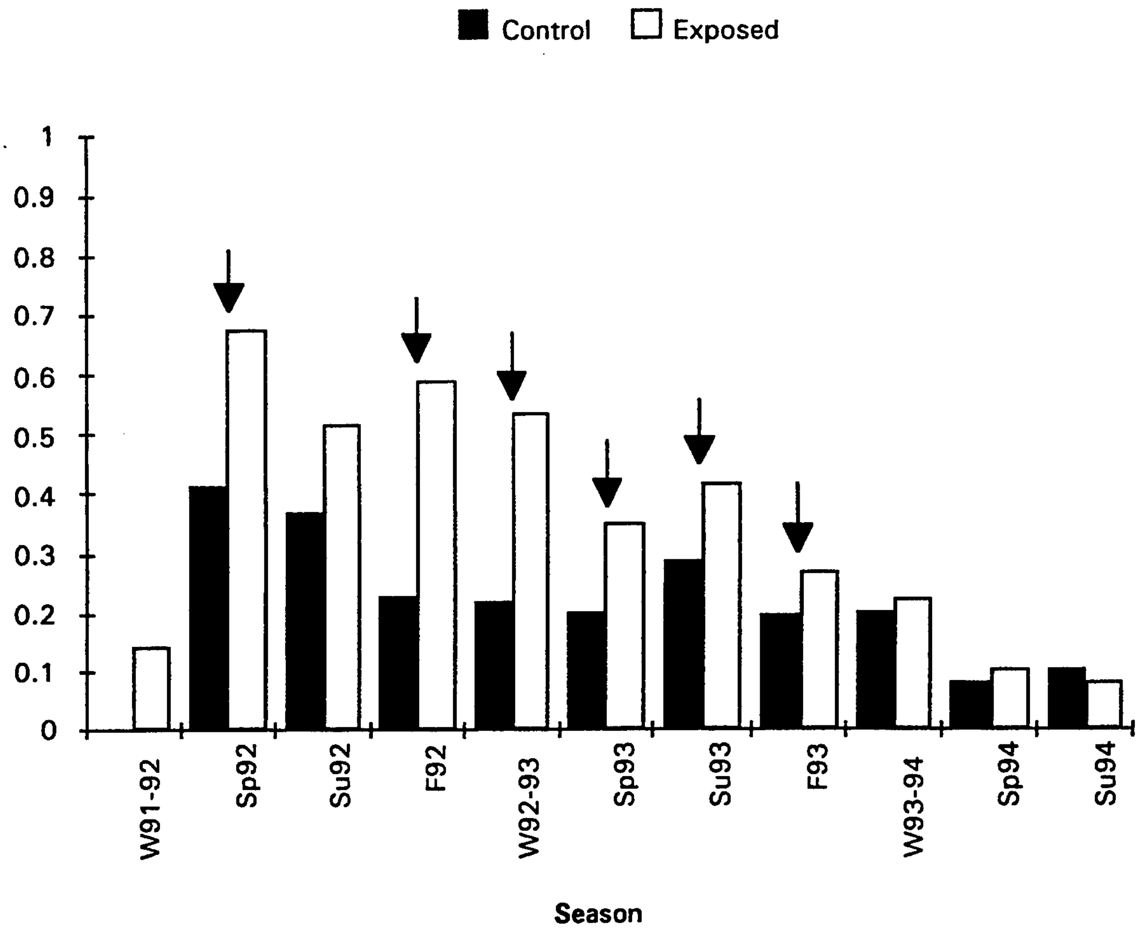
Figure 5-8 *Reproductive activity in male (top) and female (bottom) Perognathus amplus on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.*



Seasons with significant differences in reproductive activity between control and exposed plots are indicated by arrows. See text for determination of breeding condition in males and females.

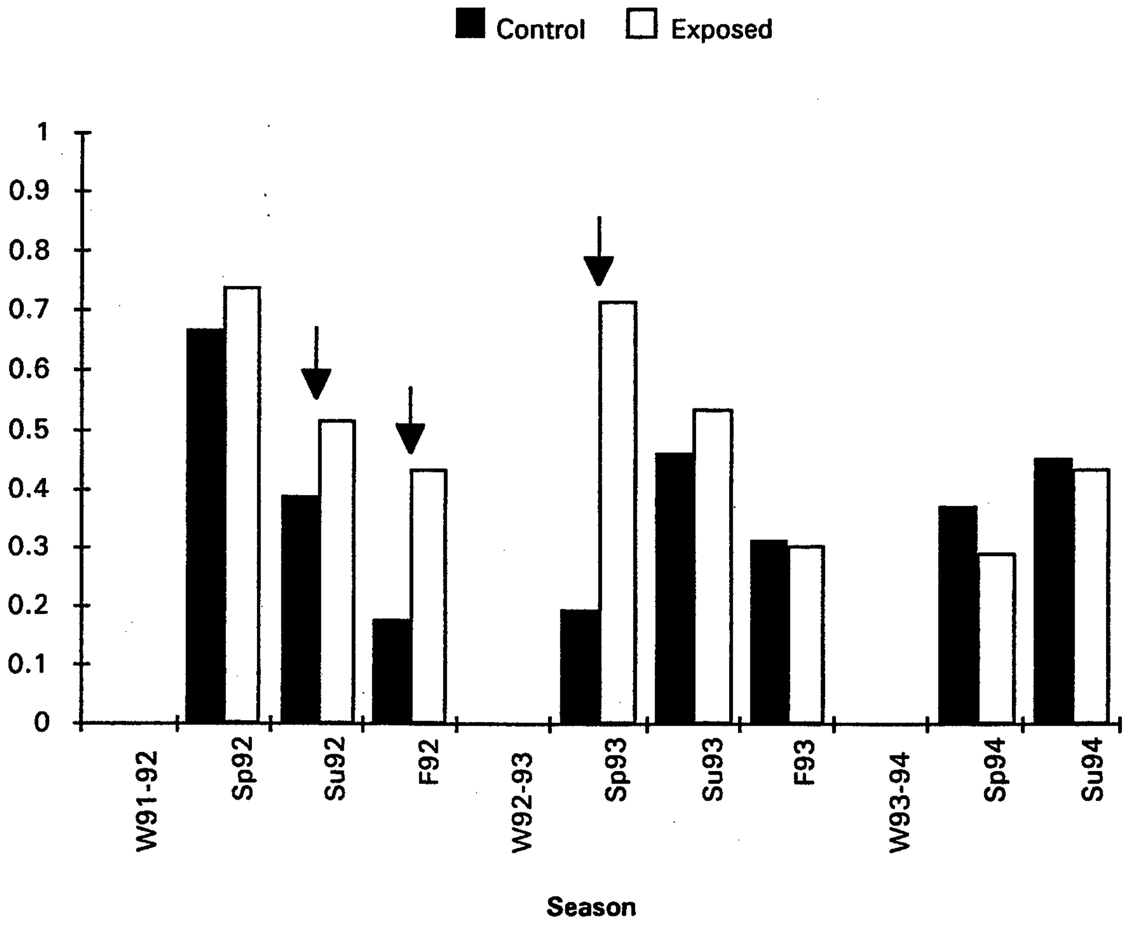
Figure 5-9 *Reproductive activity in male (top) and female (bottom) Chaetodipus penicillatus on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.*

Differences in recruitment between control and exposed plots in each season were assessed for each species by chi-square tests of heterogeneity. Chi-square tests were also used to determine year-to-year heterogeneity for each species in recruitment for each season on control and exposed plots (Table 5-7).



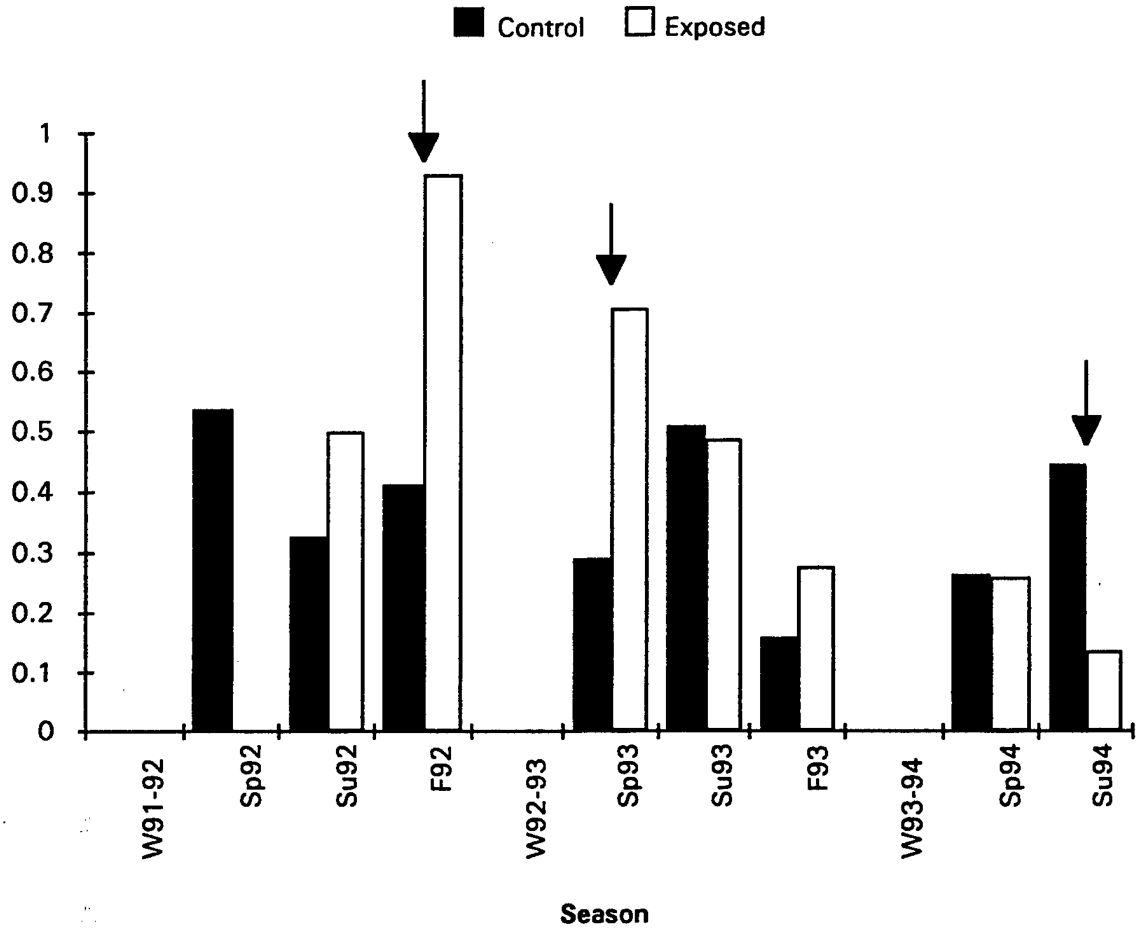
Recruitment was measured as the proportion of animals captured for the first time each month pooled by season. Seasons with significant differences in recruitment between control and exposed plots are indicated by arrows.

Figure 5-10 Seasonal rates of recruitment for Dipodomys merriami on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.



Recruitment was measured as the proportion of animals captured for the first time in each month pooled by season. Seasons with significant differences in recruitment between control and exposed plots are indicated by arrows.

Figure 5-11 Seasonal rates of recruitment for Perognathus amplus on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.



Recruitment was measured as the proportion of animals captured for the first time in each month pooled by season. Seasons with significant differences in recruitment between control and exposed plots are indicated by arrows.

Figure 5-12 *Seasonal rates of recruitment for Chaetodipus penicillatus on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.*

Over the course of the study, recruitment rates varied significantly among seasons for D. merriami on both the control and exposed plots (Figure 5-10, Table 5-7); rates of recruitment generally decreased over the course of the study for both groups of plots. Significant among-year heterogeneity was observed in rates of recruitment for D. merriami for summer and spring on the control plots and for all seasons on exposed plots; rates were greater for these seasons in 1992 and 1993 than in 1994. When control and exposed grids were compared for each season, six out of ten comparisons were statistically significant (Figure 5-10); recruitment rates were greater on exposed grids in all six significant comparisons.

Table 5-7 *Results of heterogeneity chi-square tests for recruitment on control and exposed plots from the Barry M. Goldwater Air Force Range, Arizona.*

Plot and Species	Season				Total
	Spring	Summer	Fall	Winter	
Control Plots:					
D. merriami	**56.04** (2)	**45.78** (2)	0.76 (1)	0.22 (1)	**108.36** (9)
P. amplus	**70.42** (2)	3.78 (2)	**6.50** (1)	---	**108.46** (7)
C. penicillatus	4.01 (2)	3.26 (2)	**6.80** (1)	---	**23.01** (7)
Exposed Plots:					
D. merriami	**64.51** (2)	**71.46** (2)	**25.48** (1)	**13.06** (2)	**186.32** (10)
P. amplus	**44.12** (2)	2.67 (2)	2.00 (1)	---	**67.97** (7)
C. penicillatus	**11.76** (1)	**8.50** (2)	**16.85** (1)	---	**42.20** (6)

Individual seasons were compared for the total chi-square. Seasonal values assess among-year heterogeneity for each season. Significant values ($p < 0.05$) are given in bold and degrees of freedom are in parentheses.

Significant among-season heterogeneity in recruitment rates was observed for P. amplus on both the control and exposed plots (Table 5-7). When individual seasons were compared among years, significant heterogeneity in recruitment was observed in spring for both the control and exposed plots and in fall for control plots; recruitment in the spring of 1992 and 1993 was greater than in spring of 1994. Rates of recruitment were significantly greater on the exposed grids than on the control grids in three out of eight seasonal comparisons (Figure 5-11).

Recruitment rates for C. penicillatus varied significantly among seasons on both groups of plots (Figure 5-12, Table 5-7). Significant among-year heterogeneity in recruitment for this species was observed for fall on control plots and for spring, summer and fall on exposed plots; recruitment rates on exposed plots generally declined over the course of the study. Significant within-season differences in recruitment between the control and exposed plots were found in three out of seven comparisons; exposed plots had greater recruitment in the fall of 1992 and the spring of 1993, while control plots had greater recruitment in the summer of 1994.

5.2.7 Body Weight

Mean weights for *D. merriami*, *P. amplus* and *C. penicillatus* for each month on each plot were used to compute means for control and exposed plots (Figures 5-13, 5-14, and 5-15); sexes were treated separately. Differences in body weight between control and exposed plots were assessed by ANOVA with repeated measures. *C. penicillatus* was excluded from this analysis due to small sample size.

Body weights for both male and female *D. merriami* on all plots fluctuated in a seasonal fashion (Figure 5-13), with the heaviest animals typically present in spring and the lightest animals typically present in winter. The repeated measures ANOVA indicated that mean male body weight did not differ between exposed and control plots (F = 0.45, p = 0.5512, d.f. = 1, 3).

Weight for males did vary across months (F = 23.09, p = 0.0000, d.f. = 17, 17), but the patterns were not different for males on control and exposed plots (F = 1.11, p = 0.3675, d.f. = 17, 51). The pattern was similar for female *D. merriami*. Mean body weight did not differ between exposed and control plots (F = 4.87, p = 0.1145, d.f. = 1, 3), but female weights did vary significantly across months (F = 26.71, p = 0.0000, d.f. = 17, 17). In the case of females, these changes were significantly different for control and exposed areas (F = 1.85, p = 0.0468, d.f. = 17, 51).

Patterns of temporal changes in body weight for *P. amplus* (Figure 5-14) were similar to those seen for *D. merriami*, with largest body weights for both sexes being observed in the spring and the lowest weights in the fall, just before hibernation. Mean weights for males did not differ for control and exposed areas (F = 1.33, p = 0.3321, d.f. = 1, 3). Male mean weight varied significantly over months (F = 21.51, p = 0.0000, d.f. = 8, 8), but patterns of change for control and exposed plots were not different (F = 1.47, p = 0.2208, d.f. = 8, 24). Mean weights did not differ for female *P. amplus* between control and exposed plots (F = 0.15, p = 0.7247, d.f. = 1, 3). Mean female body weight varied significantly over months (F = 18.63, p = 0.0000, d.f. = 8, 8) and patterns of change were different for females on exposed and control plots (F = 2.83, p = 0.0231, d.f. = 8, 24).

Sample sizes were much smaller for *C. penicillatus* and statistical comparisons were not possible for this species. However, Figure 5-15 demonstrates that the patterns of change over the course of the study in body weight for *C. penicillatus* closely parallel those seen in the other two species.

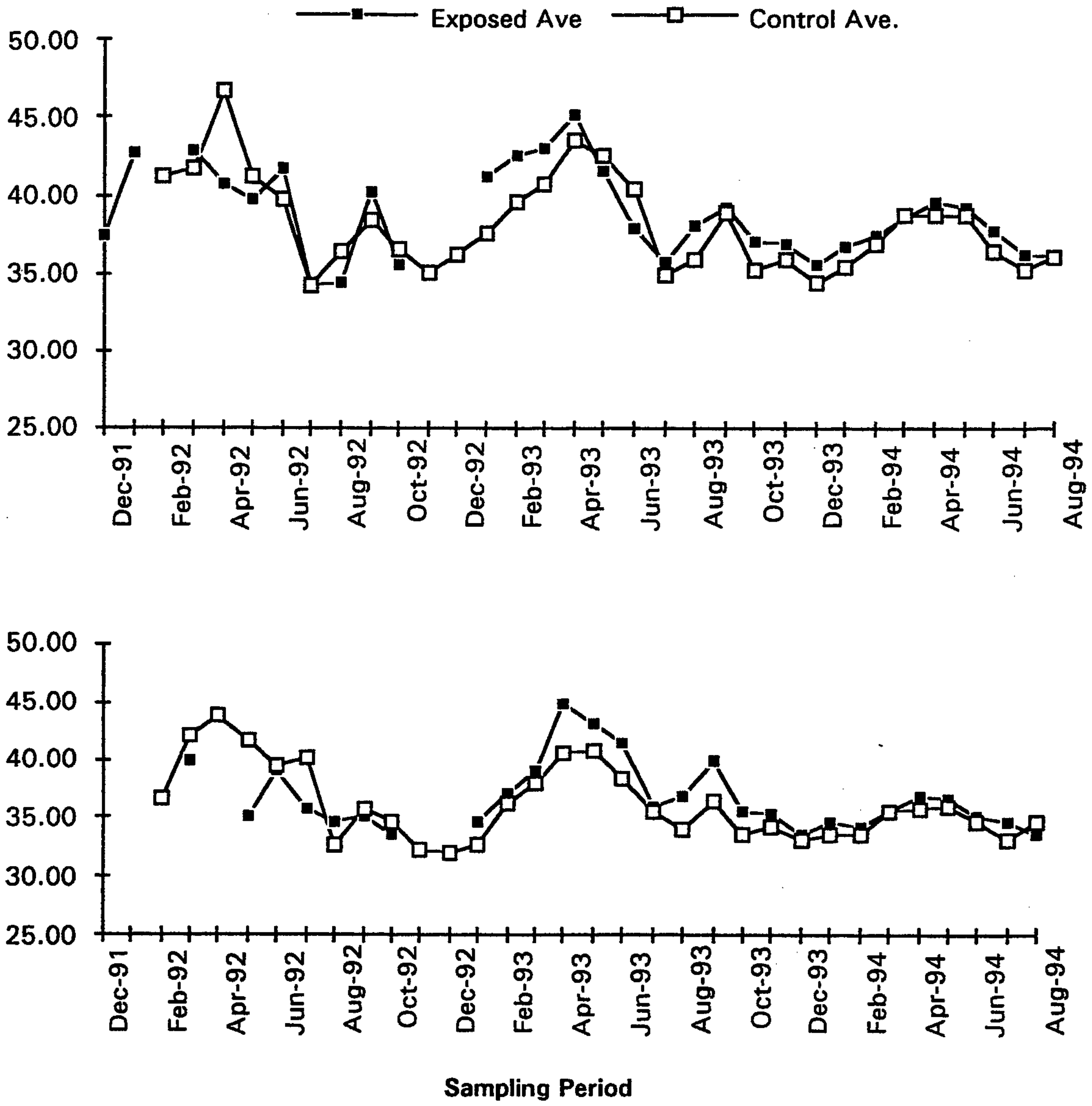


Figure 5-13 Mean monthly body weights for male (top) and female (bottom) Dipodomys merriami on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.

5.2.8 Survival Rates

Survival for D. merriami, P. amplus and C. penicillatus on the study sites was measured as the minimum monthly survival rate of individuals in the trappable population. Survival rates were calculated separately for males and females, and monthly rates were then pooled by season (Figures 5-16, 5-17 and 5-18).

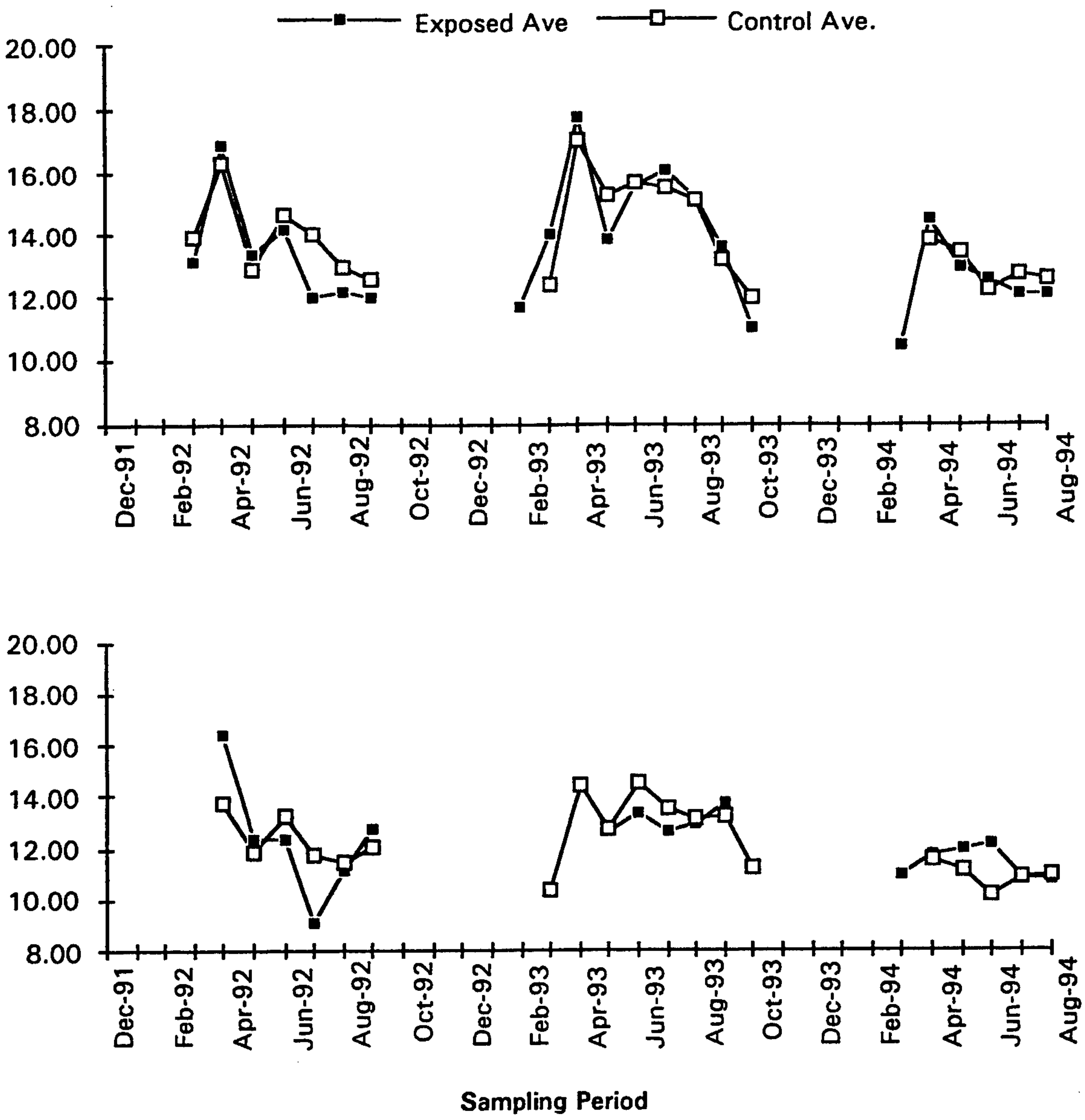


Figure 5-14 *Mean monthly body weights for male (top) and female (bottom)* ***Perognathus amplus*** *on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.*

These values include losses due to mortality and to dispersal. Chi-square tests were used to examine heterogeneity in survival rates for plots over the entire study, for each season among years, and between exposed and control plots for each season (Tables 5-8 and 5-9).

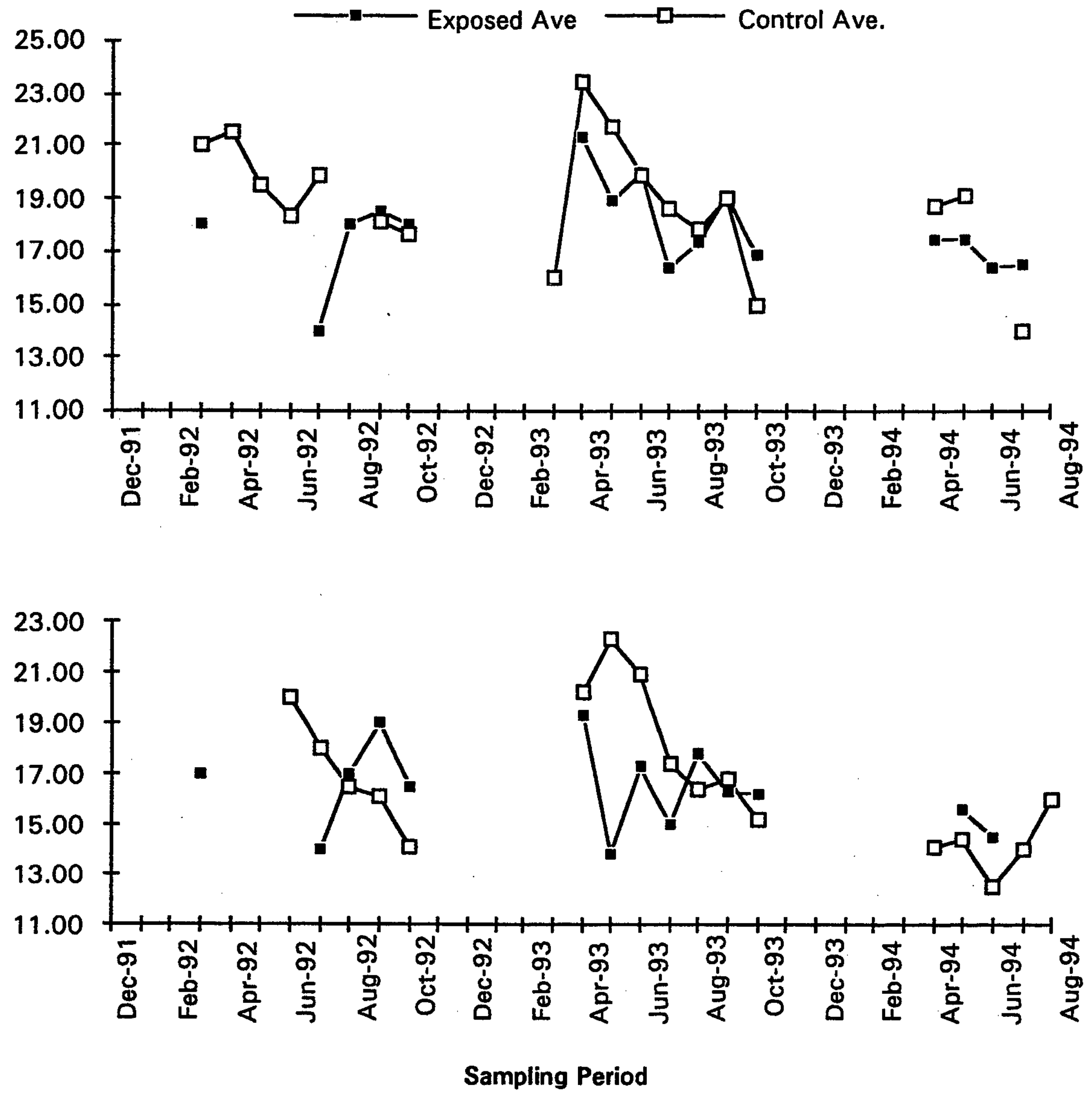
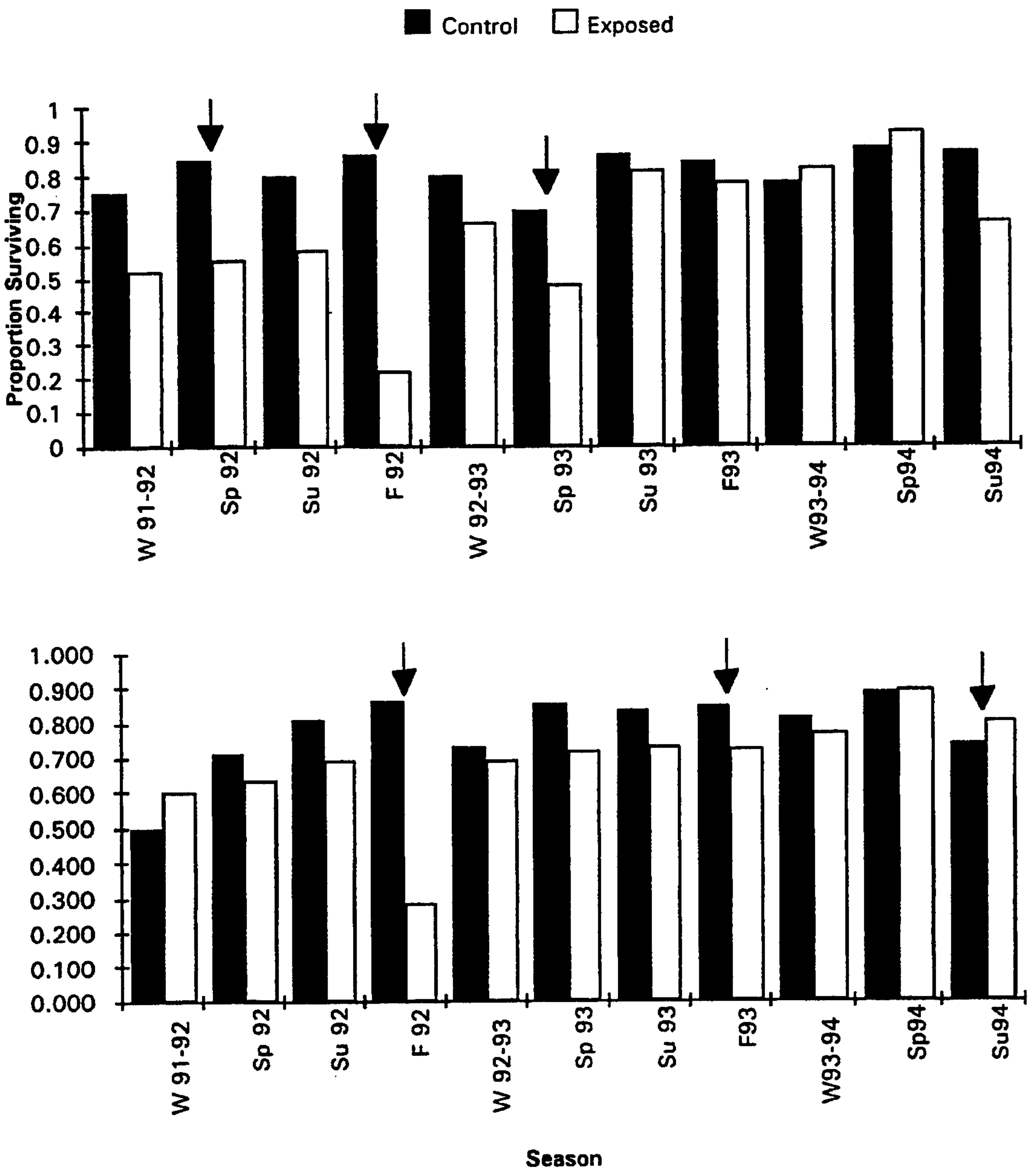


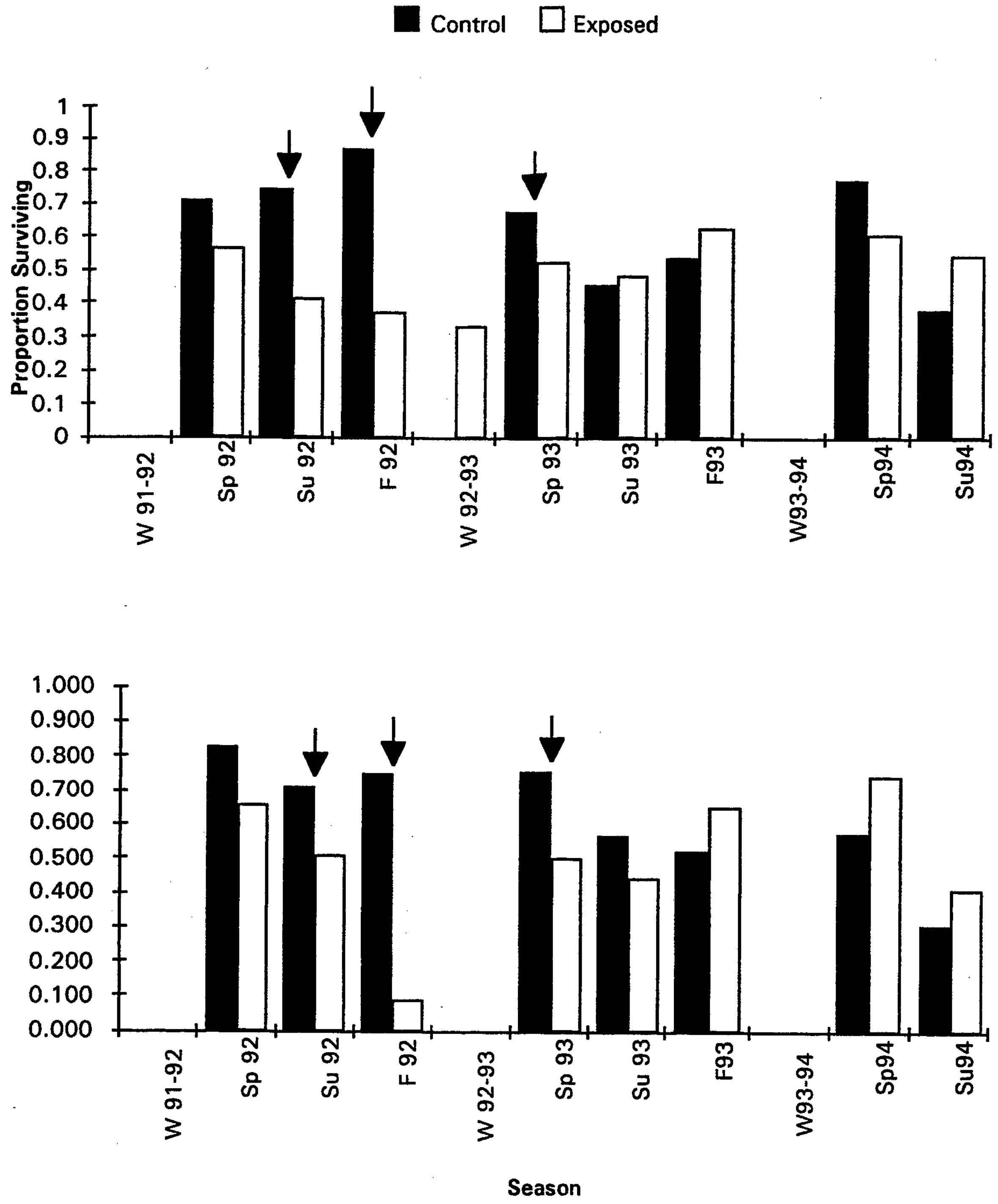
Figure 5-15 *Mean monthly body weights for male (top) and female (bottom) Chaetodipus penicillatus on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.*

Average monthly survival for D. merriami over the course of the study on control plots was 0.822 and 0.825 for males and females, respectively; these rates were not significantly different. On exposed plots, average monthly survival was 0.724 for males and 0.745 for females; these rates were also not significantly different. Overall survival was significantly greater for males and females on control grids (males: X^2 = 26.64, p = 0.0001, d.f. = 1; females: X^2 = 17.52, p = 0.0001, d.f. = 1) when compared to their counterparts on exposed areas.



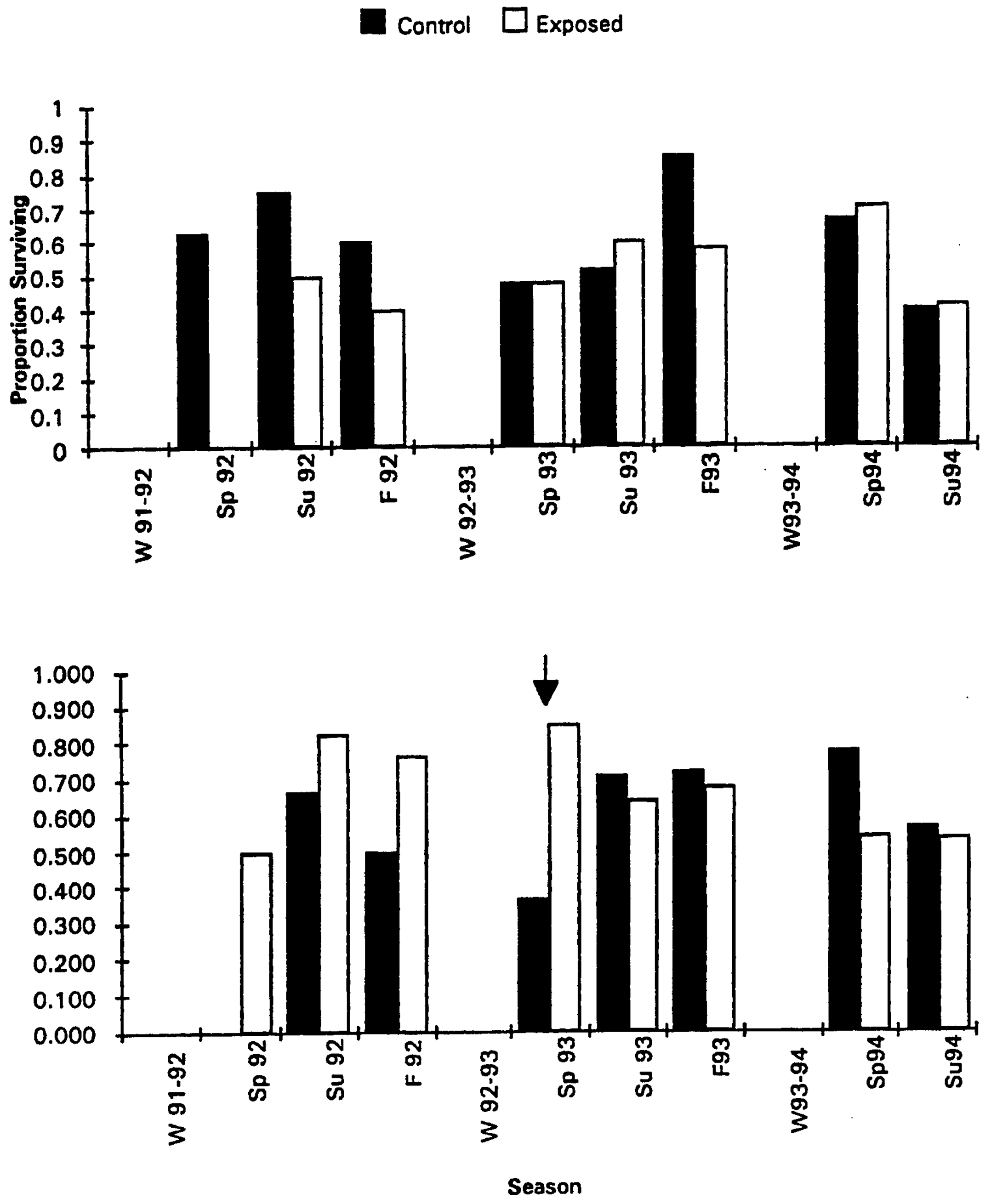
Survival was measured as the proportion of animals surviving in each month pooled by season. Seasons with significant differences in survival between control and exposed plots are indicated by arrows.

Figure 5-16 Seasonal rates of survival for male (top) and female (bottom) Dipodomys merriami on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.



Survival was measured as the proportion of animals surviving in each month pooled by season. Seasons with significant differences in survival between control and exposed plots are indicated by arrows.

Figure 5-17 Seasonal rates of survival for male (top) and female (bottom) Perognathus amplus on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.



Survival was measured as the proportion of animals surviving in each month pooled by season. Seasons with significant differences in survival between control and exposed plots are indicated by arrows.

Figure 5-18 *Seasonal rates of survival for male (top) and female (bottom) Chaetodipus penicillatus on exposed and control plots on the Barry M. Goldwater Air Force Range, Arizona.*

When data for the predator-disturbed plots were removed, average monthly survival on exposed plots was 0.778 for males and 0.775 for females; these rates were still significantly different from rates on control plots (males: $X^2 = 4.83$, $p = 0.0279$, d.f. = 1; females: $X^2 = 6.43$, $p = 0.0112$, d.f. = 1).

Seasonal changes in survival for D. merriami are seen in Figure 5-16. Males and females on control and experimental plots displayed significant heterogeneity in survival rates among seasons (Tables 5-8 and 5-9). When individual seasons were compared among years, significant heterogeneity was seen in spring for males and females on control plots (Table 5-8), in spring and fall for females on exposed plots and in all seasons for males on exposed plots (Table 5-9). For males, survival rates were significantly greater on control plots than on exposed plots in the spring of 1992, the fall of 1992, and the spring of 1993. Females on control plots enjoyed higher survival rates than females on exposed plots in the fall of 1992 and the fall of 1993; exposed-plot females had higher survival than control-plot females in the summer of 1994.

Table 5-8 ***Results of heterogeneity chi-square tests for survival rates on control plots from the Barry M. Goldwater Air Force Range, Arizona.***

Species and Sex	Season				Total
	Spring	Summer	Fall	Winter	
D. merriami males	**12.77** (2)	1.76 (2)	0.10 (1)	0.23 (2)	**20.24** (9)
D. merriami females	**7.94** (2)	4.24 (2)	0.11 (1)	0.51 (2)	**29.01** (9)
P. amplus males	1.59 (2)	**56.89** (2)	**13.17** (1)	---	**62.32** (7)
P. amplus females	**9.52** (2)	**17.98** (2)	4.23 (1)	---	**41.40** (7)
C. penicillatus males	1.69 (2)	3.44 (2)	4.29 (1)	---	9.02 (7)
C. penicillatus females	**3.37** (1)	0.51 (2)	0.52 (1)	---	7.32 (6)

Individual seasons were compared for the total chi-square. Seasonal values assess among-year heterogeneity for each season. Significant values ($p < 0.05$) are given in bold and degrees of freedom are in parentheses.

Overall monthly survival for P. amplus on control plots was 0.658 for males and 0.630 for females; these rates were not significantly heterogeneous. Overall survival on exposed plots was 0.499 and 0.488 for males and females, respectively; these rates were also not significantly heterogeneous.

Overall survival was greater for males on control plots than for males on exposed plots (X^2 = 32.02, p = 0.0001, d.f. = 1) and greater for control-plot females than for exposed-plot females (X^2 = 21.82, p = 0.0001, d.f. = 1).

When data from the grids that were disturbed by predators were removed, monthly survival increased to 0.541 and 0.530 for males and females, respectively, but these rates were still significantly lower (males: X^2 = 12.52, p = 0.0004, d.f. = 1; females: X^2 = 6.83, p = 0.0091, d.f. = 1); the difference between the two was approximately 32%.

Table 5-9 *Results of heterogeneity chi-square tests for survival rates on exposed plots from the Barry M. Goldwater Air Force Range, Arizona.*

Species and Sex	**Season**				**Total**
	Spring	**Summer**	**Fall**	**Winter**	
D. merriami males	**51.46** (2)	**7.66** (2)	**47.59** (1)	**10.72** (2)	**128.16** (9)
D. merriami females	**10.37** (2)	1.56 (2)	**31.68** (1)	1.34 (2)	**52.86** (9)
P. amplus males	0.69 (2)	1.87 (2)	2.72 (1)	—	11.53 (7)
P. amplus females	3.65 (2)	1.60 (2)	**28.94** (1)	—	**50.67** (7)
C. penicillatus males	3.34 (2)	0.84 (2)	0.08 (1)	—	9.02 (7)
C. penicillatus females	**3.37** (2)	0.51 (2)	0.52 (1)	—	**26.94** (7)

Individual seasons were compared for the total chi-square. Seasonal values assess among-year heterogeneity for each season. Significant values ($p < 0.05$) are given in bold and degrees of freedom are in parentheses.

Figure 5-17 illustrates seasonal changes in survival rates for P. amplus. Significant among-season heterogeneity in survival was observed for males and females on control plots and for females on exposed plots (Table 5-9). Significant heterogeneity within seasons among years was observed in control-plot males for summer and fall, in control-plot females for spring and summer (Table 5-8) and in exposed-plot females for fall (Table 5-9). When control and exposed plots were compared, both males and females on control plots displayed better survival than their counterparts on exposed plots in the summer of 1992, the fall of 1992 and the spring of 1993.

Overall survival rates for male and female C. penicillatus on control plots were 0.618 and 0.660, respectively, and these values were not significantly different. Similarly, overall rates for males and females on exposed plots were 0.556 and 0.690, respectively, and were homogeneous. When survival rates on control and exposed plots were compared, no significant heterogeneity was seen for males or females. When data from the predator-disturbed plots were removed from the analysis, overall survival rates on exposed plots were 0.570 and 0.664 for males and females, respectively; these values did not significantly differ from those for males and females on control plots.

Seasonal changes in survival rates for C. penicillatus are shown in Figure 5-18. While rates fluctuated seasonally, significant heterogeneity was detected only for females on exposed plots (Table 5-9). Significant among-year heterogeneity was seen for fall in females from both control and exposed plots. Comparisons of survival by season on control and exposed plots indicated that exposed-plot females had better survival in the spring of 1993 than control-plot females.

5.2.9 Life Spans

Survival of individuals in populations was also examined by estimating times of persistence on the study plots for D. merriami, P. amplus and C. penicillatus. Life spans were estimated as the mean number of months that elapsed between when an individual was first marked and when it disappeared from a study area. For each species, differences between means for exposed and control plots were assessed by t-tests. These estimates are clearly conservative measures of life span: Individuals were probably several months old before they entered the trappable population and were marked, and may have persisted after the latest observation and become untrappable. Like the survival rates above, the disappearance of an individual from a study plot may be due to either emigration or mortality. Because of the obvious effects of predator disturbances on the life spans of individuals on Grids A-C, these plots were not included in this analysis. Only individuals marked between February 1992 and August 1993 on Grids D-F and between February 1993 and August 1993 on Grids H and I were used in this analysis; including cohorts of individuals still alive at the end of the study in August 1994 would further bias life span estimates downward. Results of this analysis are seen in Table 5-10. Mean time of persistence for D. merriami on control grids was significantly greater than that for the species on exposed plots. Mean length of time for P. amplus on study plots was also significantly greater on control plots than on exposed plots. Mean persistence time for C. penicillatus on control plots was greater than that for exposed plots, although the difference was not statistically significant.

Table 5-10 ***Mean times of persistence in months for rodents on exposed (Grids H and I) and control (Grids D-F) study plots on the Barry M. Goldwater Air Force Range, Arizona.***

Species and Plot	**Mean ± SE (N)**
D. merriami	
Control	4.65 ± 0.31 (308)
Exposed	3.15 ± 0.36 (150)
t-value	**2.92**
P. amplus	
Control	3.14 ± 0.25 (442)
Exposed	1.85 ± 0.28 (175)
t-value	**3.01**
C. penicillatus	
Control	3.04 ± 0.53 (98)
Exposed	2.45 ± 0.58 (64)
t-value	0.73

For each species, control and exposed means were compared by t-test. t-values in bold are statistically significant ($p < 0.05$).

6 KIT FOX FIELD STUDIES

The density, abundance, behavior and prey preferences of one heteromyid predator, the kit fox, were examined to determine whether aircraft had a significant effect. Populations of kit foxes on the BMGAFR were estimated by several methods because densities and abundances of canids are notoriously difficult to measure. These consisted of trapping surveys, radio-tracking to obtain estimates of home range, and camera station surveys to determine relative abundances of both kit foxes and their most important competitors in the area, grey foxes and coyotes. In addition, scat samples were collected to obtain an estimate of the relative importance of heteromyid prey in the diet, and short-term observations of movements were collected to determine fox behavior in the presence of aircraft noise.

Procedures involving handling of foxes were permitted by the Arizona Department of Game and Fish (permit numbers GLGHT000247 and FRNCN000228). Field personnel were trained by Dr. Golightly at Humboldt State University. All procedures were approved by the HSWRI Institutional Animal Care and Use Committee after evaluation according to guidelines developed by the American Veterinary Medical Association and the Animal Society of Mammalogists.

6.1 METHODS

6.1.1 Population Estimates: Trapping Surveys

Kit foxes on the BMGAFR were trapped using large raccoon traps (Tomahawk Trap Company). The traps were set on level ground and baited with a mixture of cat food and canned mackerel wrapped in a gauze bag. Traps were spaced approximately 0.4 km apart along roads in both study areas (Figure 6-1), with coverage as widely distributed as possible within the Sonora Desert scrub habitat in both areas. Traps were set just before sunset and reexamined very early the following morning to avoid exposing trapped foxes to excessive heat. Traps were closed in the event of rain to avoid undue chilling of foxes. When foxes were found in traps, they were initially examined to gauge their conditions and to look for signs of diseases such as rabies. After that, foxes were shooed out of the traps into a cloth bag for further handling.

Morphometric measurements were collected from each animal captured. Each animal was weighed in the cloth bag with a spring balance to the nearest 0.01 kg. Hind foot length was measured to the nearest mm from the back of the heel to the tip of the longest toe (including the claw). Tail length was measured from the base to the end of the last vertebra in the tail. Ear length was measured from the notch at the base of the ear to the furthermost point on the edge of the pinna. The animal was sexed and its reproductive condition noted. Ears were checked for ectoparasites and sample specimens were collected when parasites were found. The condition of the eyes, feet, and pelage was noted. Any

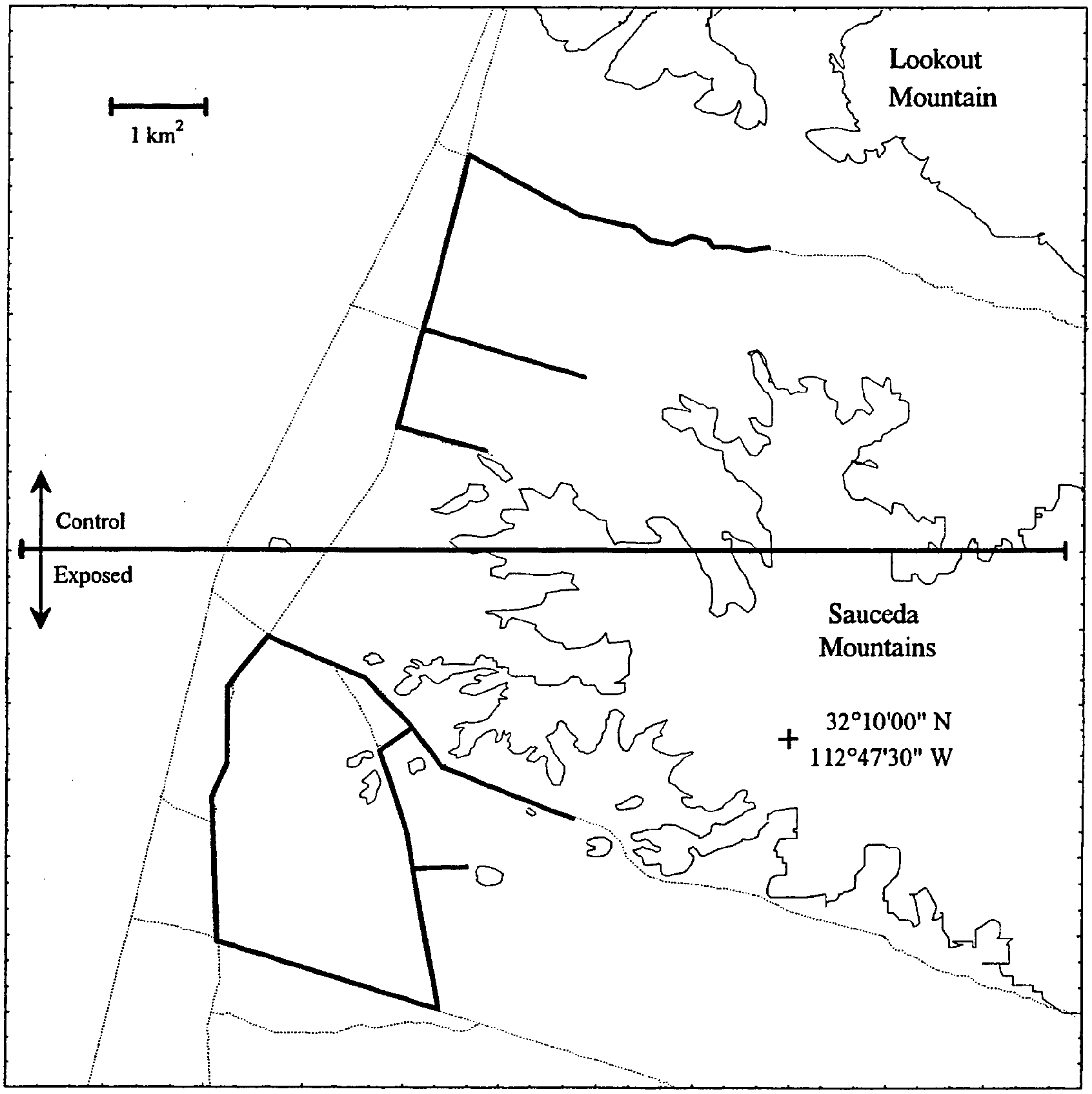


Figure 6-1 *Map of the study area showing roads along which traplines for kit foxes were set (thick solid lines).*

missing, worn, or broken teeth were noted, as well as descriptions of tooth wear. Each fox was given a uniquely numbered rototag ear tag (Nasco Industries) after spraying the ear and rototag with a disinfectant. When a radio collar was deployed, it was fitted around the neck snugly enough to prevent the fox from putting its foot through the collar but not so tightly as to chafe or prevent the animal from swallowing whole prey.

The field team carried an immobilization kit for use on animals with serious trap-related wounds or signs indicative of rabies. Although the need for such immobilization never arose, it is conceivable that foxes could have sustained wounds serious enough to require anaesthesia or euthanasia. Any lacerations found on trapped animals were coated with Neosporin antibiotic cream before release to reduce the chances of infection.

The trapping effort had two main goals—to obtain a minimum estimate of the number of foxes in the area and to capture adult foxes and equip them with radio collars. Trapping effort was expended over as broad an area as possible during the first year and throughout the breeding season. It quickly became clear that trappability differed dramatically with season; therefore, a balanced trapping schedule was not adopted thereafter. However, over the four years of the study, trapping effort was balanced by area as much as the roads would allow. Most of the trapping effort was concentrated in the winter when fox trappability was high. Trappability should not be treated as an estimator of relative abundance in any year.

6.1.2 Population Estimates: Radio-Telemetry

After capture, adult foxes in good health were fitted with either Telonics MOD-80 or Advanced Telemetry Systems (ATS) Model 16m radio-telemetric transmitters on heavy nylon mesh collars. The radio collars were equipped with a 30-cm external antenna, which ran around the collar and over the back of the animal. Collars weighed 38.0-44.1 gm and had approximately one year of battery life. Each animal had a unique transmitting frequency in the 148 MHz range. ATS collars had a mortality sensor that doubled the transmitter pulse rate if the collar had not moved for 18 hours. Any movement of the collar returned the pulse rate to normal. Collars were retrieved when foxes were discovered dead or at the conclusion of each field season.

6.1.2.1 Error, Accuracy and Sampling

Bearings and locations collected using radio telemetry are subject to error (White and Garrott, 1990; Lee *et al.*, 1985). Sources of variation and bias are numerous and include equipment imprecision, compass inaccuracy, observer variability, meteorological disturbances (Saltz and Alkon, 1985; Springer, 1979), and signal bounce from geographic features (Golightly, pers. comm.). Conservative estimates of error have been calculated traditionally by drawing a polygon on a map using the intersection of the bearings from telemetry stations. If bearings were perfectly accurate and precise, all the lines would converge on a single point and would define a polygon with zero area. This measure tends to greatly overestimate the error in location.

Error can also be estimated as a probability density function around the estimated location, by collecting a number of locations using radio collars with known locations (*e.g.*, a test collar placed at a known site or a fox in a burrow) and comparing these points with the actual location. The circle described by the 95% confidence interval around the real location gives an estimate of error, usually having greater precision than an error polygon.

The bearing estimated by an observer (Θ') will be the sum of error (*e*) and the true bearing (Θ) (Lee, *et al.*, 1985).

$$\Theta_i' = e_i + \Theta_i \qquad \textbf{(Eq. 7)}$$

The error can be broken into two components: bias and sampling error. Bias ($\bar{e}$) is any error of a consistent nature, *e.g.*, bias due to bounce or interference. It is measured as the average difference between estimated and true bearings. It can be either positive or negative; when it is zero, the system is unbiased (Garrott *et al.*, 1986). Lee *et al.* (1985) estimate bias as

$$\bar{e} = \frac{\sum_{i=1}^{n} e_i}{n} \qquad \textbf{(Eq. 8)}$$

where *n* is the total number of bearings taken.

Sampling error is dependent on the number of replicate bearings taken (Springier, 1979), presuming that bias is constant over all measurements. Sampling error is reported as the standard deviation (*SD*) of replicate bearings (Lee *et al.*, 1985)

$$SD = \left[\frac{\sum_{i=1}^{n} (e_i - \bar{e})^2}{(n - 1)} \right]^{1/2} \qquad \textbf{(Eq. 9)}$$

To estimate bearing error, test radio collars were placed in three known locations and replicate bearings were taken by three observers. Figure 6-2 shows the frequency distribution of these errors (*e*) in degrees (data were lumped for all telemetry stations). Errors ranged from -3° to +4°. The mean error, , was s\all (0.10°), showing a small bias, and the standard deviation was 1.56°. This is well within the errors reported in the literature (Table 6-1).

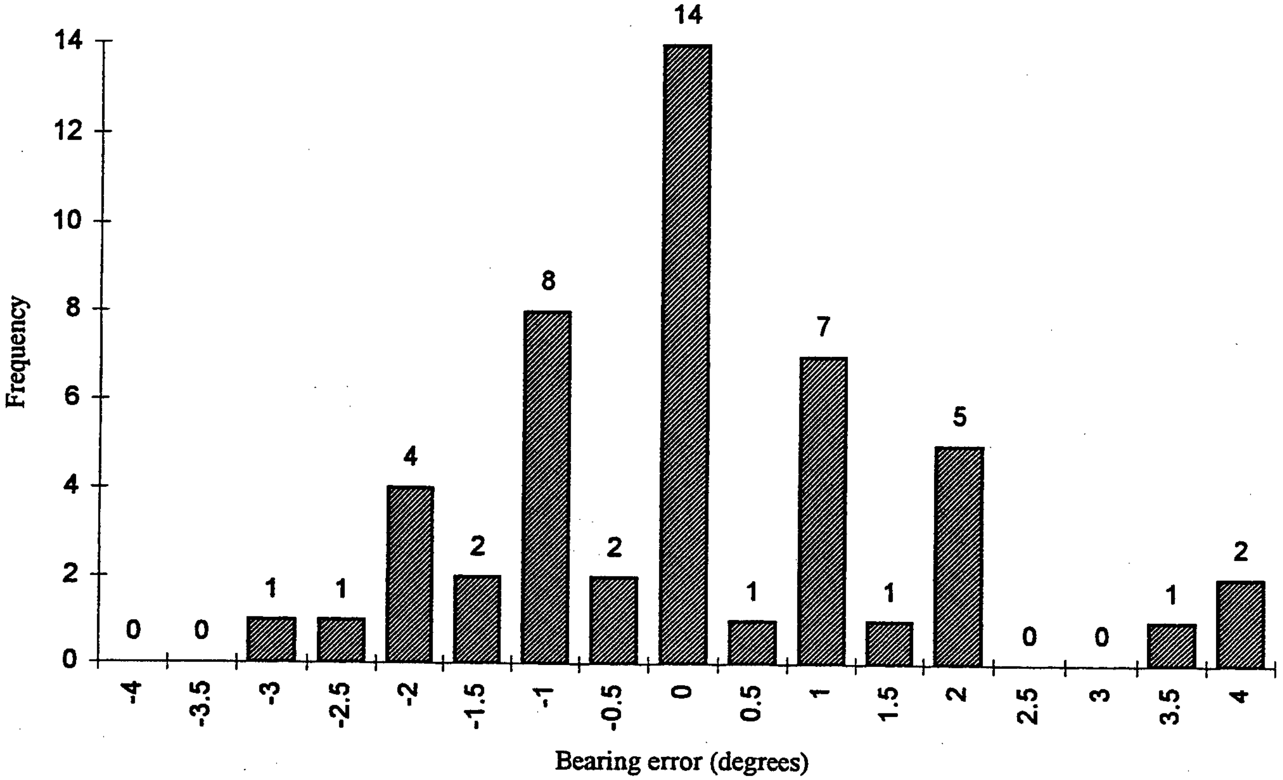


Figure 6-2 Frequency distribution of telemetry bearing error.

The distance between the known location and the estimated location was measured on a 7.5-minute topographic map and the 95% confidence interval around the actual location was calculated using a

Table 6-1 *Errors in bearing estimates from other telemetry studies of mid-sized carnivores.*

AUTHOR	ERROR ARCS (DEGREES)	SAMPLING ERROR (SD) (DEGREES)	STUDY ANIMAL	METHOD OF TELEMETRY
Gipson and Sealander, 1972	e_i= ± 2° to 5°		coyote	2 station, fixed
Laundré and Keller, 1981	e_i= ± 1.4°		coyote	2 station, mobile
Smith *et al.*, 1981	e_i= ± 1°		coyote	mobile
Zoellick *et al.*, 1987		station 1 = 1.37° station 2 = 1.70° station 3 = 0.97° station 4 = 1.64°	kit fox	2 station, fixed
Gese *et al.*, 1990	e_i= ± 4°		coyote	≥2 station, mobile

radius of two standard deviations. The average distance between the known location and estimated location was 158 meters with a standard deviation of 183 meters (N=17). The error circle had a radius of 366 meters.

Error distances reported in the literature were variable and smaller than these values. The difference appears to be a product of differing conditions or estimation methods. Laündré and Keller (1981) reported an error of 50 meters, but observers were less than 1 km from the transmitter rather than at 4-5 km. Zoellick and Smith (1992) reported an error of 94 meters, with the radius of the error circle less than 236 meters; however, they estimated the error using the difference in distance among successive estimated locations. Grenier (1991) reported an error of 104.3 meters using the same method.

Previous telemetric studies of carnivores have estimated location using either two bearings (O'Farrell and Gilbertson, 1979; Laundré and Keller, 1981; Hardenbrook, 1987; and Zoellick *et al.*, 1987) or three bearings (Lawhead, 1984; Grenier, 1991; Zoellick *et al.*, 1989; and Zoellick and Smith, 1992). In the absence of error, the two methods should yield similar results, but two-bearing locations are subject to greater error.

Results from the tracking conducted in the 1991-1992 season suggested that there was not a large difference in the precision of two-bearing and three-bearing estimates on the BMGAFR study site. Two-bearing locations were created by randomly selecting two bearings from the original set of three bearings, eliminating the cases where one bearing was suspect, and recalculating the location. The average distance to the actual location using two bearings was 191 meters with a standard deviation of 162 meters, indistinguishable statistically from the locations calculated using three bearings. Therefore, in cases where one of the three bearings was suspect, two-bearing locations were used to increase the efficiency of the tracking effort.

6.1.2.2 Telemetry Stations

Radio-collared animals were located by triangulation from fixed receiving stations, or known mobile locations. Figure 6-3 shows the positions of the receiving stations. Fixed stations were equipped with Telonics TR-4 receivers and two out-of-phase Yagi H antenna systems mounted atop a 3-m mast. This "null" system is rated for bearing accuracies of ± 0.05. A staff compass was used to orient a compass rosette on the mast base. During telemetry, the mast could be rotated until the radio signal was strongest, after which the bearing was read directly off the compass rosette. Fixed telemetry stations were selected using the following criteria: accessibility by vehicle, elevation above the desert floor, and position relative to other stations. Fixed sites were at least 6 m above the desert floor.

Three stations were used each night and personnel rotated among the stations systematically to insure equal coverage in all parts of each study area. Bearings were reported over two-way VHF radios and were plotted on a 7.5-minute topographic map to insure that the estimated position was sufficiently accurate; if not, the bearings were collected again. A position was rejected if any one side of the triangle formed by the three bearings was greater than 300 m. Locations were plotted using the Universal Transverse Mercator (UTM) coordinate system.

Mobile telemetry was used under special circumstances. During the second field season (1992-1993), several radio-collared foxes lived at the base of the Sauceda Mountains on the exposed side, moving in and out of the canyons in the range. Close proximity to the mountains decreased the accuracy of fixed site bearings due to signal bounce. When foxes were in areas that heightened signal bounce, mobile telemetry stations were used to decrease the distance between the observers and foxes, thereby increasing accuracy. In addition, some of the tracking effort out on the alluvial flats near the Nuclear Racetrack was made from mobile stations, as there were no hills in the area high enough to mount a fixed station in the area. The accuracy gained by mobile telemetry was offset by the increased time it took to gather bearings from the mobile platform, as the telemetry vehicle had to move to at least two and preferably three locations. Eleven minutes on average lapsed between the first and last bearings collected. This tended to decrease accuracy when foxes were traveling rapidly. Location polygons that were not sufficiently accurate were rejected from the home range analysis.

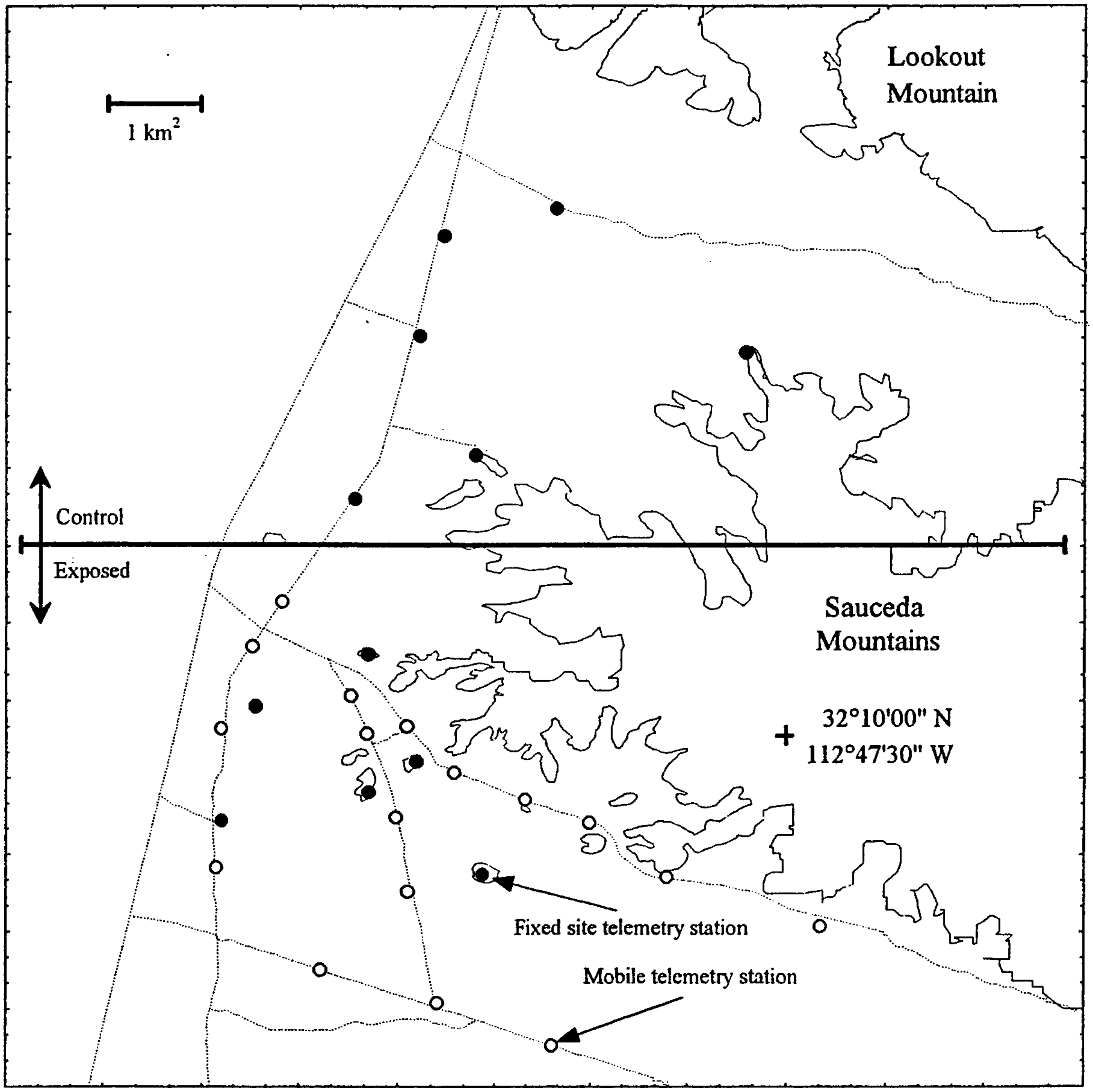


Figure 6-3 *Map of the study area showing the location of telemetry receiving stations.*

6.1.2.3 Telemetry Sampling

Individual locations were collected on an hourly basis for use in home range analysis. A general rule of thumb for assuring independence of consecutive points is to collect them no more often than the time it takes the animal to travel the length of the home range (White and Garrott, 1990). Foxes were found to travel up to 4.8 km/hr, therefore, hourly locations were assumed to allow ample time for foxes to traverse their home range.

6.1.2.4 Animal Locations

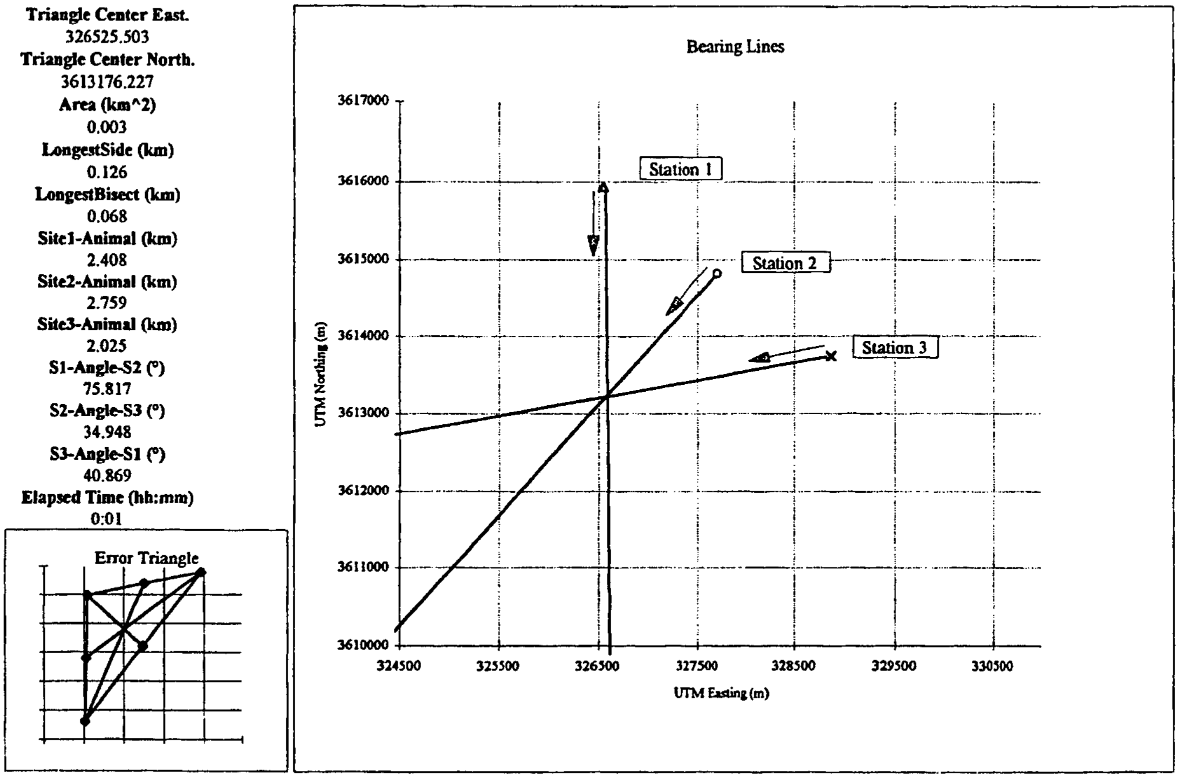
HSWRI staff (J. Francine and J. Matesic) wrote a custom telemetric analysis program to calculate parameters of the error triangle such as longest side, longest bisector, distance from telemetry site to estimated animal location, angle between telemetry sites, and the elapsed time between first and last bearings (Figure 6-4). The mean length of the longest side of triangles used in home range analysis was 150 ±10 m (s.e.; n = 166). The average distance from the observer to the estimated animal location was 1.74 km ± 0.04 (s.e.; n = 498).

6.1.3 Camera Station Surveys

In addition to direct enumeration and radio-telemetry estimates of population size, a sampling grid of remotely triggered camera stations was established to obtain an index of abundance for canids in both areas. Many researchers use such indices to gain general information about the relative abundance of species, as complete counts of the population are often difficult, if not impossible to obtain. Indices of abundance are useful for spatial or temporal comparisons.

The index selected for this study was visitation rate at baited camera stations. Figure 6-5 shows a diagram of a camera station. A mix of mackerel and cat food wrapped in muslin was used to attract predators to the camera stations. The bait was attached to a monofilament line which triggered the camera when the animal attempted to remove the bait. Instamatic 110 cameras were powered by D-cell batteries to extend the operating life of the flash. Twenty-four stations were deployed at one kilometer intervals in each of the study areas (Figure 6-6).

During camera station surveys, baited stations were visited every other day to ensure they were in working condition, and to rebait and reset the camera.



```
Triangle Center East.
326525.503
Triangle Center North.
3613176.227
Area (km^2)
0.003
LongestSide (km)
0.126
LongestBisect (km)
0.068
Site1-Animal (km)
2.408
Site2-Animal (km)
2.759
Site3-Animal (km)
2.025
S1-Angle-S2 (°)
75.817
S2-Angle-S3 (°)
34.948
S3-Angle-S1 (°)
40.869
Elapsed Time (hh:mm)
0:01
```

Figure 6-4 Sample output of telemetry plotting program.

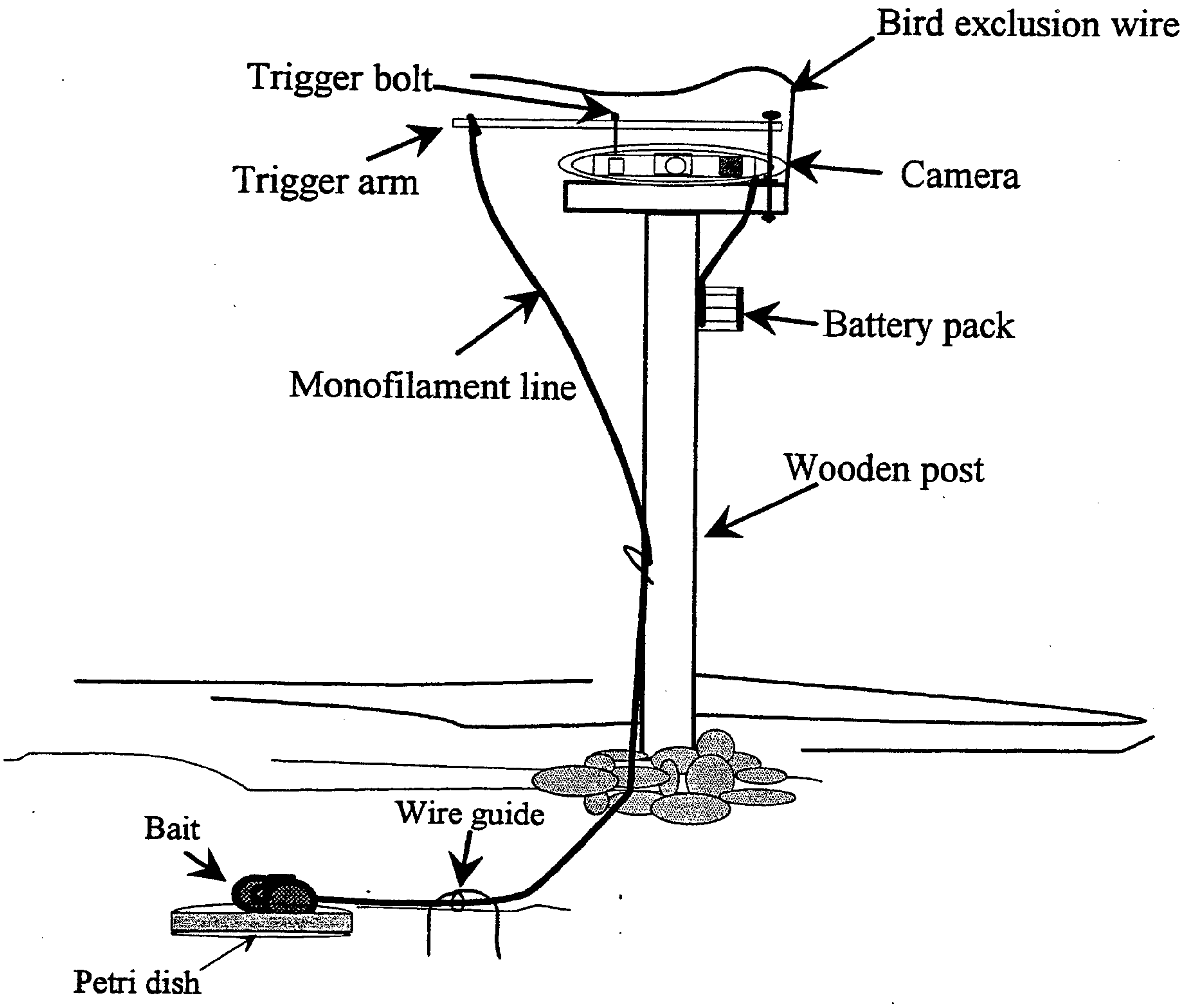


Figure 6-5 Diagram of a remotely triggered camera station.

6.1.4 Estimates of Prey Consumed by Foxes

The relative importance of the prey items taken by foxes was estimated from hard matter recovered from scats. This included hair, bones, bone fragments, teeth, scales, and chitinous portions of arthropods. Quantitative measurements of these fragments by weight have been attempted in several species of canids after making calibration measurements with the remains of known quantities of experimental prey. However, digestion efficiency changes in captivity and is likely to change frequently in the wild depending on the availability of water and other natural factors; so, estimates of prey biomass based on hard matter are suspect (Golightly, pers. comm.). Most authors measure relative importance of prey items by reporting the presence or absence of prey types in each scat sample. The proportion of scats

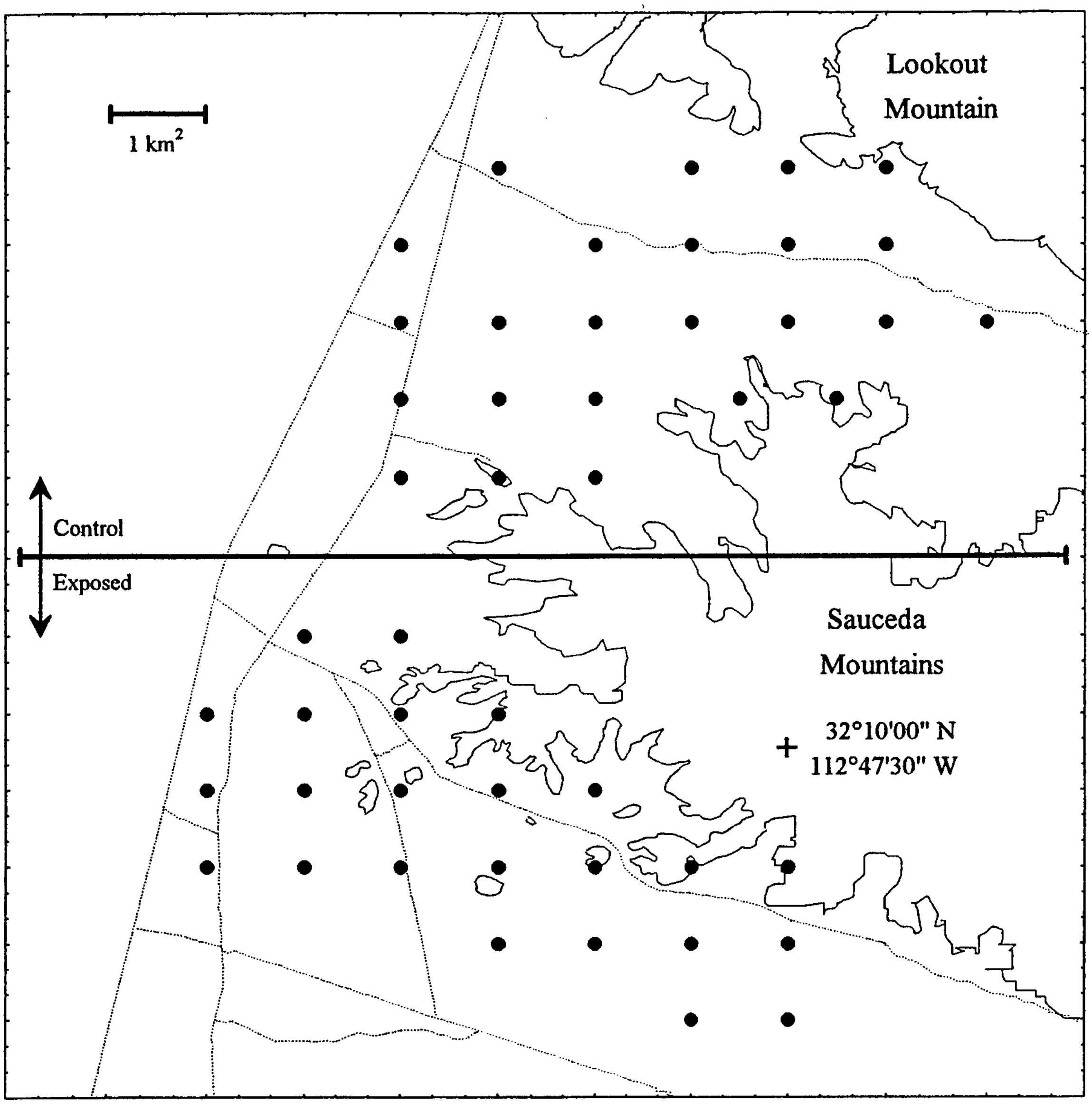


Figure 6-6 ***Map of the study area showing locations of remotely triggered camera stations.***

containing each prey type is then used to estimate relative importance.

Foxes often defecate when they are disturbed, when they detect unusual intrusions, and as markers for important sites in their territories. Feces of known origin could therefore be collected from traps, at denning sites, at camera stations, and from around rodent traps throughout the year. These feces were examined to determine what types of prey the foxes were eating.

All scats encountered during surveys (described below) were examined. If the origin of the scat could not be determined, it was estimated by sample size and weight. The data reported below are only from scats of known origin; *data from other scats will be reported later.*

Scats were cleaned by placing them in bags of 170-μm Nytex mesh, closed tightly, and washing them in a commercial washing machine until all the soft matter was removed. The hard remains were then categorized into major classes of prey types. Example prey specimens were collected from the field site for comparison with the remains in the scats, to allow individual species identification.

6.1.5 Short Interval Telemetry During Range Shutdown

In July 1994, Range 2 was scheduled for routine maintenance. During this time, there were no flights on the exposed site. Fox behavior, home range, and small mammal abundance were measured during this period to determine whether there was a difference before and during the overflights. Fox behavior was measured by collecting telemetry points every 5-10 min for a 2-4 hr period, producing a track from which areas of usage and rate of travel could be determined.

6.2 RESULTS

6.2.1 Trapping Effort and Success

Figure 6-7 and Table 6-2 show trapping effort and success throughout the course of the study. A total of 67 foxes were trapped 109 times during 1,286 trap nights from September 1991 to September 1994. Overall, trapping success was higher in the control area (Table 6-2) at 12% success while on the exposed site trapping success was only 6.88%. When each year was examined individually, the exposed site, until the winter of 1993-1994, had consistently higher trapping success. During this winter, foxes suffered high mortality rates (see Section 6.2.5) leading to a greatly increased trapping effort on the exposed site to radio-collar more foxes. This led to a drop in the success that explained most of the difference.

6.2.1.1 Mark and Recapture Analysis

Capture and recapture data from the trapping effort could be used to estimate population size with multiple capture-mark-release (mark-recapture) models. Several models have been used by wildlife biologists to estimate population size for many years (*e.g.*, Harris *et al.*, 1987; Hammond, 1986; Adams, 1959). Mark-recapture statistical models are of two types: those that assume populations are open, in which birth, death, and migration are considered; and those that assume populations are closed, in which numbers of individuals are assumed to be static during the survey period. Carnivore population sizes

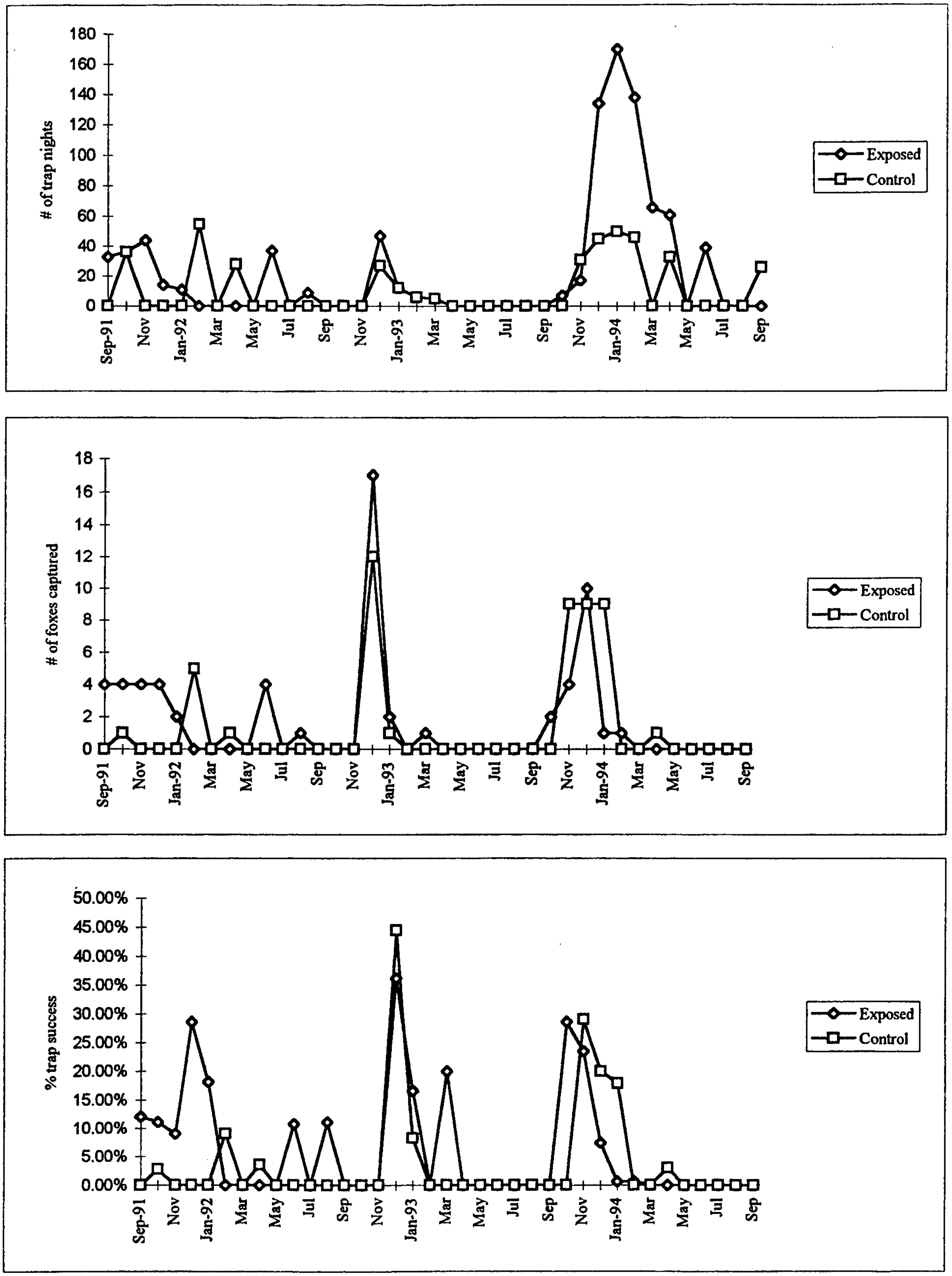


Figure 6-7 Monthly trap effort and success during the course of the study.

have been investigated using mark-recapture methods, but with difficulty, and results of studies have been inconsistent with each other.

Table 6-2 *Trapping effort and success by season and year.*

Season	Exposed			Control			Combined		
	Trap nights	# of foxes captured	Success	Trap nights	# of foxes captured	Success	Total trap nights	# of foxes captured	Success
Fall 1991	113	12	10.62%	36	1	2.78%	149	13	8.72%
1991 Totals	**113**	**12**	**10.62%**	**36**	**1**	**2.78%**	**149**	**13**	**8.72%**
Winter 1991-1992	25	6	24.00%	55	5	9.09%	80	11	13.75%
Spring 1992	0	0	0.00%	28	1	3.57%	28	1	3.57%
Summer 1992	46	5	10.87%	0	0	0.00%	46	5	10.87%
Fall 1992	0	0	0.00%	0	0	0.00%	0	0	0.00%
1991-1992 Totals	**71**	**11**	**15.49%**	**83**	**6**	**7.23%**	**154**	**17**	**11.04%**
Winter 1992-1993	65	19	29.23%	45	13	28.89%	110	32	29.09%
Spring 1993	5	1	20.00%	5	0	0.00%	10	1	10.00%
Summer 1993	0	0	0.00%	0	0	0.00%	0	0	0.00%
Fall 1993	24	6	25.00%	31	9	29.03%	55	15	27.27%
1992-1993 Totals	**94**	**26**	**27.66%**	**81**	**22**	**27.16%**	**175**	**48**	**27.43%**
Winter 1993-1994	442	12	2.71%	141	18	12.77%	583	30	5.15%
Spring 1994	127	0	0.00%	33	1	3.03%	160	1	0.63%
Summer 1994	39	0	0.00%	0	0	0.00%	39	0	0.00%
Fall 1994	0	0	0.00%	26	0	0.00%	26	0	0.00%
1993-1994 Totals	**608**	**12**	**1.97%**	**200**	**19**	**9.50%**	**808**	**31**	**3.84%**
All Year Totals	**886**	**61**	**6.88%**	**400**	**48**	**12.00%**	**1286**	**109**	**8.48%**

White *et al.* (1982) described in detail the analysis of mark-recapture data on foxes and other small carnivores. The important requirements were:

(1) That 6-10 or more trapping sessions must be conducted in each part of the study area;
(2) That capture probabilities must be over 0.30-0.35 both initially and with successive captures; and
(3) That emigration and immigration during the period when data were collected must be close to negligible.

Of these, the probability of capture requirement posed the greatest difficulties because carnivores are wary of human presence and learn quickly to avoid traps after being handled (Spowart and Samson, 1986).

In addition to the requirements outlined by White, there was an additional requirement common to mark-recapture surveys that trapping effort must be balanced with respect to animal distribution. Some species, including the kit fox, have clumped denning territories (Hardenbrook, 1986; Egoscue, 1962), probably due both to social interactions and preferences for particular habitat types. Design of surveys for clumped distributions requires previous knowledge of interclump distances; so, initial trapping surveys must be conducted to determine distribution before trapping surveys to obtain population estimates are conducted.

Harris *et al.* (1987) tried to use mark-recapture models to estimate population size of the endangered San Joaquin Valley kit fox (V. m. mutica). They evaluated the Jolly-Seber open population model, the standard model in studies of small animals. The Jolly-Seber method is based on an open population model and assumes that:

(1) Marked and unmarked individuals have the same probability of being caught over all sampling periods;
(2) Survival rates are the same for all animals over the entire sampling period;
(3) There is no tag loss; and
(4) All samples are taken instantaneously (Seber, 1972).

They rejected this model because kit foxes had an average probability of capture slightly lower than the expected minimum. Population estimates were further hindered because foxes did not have equal trappability (Egoscue, 1962, 1975), and probability of capture declined markedly after the first capture (Egoscue, 1962; O'Farrell and Gilbertson, 1986).

Hallett *et al.* (1991) reviewed methods for determining population sizes of small predators. They included mark-recapture methods, enumeration (minimum population size), and estimates based on home-range sizes. They found that mark-recapture methods (both open and closed models) and estimates based on home range were consistent with each other and superior to enumeration as estimators of population size, even when probabilities of capture were too low and some biases were present.

Because the conclusions of various authors were inconsistent, it seemed reasonable to attempt to calculate mark-recapture estimates for the trapping surveys on the BMGAFR for each year of the study. The probability of capture of foxes was lower than the required value for both open and closed models, typically 10-15%. There was also evidence that foxes become less susceptible to trapping after several captures. Figure (6-8) shows the number of captures and recaptures in the fox trapping surveys. A few individuals were prone to repeated capture ("trap happy"), but most individuals were not recaptured at all, even those with established home ranges in the study area.

There are several robust closed population models available for animals with heterogeneous capture probabilities. A method developed by Chao (1987) was selected because it provides a more useful estimator than jackknife methods (Otis *et al.*, 1978) when animals are recaptured only once or twice. The Chao method yielded a population estimate of 28 ± 155 foxes for the 1991-1992 season, 104 ± 4,820 for the 1992-1993 season, and 133 ± 3,135 for the 1993-1994 season. The Chao method was deemed unsuitable because the confidence limits were unreasonably high. Although the estimate of population size was in reasonable agreement with enumeration methods in the first year, the later estimates were unreasonably high.

6.2.1.2 Direct Enumeration

Direct enumeration gave the most conservative estimate of the number of animals that used the study area during the given period. Fifteen individuals were captured in the 1991-1992 season (11 on the exposed and 4 on the control), 18 in the 1992-1993 season (11 on the exposed and 7 on the control), and 34 in the 1993-1994 season (16 on the exposed and 18 on the exposed). These numbers reflect the combined yearly effort and were influenced by the seasonal timing of trapping. The influence of seasonal timing on the estimates is easily shown by the results of the 1993-1994 season. Although 34 foxes were captured throughout the final field season, the foxes suffered high mortality during January, reducing the population of radio-collared kit fox by 64%, which yields an estimate of 12 individuals.

6.2.2 Results of Radio-Tracking: Home Range Analysis

Overall, 44 foxes were radio-collared, with 24 on the control site and 20 on the exposed. Radio collars were placed on 21 female and 23 male foxes. Almost 250 locations for 7 foxes were collected during the 1991-1992 field season. During the 1992-1993 field season 17 foxes were radio-collared resulting in over 900 triangulations. In the third field season (1993-1994) 20 individuals were captured and

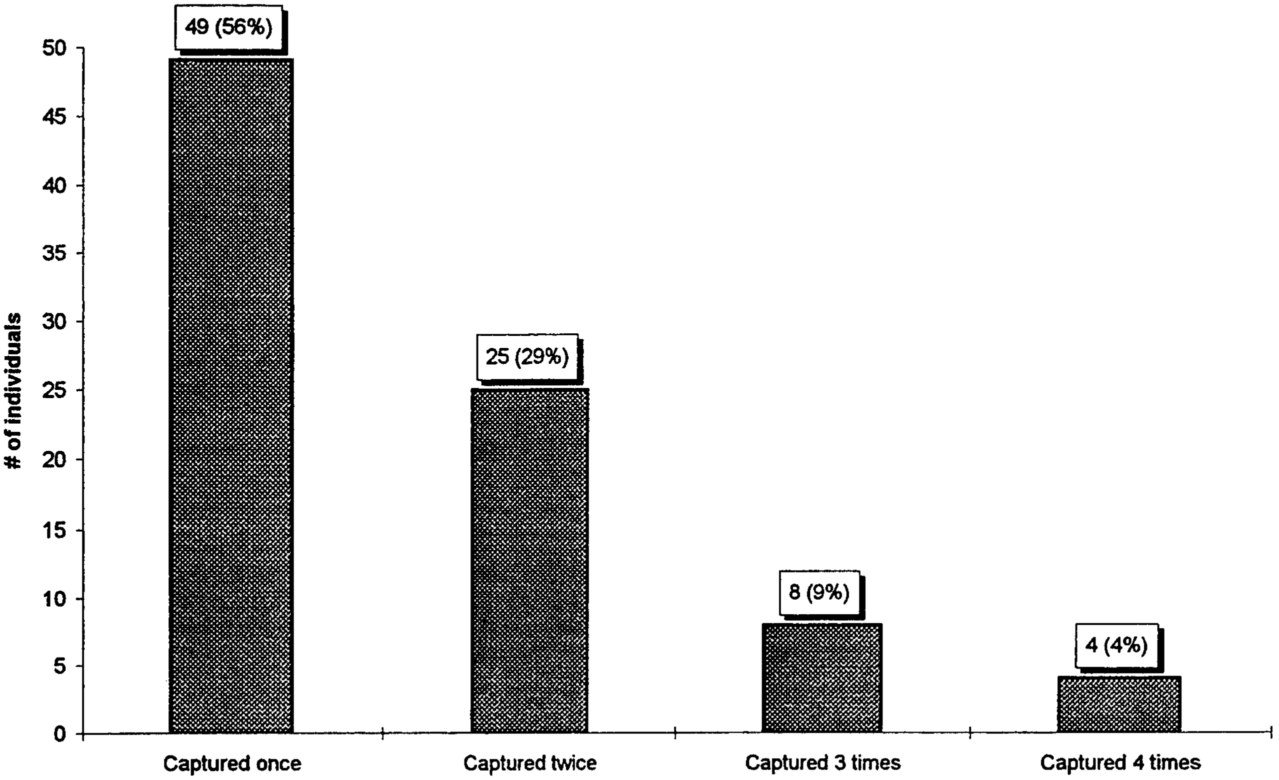


***Figure 6-8** Frequency distribution of the number of times foxes were captured.*

collared resulting in over 1,100 sets of bearings.

Figure 6-9 shows the cumulative estimate of home range area *vs.* number of locations for three representative individuals and for the 16 home ranges estimated with greater than 35 locations. The cumulative area curves approached asymptotes at around 45 points. The mean number of points collected per animal during the study was 47.5 ± 2.99 (mean ± s.e., n = 20).

Home ranges are usually estimated using the minimum convex polygon method of Mohr (1947). This method takes the outermost locations from a series and connects them to form a polygon. This method is widely used to assess the home range size of small and medium sized mammals (White and Garrott, 1990, p. 148). For the purposes of this study, all minimum convex polygon values were calculated at the 95% level, *i.e.*, to include 95% of the locations within the borders of the polygon.

To more accurately describe fox use of areas within the home range, the adaptive kernel method of Worton (1989) was also used to estimate home range. This method generates contours in 10% increments around the locations collected, moving from the areas with the greatest numbers of locations

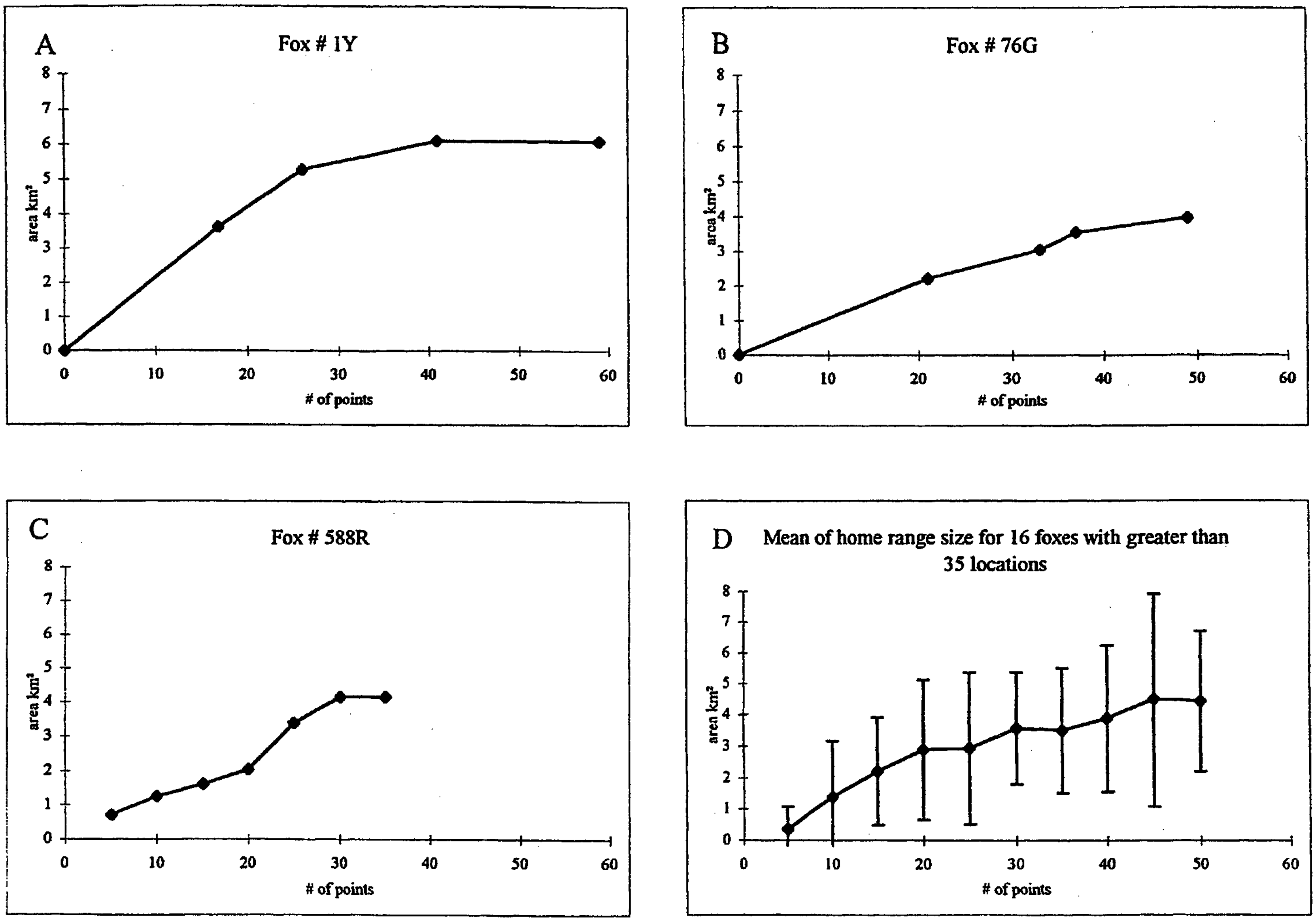


Figure 6-9 *Cumulative area curves used to determine the number of telemetry points for minimum convex polygon estimates. Home range areas for three representative individuals (A-C) and the mean of 16 individuals (D).*

(typically around den sites) to the entire area traversed by the animal. Minimum convex polygon and adaptive kernel estimators were calculated using the CALHOME home range estimation program (Version 1.0, California Fish and Game).

Estimates of fox home range size estimated by the Minimum Convex Polygon on the exposed and control sites are given for individuals in Table 6-3 and by groups in Table 6-4. Mean home range size for all foxes throughout the three years of the study was 3.73 ± 0.28 km^2 (mean ± s.e., n = 20). The difference in mean home range size for all foxes from the exposed site (4.00 ± 0.41 km^2, n = 10) and control site (3.46 ± 0.38 km^2, n = 10) was not significant (t = 0.369, d.f. = 18, p = 0.716). However, variation in mean home range size was around 25-35% and this test had only 28% statistical power. Therefore, a small undetected difference could have been present. Mean home range size for the exposed site was around 15% greater than in the control site.

Home range sizes of females in the exposed area (4.60 ± 0.69 km^2, n = 3) did not differ significantly (t = 0.734, d.f. = 4, p = 0.503) from home ranges of control area females (3.90 ± 0.66 km^2, n = 3), but sample sizes were small. Home ranges of male foxes in the exposed area (3.73 ± 0.51 km^2, n = 7) also did not differ significantly (t = 0.091, d.f. = 6, p = 0.928) from those of males in the control area (3.27 ± 0.47 km^2, n = 7). Variation in home range size ranged from 25-32% within years and 21% between years. Therefore, the variation between the two areas was on the order of annual variation within area.

Although they were 21% larger, female (4.25 ± 0.45 km^2, n = 6) home ranges were not significantly different from male home ranges (3.50 ± 0.34 km^2; n = 14; t = -1.253, d.f. = 18, p = 0.226) when animals from all years were combined (Table 6-5). The smaller size of male home ranges, in comparison to females, is in contrast to the findings of Zoellick and Smith (1992). However, because the home ranges of the sexes could not be distinguished statistically, this difference may have been the result of random chance.

The smaller home ranges of males collared during this study probably belonged to younger animals. Fox #172 moved from the exposed to the control site and lived almost entirely within the home range of fox #1 (Figure 6-10). Fox #148 was collared as a young male during the 1992-1993 season and again during the 1993-1994 season. The results of the 1993-1994 telemetry showed that his home range had increased by 2.92 km^2 in what was probably his second year (Figure 6-11).

Similar to the findings of Zoellick and Smith (1992), home ranges of mated pairs overlapped greatly (Figure 6-12) while adjacent pairs tended to have minimal overlap. Figure 6-10 and 6-13 show home ranges for 1992-1993 and 1993-1994 males.

Table 6-3 *Home ranges of individual kit foxes as estimated by the minimum convex polygon method at the 95% level.*

Fox ID	Sex	Area	Year	Home range km^2	n =
75	male	exposed	1992	5.77	55
132	female	exposed	1992	5.72	44
137	female	exposed	1992	3.35	24
1	male	control	1993	4.35	59
5	male	exposed	1993	4.01	41
22	male	exposed	1993	3.25	38
24	male	exposed	1993	4.13	39
72	male	control	1993	4.85	36
76	female	control	1993	3.08	49
77	male	control	1993	2.57	46
140	male	control	1993	3.48	33
141	female	control	1993	3.42	49
142	male	control	1993	1.5	34
148	male	exposed	1993	1.79	43
172	male	control	1993	2.1	33
56	female	exposed	1994	4.74	69
87	female	control	1994	5.21	63
148	male	exposed	1994	4.71	71
158	male	exposed	1994	2.48	64
588	male	control	1994	4.04	60

Home ranges calculated with the adaptive kernel method for males on the exposed site in 1994 are shown in Figure 6-14. Contours denote boundaries of home range use for 10%-100% of telemetry points collected. As would be expected, the most active areas center around den sites. For comparison, minimum convex polygons are also shown on the figure.

Using only the minimum convex polygon method it would appear that a strict boundary separates the two males when, in fact, adaptive kernel contours reveal the overlap of home range edges.

Table 6-4 *Mean minimum convex polygon estimates of kit foxes.*

	All Exposed Foxes	**All Control Foxes**	**All Foxes Combined**	**Number Of Points Per Fox**
Mean (km^2)	4.00	3.46	3.73	47.50
Standard Error	0.41	0.38	0.28	2.99
Standard Deviation	1.31	1.19	1.25	13.38
Median	4.07	3.45	3.75	45.00
Minimum	1.79	1.50	1.50	24
Maximum	5.77	5.21	5.77	71
N =	10	10	20	20
	All 1992-1993 Exposed	All 1992-1993 Control	All 1993-1994 Exposed	All 1993-1994 Control
Mean (km^2)	3.30	3.17	3.98	4.63
Standard Error	0.54	0.39	0.75	0.58
Standard Deviation	1.08	1.11	1.30	0.83
Median	3.63	3.25	4.71	4.63
Minimum	1.79	1.50	2.48	4.04
Maximum	4.13	4.85	4.74	5.21
N =	4	8	3	2
	Exposed Site Females	Control Site Females	Exposed Site Males	Control Site Males
Mean (km^2)	4.60	3.90	3.73	3.27
Standard Error	0.69	0.66	0.51	0.47
Standard Deviation	1.19	1.14	1.35	1.24
Median	4.74	3.42	4.01	3.48
Minimum	3.35	3.08	1.79	1.50
Maximum	5.72	5.21	5.77	4.85
N =	3	3	7	7

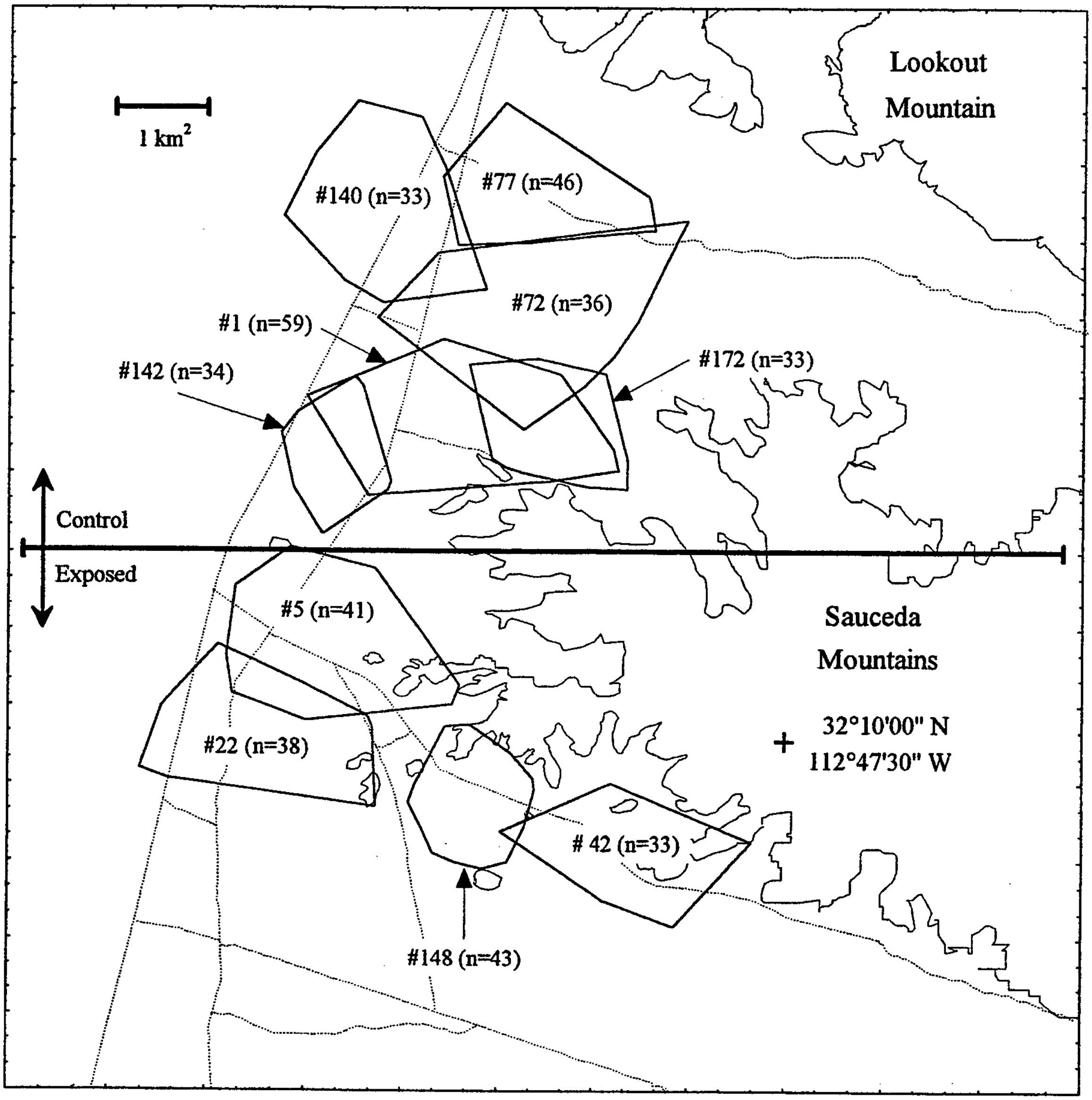


Figure 6-10 *Map of the study area showing home ranges for 1992-1993 male kit foxes as estimated by the minimum convex polygon method at the 95% level.*

6.2.2.1 Estimates of Population Based on Home-Range Analysis

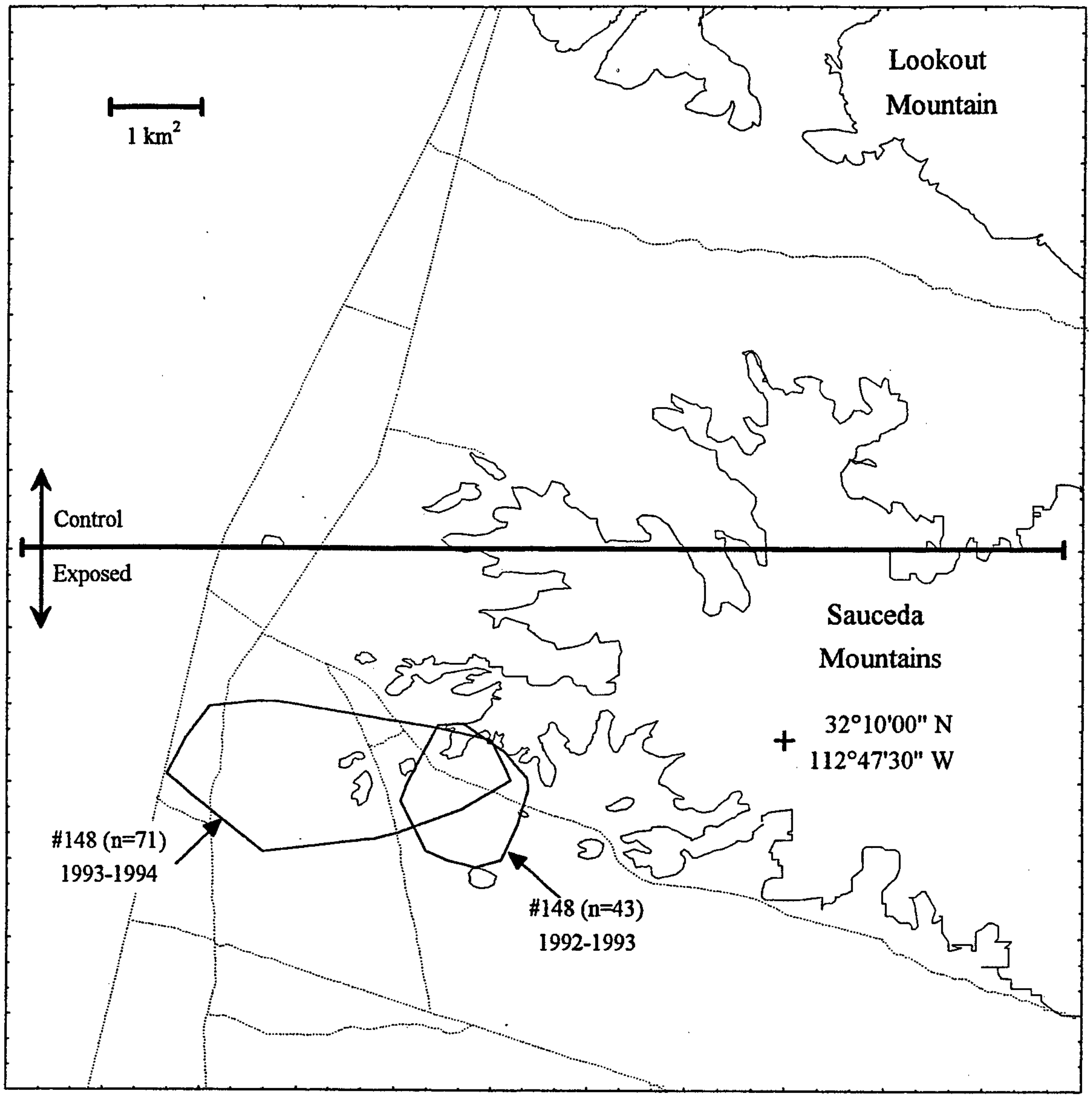
Densities of kit foxes on the study site were estimated to be 0.35 foxes/km^2 during the 1991-1992 field season, 0.45 foxes/km^2 in the 1992-1993 season, and 0.63 foxes/km^2 in the 1993-1994 season. These estimates were made by dividing the minimum number known alive by the size of the study area. The values agreed well with estimates based on home range size.

Table 6-5 *Home ranges for kit foxes estimated by the minimum convex polygon method at the 95% level.*

	All Female Foxes	**All Male Foxes**	**All 1991-1992 Foxes**	**All 1992-1993 Foxes**	**All 1993-1994 Foxes**
Mean (km²)	4.25	3.50	4.95	3.21	4.24
Standard Error	0.45	0.34	0.80	0.30	0.48
Standard Deviation	1.11	1.27	1.38	1.05	1.07
Median	4.08	3.75	5.72	3.34	4.71
Minimum	3.08	1.50	3.35	1.50	2.48
Maximum	5.72	5.77	5.77	4.85	5.21
N =	6	14	3	12	5
	1991-1992 Females	1992-1993 Females	1993-1994 Females	1992-1993 Males	1993-1994 Males
Mean (km²)	4.54	3.25	4.98	3.20	3.74
Standard Error	1.19	0.17	0.24	0.37	0.66
Standard Deviation	1.68	0.24	0.33	1.16	1.14
Median	4.54	3.25	4.98	3.37	4.04
Minimum	3.35	3.08	4.74	1.50	2.48
Maximum	5.72	3.42	5.21	4.85	4.71
N =	2	2	2	10	3

The average home range size for both exposed and control areas was 3.73 km^2 (Table 6-4), which would allow 16 pairs of kit foxes to live within the 60-km^2 study area, for a total of 38 animals and a density of 0.63/km^2. The minimum population estimates from 1993 and 1994 (18 and 34 respectively) were probably the most reliable, as trapping effort in the last two years was better-designed to capture a high proportion of the total population. These values agreed reasonably well with the estimate based on home range size.

Table 6-6 gives the densities of the three subspecies of the kit fox reported in literature. Based on these data, densities varied from .05 foxes/km^2 to over 20 foxes/km^2. White and Ralls (1993) explain that kit fox spacing may be a result of the type and availability of their primary prey. Those foxes feeding on nocturnal rodents, such as on the BMGAFR, are apt to have larger home ranges than foxes feeding primarily on lagomorphs. Some authors also found communal denning (*e.g.*, Hardenbrook, 1986), which did not appear to occur on the BMGAFR.



Note that the home range moved from an area of lower to higher exposure.

Figure 6-11 *Map of the study area showing home ranges of male kit fox #148 during the 1992-1993 and 1993-1994 field seasons. Polygons derived by minimum convex polygon estimates at the 95% level.*

6.2.3 Den Surveys

Figure 6-15 shows the locations of all the kit fox dens found during the course of the study. Dens close to the roads were more likely to be located by casual observation. The majority of dens were found by tracking radio-collared foxes. In April 1992, students from a wildlife biology course at HSU walked transect lines 50-m apart to locate dens systematically. They marked suspected dens with flagging so that field personnel from HSWRI could confirm the species that constructed the den. The majority of actively used dens were located on the alluvial fan away from the mountain ranges on the study site.

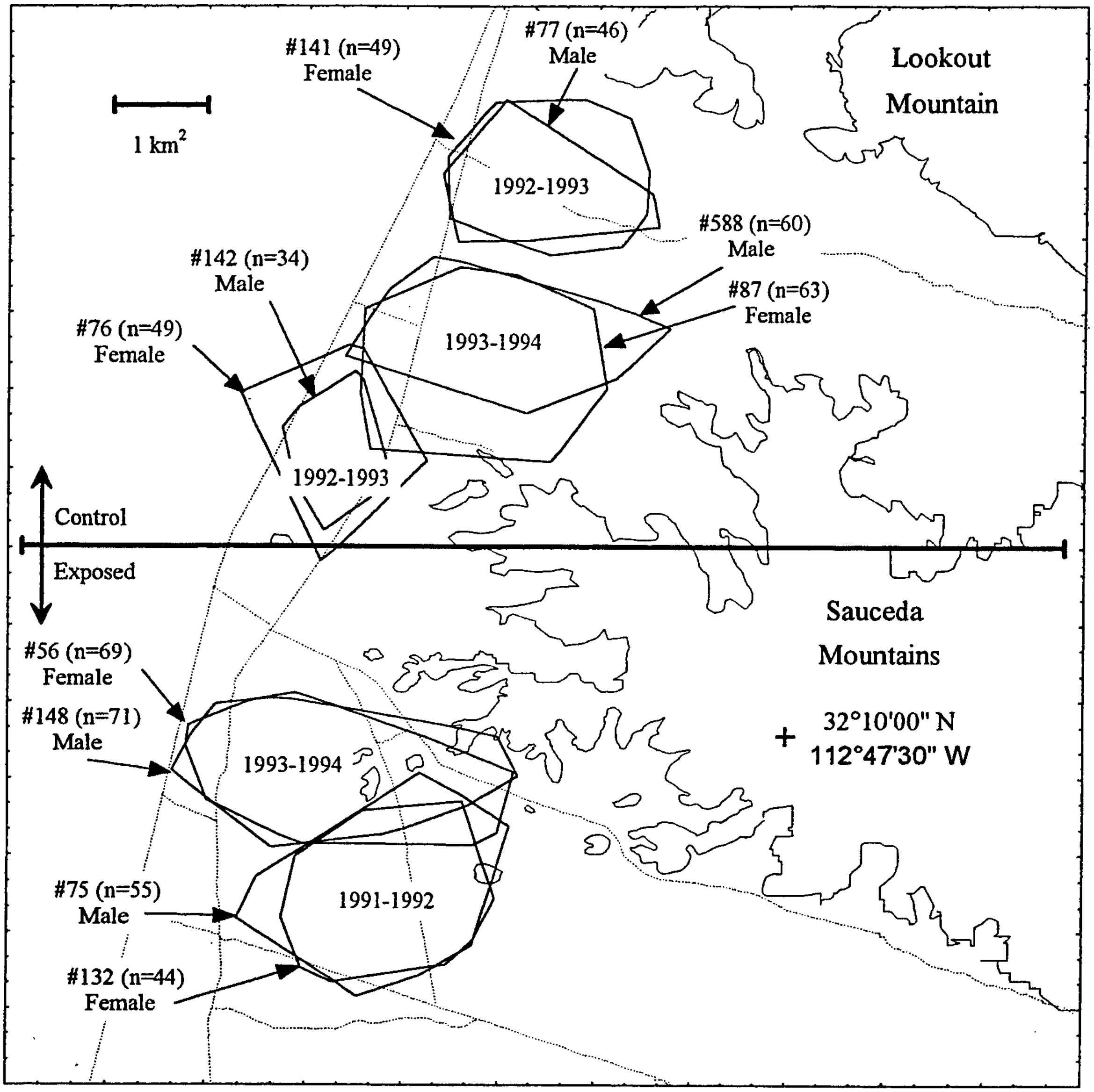
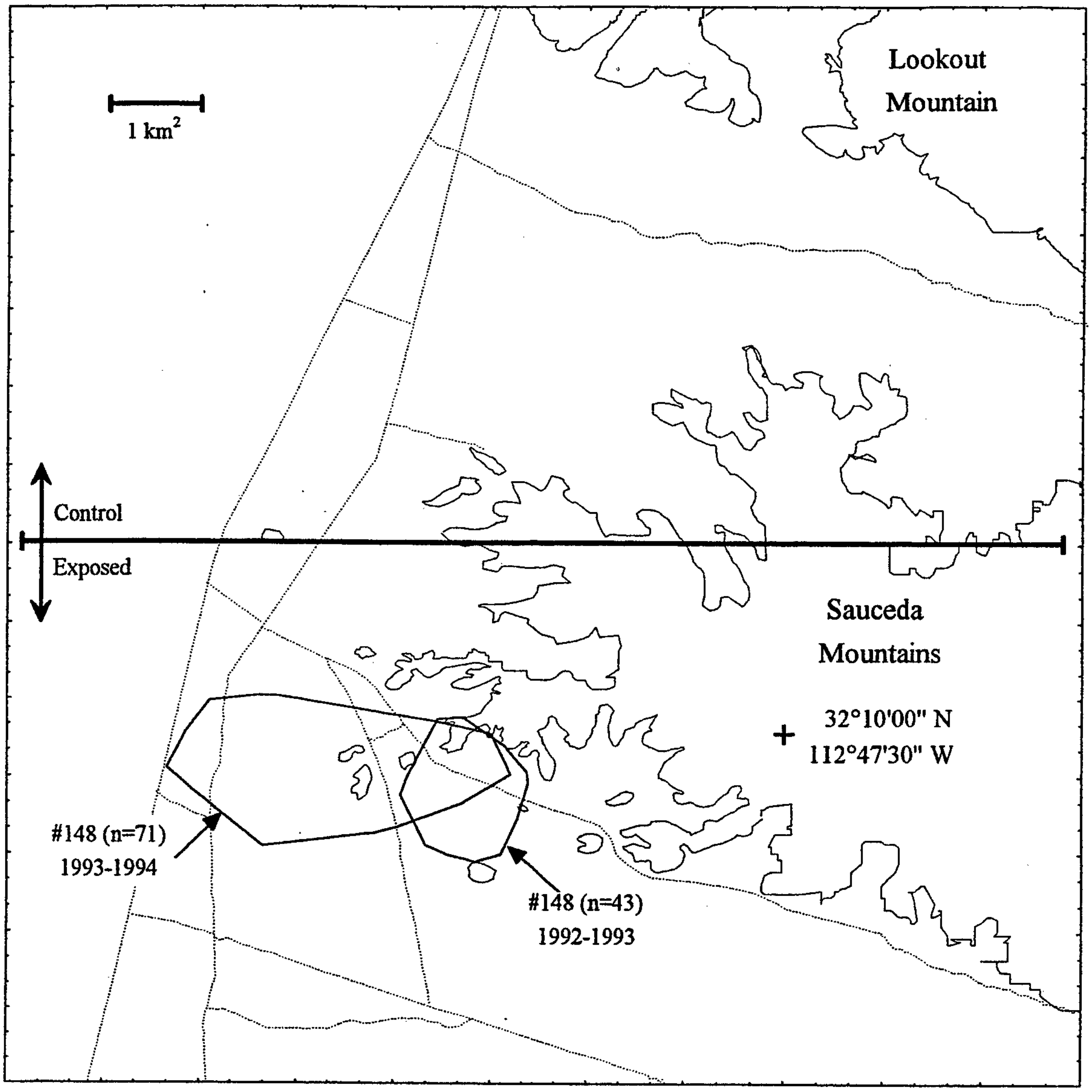


Figure 6-12 Map of the study area showing home ranges of kit fox mate pairs during the 1991-1994 field seasons. Polygons derived by minimum convex polygon estimates at the 95% level.

Den site locations were not obviously clumped on the alluvial fans, consistent with the observation that the home ranges of pairs did not overlap. The absence of dens at the east end of both control and exposed areas was the result of (1) minimal search effort and (2) the transition in habitat type from creosote desert scrub to mixed Sonoran desertscrub.

6.2.4 Morphometrics of Captured Foxes

Morphometric measurements of the adult foxes captured are summarized in Table 6-7. There was no significant difference between the mean weight of foxes on the exposed and control sites (two-way



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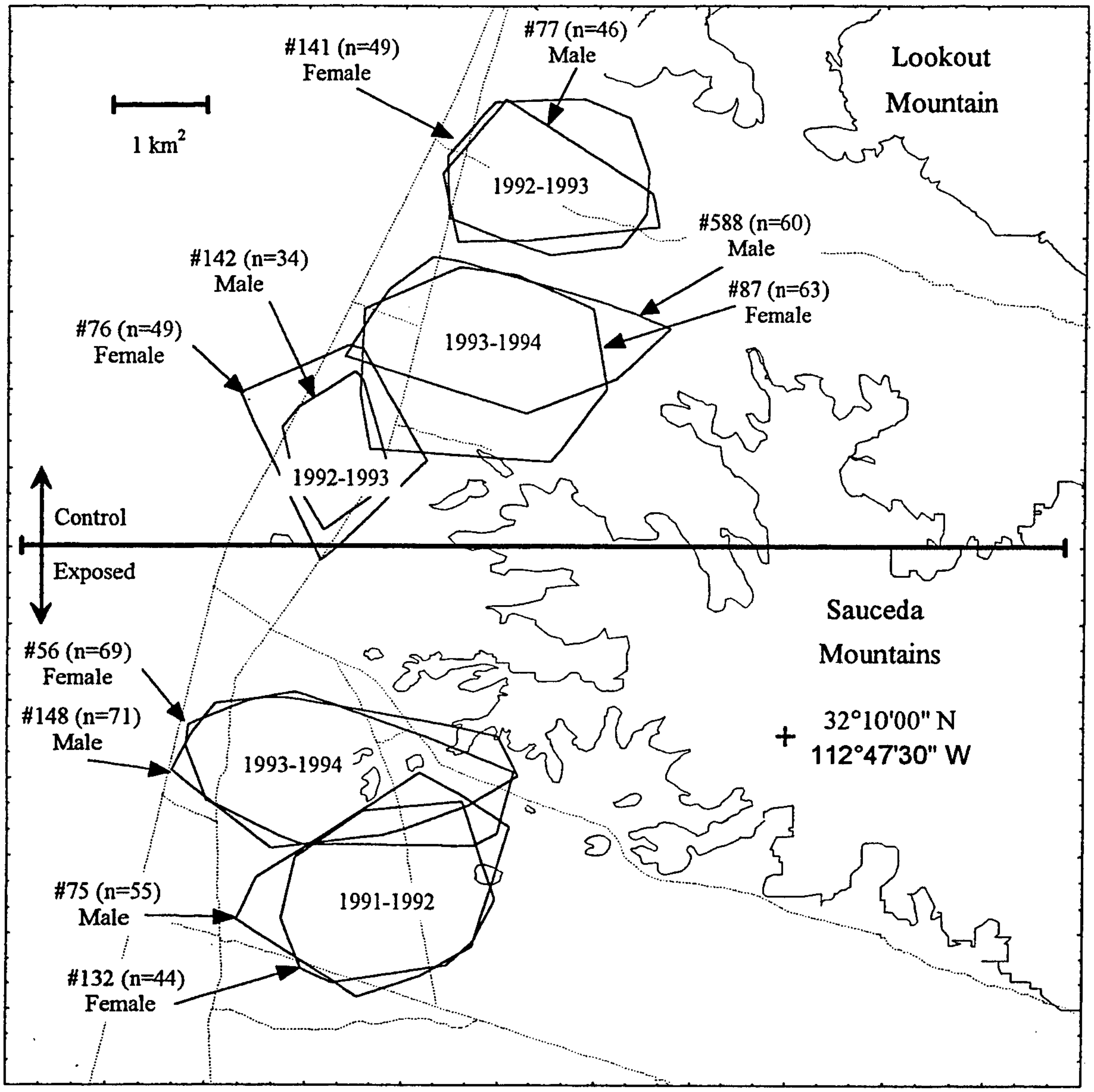

Figure 6-12 ***Map of the study area showing home ranges of kit fox mate pairs during the 1991-1994 field seasons. Polygons derived by minimum convex polygon estimates at the 95% level.***

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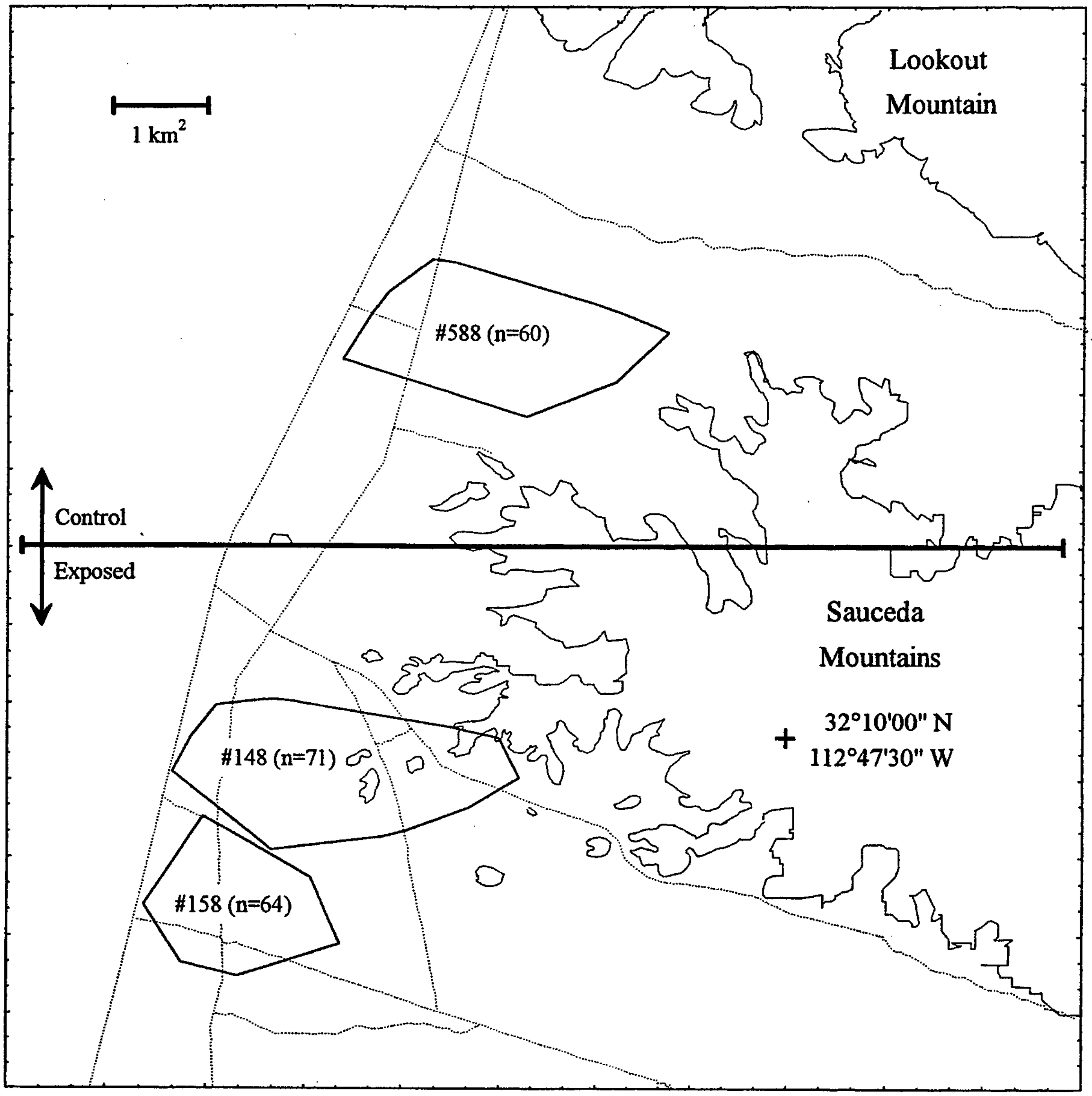
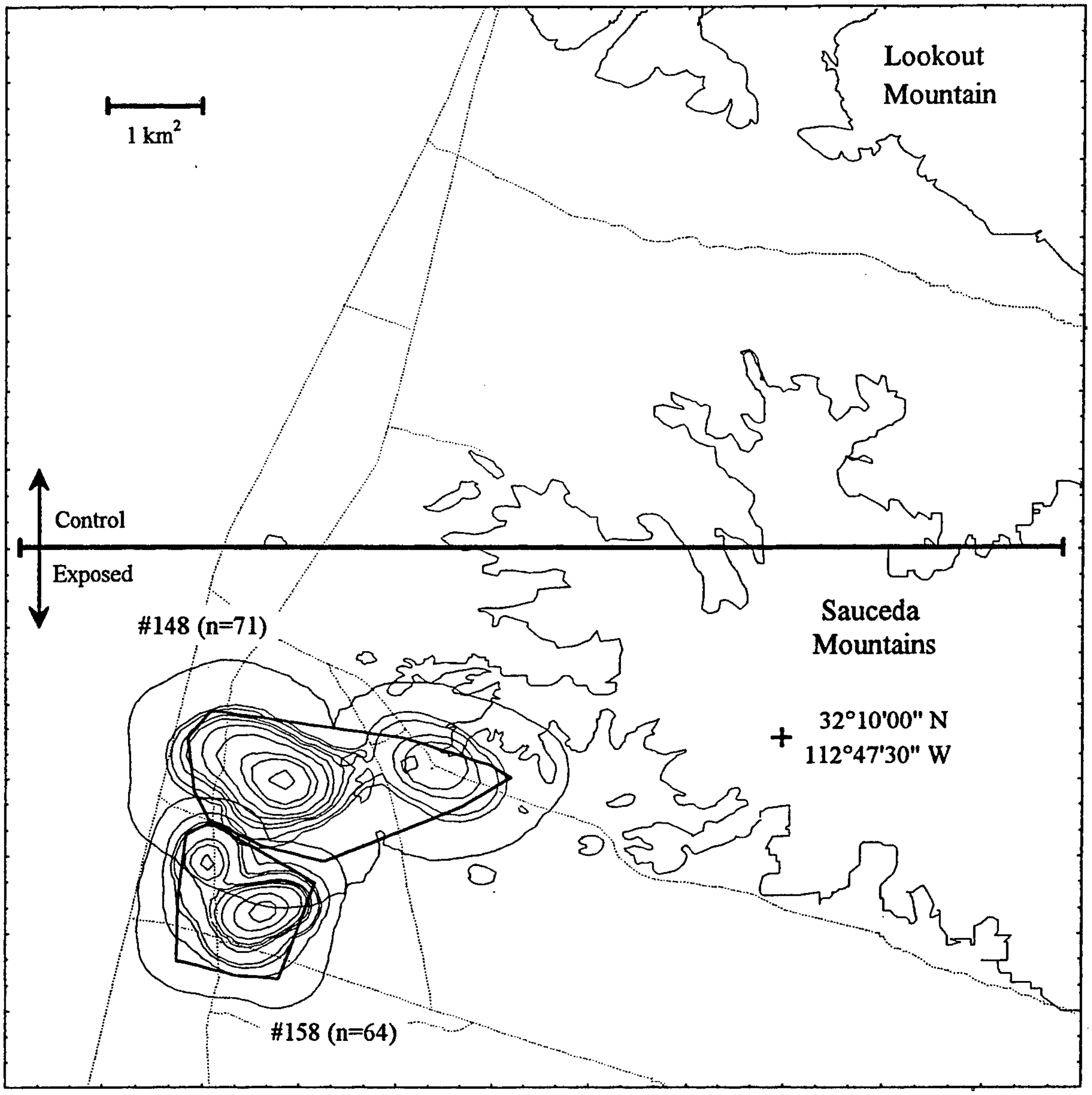


Figure 6-13 *Map of the study area showing home ranges of male kit fox during the 1993-1994 field season. Polygons are derived by the minimum convex polygon estimates at the 95% level.*

ANOVA, n = 48, F = 1.28, p = 0.263, d.f. = 54); however, foxes on the exposed site weighed 4% less than those on the control site. There was also no significant difference in the interaction between sex and site (n = 58, F = 0.003, p = 0.987, d.f. = 54). Adult males were significantly heavier than adult females (n = 58, F = 17.9, $p \ll 0.0001$, d.f. = 56).

6.2.5 Analysis of Fox Survival and Mortality

Appendix E lists all foxes that were either radio-collared or captured on more than one occasion, providing time of persistence. As in the case of the small mammals, time of persistence is a



Adaptive kernel contours represent areas of increased usage in 10% increments, with the center rings being the most heavily used.

Figure 6-14 *Map of the study area showing minimum convex polygons estimates and adaptive kernel contours for exposed site males during the 1993-1994 field season.*

conservative estimate of life span. In the initial setup of the study, an area west of State Highway 85 and north of Range 3 of the BMGAFR was tested as a control site. Information from foxes captured on Area C is presented in Appendix E, although Area C was abandoned as the control site due to large

Table 6-6 Densities of foxes reported in literature.

AUTHOR	SUBSPECIES	DENSITY
Egoscue, 1956	V. m. nevadensis	4.6 fox/km^2
Egoscue, 1962	V. m. nevadensis	5.2 fox/km^2
Laughrin, 1970	V. m. mutica	7.2 fox/km^2
Morrell, 1972	V. m. mutica	0.4 fox/km^2
Egoscue, 1975	V. m. nevadensis	11.7 fox/km^2 9.8 fox/km^2 11.7 fox/km^2 20.7 fox/km^2 12.5 fox/km^2
O'Farrell and Gilbertson, 1986	V. m. arsipus	0.5 fox/km^2
Hardenbrook, 1987	V. m. nevadensis	6.1 fox/km^2

habitat differences. The number of days each animal was known to be alive was calculated by taking the difference between the date of initial capture and final capture or the difference between the date of initial capture and the date a collared animal was known to be dead. Several foxes were uncollared at the completion of each field season, and were never recaptured. In these cases, the estimate was artificially low. Likewise, foxes that were not radio-collared but only eartagged and recaptured on later occasions probably lived beyond the time of their last capture, as most recaptures occurred within a few months of the initial capture. Figure 6-16 shows the number of foxes known to be alive for each 100-day interval. The longest-lived fox (fox #148) on the exposed site was 584 days, and fox #1 on the control site was alive for at least 862 days. No significant difference was found between days known alive in the exposed site (median = 223 days; lower and upper quartile = 35 and 325 days) and control site (median = 209 days; lower and upper quartile = 43 and 326 days; n = 49, Mann-Whitney U = 247.5, p = 0.782).

Estimates of annual mortality were made using loss rates in radio-collared animals. In 1992, seven of nine collared foxes died (77%). In 1993, mortality was very low; only one of sixteen collared foxes died (6%). This suggested that mortality was not a function of handling or the radio collar, but a function of conditions on the BMGAFR. In 1994, 16 of 25 radio-collared animals died (64%). These rates are consistent with estimates of fox mortality obtained from previous studies.

6.2.6 Determination of Prey Consumed by Foxes

A total of 52 scat samples have been analyzed to date. Of these, 30 were scats from kit foxes. A preliminary analysis of the contents of these scats has been completed. The number that contained each

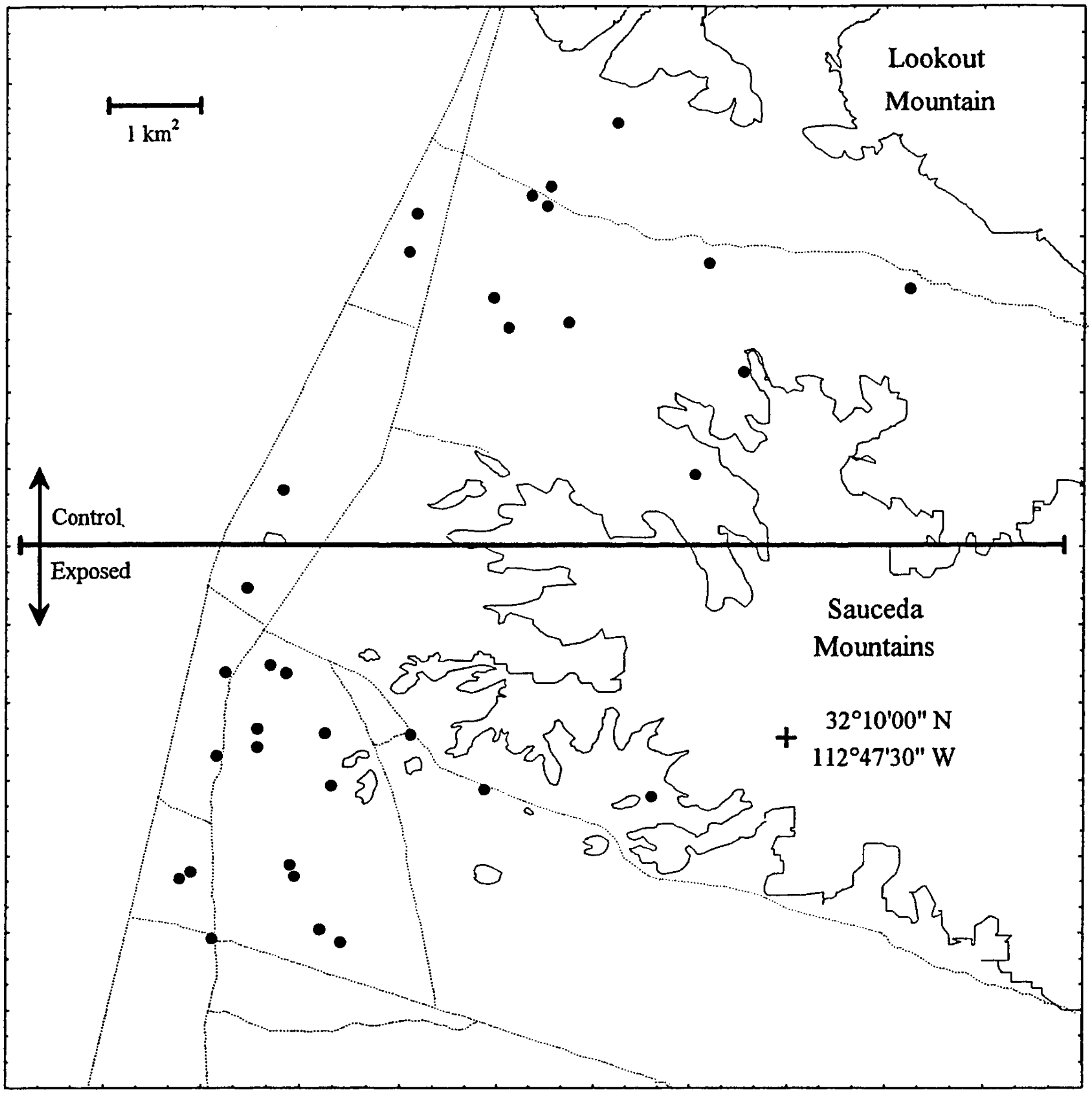


***Figure 6-15** Map of the study area showing kit fox den locations found throughout the course of the study.*

prey type is listed in Table 6-8 (most scats contained remains of various prey types). Based on this examination, heteromyids and scorpions represented the most important part of the diet.

Table 6-7 *Morphometric measurements of adult kit foxes.*

	Weight (kg)	Ear Length (mm)	Hind Foot Length (mm)	Tail Length (mm)	Weight (kg)	Ear Length (mm)	Hind Foot Length (mm)	Tail Length (mm)
	All Foxes—Control				All Foxes—Exposed			
Mean	1.79	79.2	115.6	271.7	1.73	78.8	115.9	264.3
Standard Error	0.04	0.84	1.13	3.30	0.04	0.60	1.00	4.08
Standard Deviation	0.20	4.34	5.86	17.15	0.20	3.41	5.64	23.11
Median	1.78	79.0	117.0	272.0	1.68	79.0	116.5	260.5
Minimum	1.50	71.0	99.0	230.0	1.45	72.0	105.0	185.0
Maximum	2.40	93.0	125.0	299.0	2.20	85.0	128.0	305.0
n =	27	27	27	27	31	32	32	32
	All Males—Control				All Males—Exposed			
Mean	1.89	81.1	116.4	273.3	1.84	79.6	119.8	271.6
Standard Error	0.05	1.16	1.15	4.26	0.06	1.11	0.96	4.41
Standard Deviation	0.20	4.35	4.29	15.93	0.22	4.14	3.58	16.49
Median	1.85	80.5	118.0	272.5	1.88	79.5	120.0	262.5
Minimum	1.65	75.0	108.0	238.0	1.45	72.0	114.0	256.0
Maximum	2.40	93.0	122.0	299.0	2.20	85.0	128.0	305.0
n =	14	14	14	14	14	14	14	14
	All Females—Control				All Females—Exposed			
Mean	1.69	77.1	114.6	270.1	1.64	78.2	112.8	258.5
Standard Error	0.04	0.92	2.01	5.24	0.03	0.63	1.20	6.17
Standard Deviation	0.14	3.33	7.25	18.88	0.14	2.67	5.09	26.19
Median	1.68	76.0	115.0	271.0	1.60	79.0	112.0	258.5
Minimum	1.50	71.0	99.0	230.0	1.45	72.0	105.0	185.0
Maximum	1.95	82.0	125.0	295.0	1.95	82.0	123.0	302.0
n =	13	13	13	13	17	18	18	18
	All Females				All Males			
Mean	1.66	77.7	113.6	263.4	1.86	80.4	118.1	272.5
Standard Error	0.03	0.53	1.09	4.27	0.04	0.80	0.80	3.01
Standard Deviation	0.14	2.97	6.04	23.77	0.21	4.24	4.24	15.93
Median	1.65	78.0	112.0	265.0	1.85	80.0	119.0	271.5
Minimum	1.45	71.0	99.0	185.0	1.45	72.0	108.0	238.0
Maximum	1.95	82.0	125.0	302.0	2.40	93.0	128.0	305.0
n =	30	31	31	31	28	28	28	28

Scorpions probably represented a smaller part of the diet by weight, but this cannot be estimated from the remains in scats. Lagomorphs did not seem to be as important as reported by some other authors, but the number of lagomorphs may be undercounted, as foxes tend to eat only soft parts of larger animals (Golightly, pers. comm.). Seasonality in preferences could not have been detected using the samples examined so far.

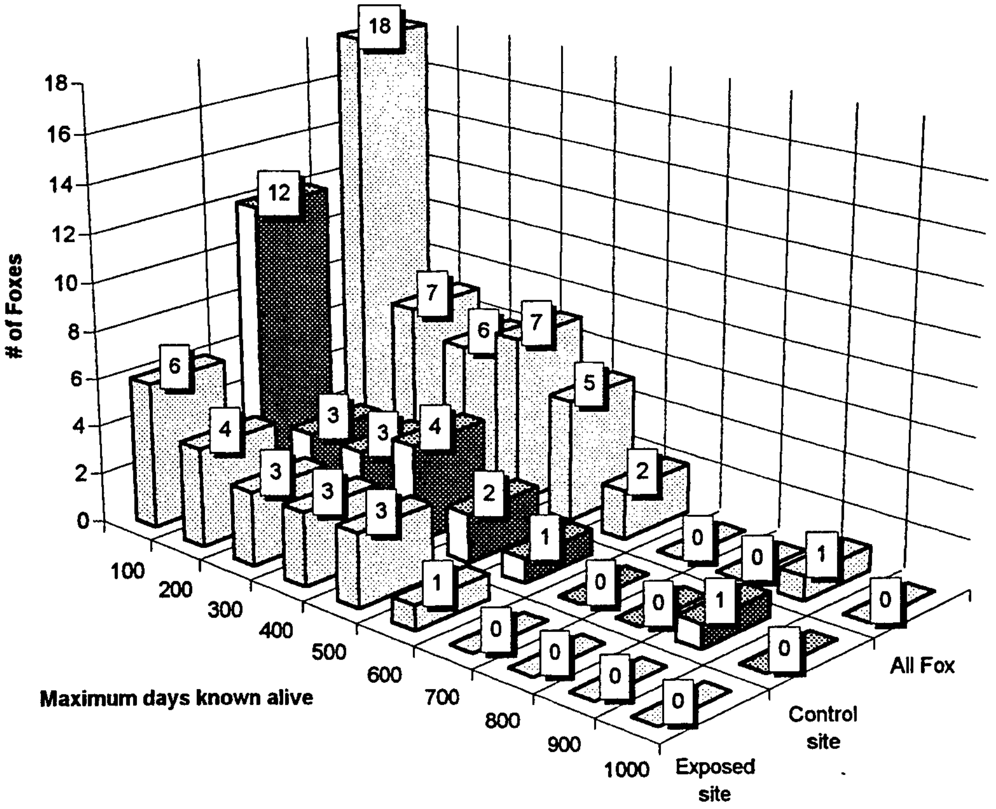


Figure 6-16 *Number of foxes known to be alive for 100-day intervals. Numbers atop columns indicate the count of foxes in each interval.*

6.2.7 Camera Station Surveys

Camera station surveys were conducted in April 1993 and January and August 1994 after some preliminary testing late in 1992. After the April 1993 survey, the triggering mechanism was improved, greatly increasing the number of photographs collected. This modification precluded direct comparison of the April 1993 surveys with the 1994 surveys, but permitted comparisons between the two areas in both survey periods.

Several possible indices were compared between the two areas. The optimum sampling interval was defined as the interval below which increased effort did not provide substantial new information. This interval is shown graphically as the number of new stations detecting kit foxes plotted against the number of times the cameras were set (Figure 6-17). In this study, the number of new stations detecting kit foxes become asymptotic after 8 to 9 resettings, or about 18 days of survey.

Table 6-8 Diet analysis from kit foxes.

Prey type	Percent detected	Number detected
Scorpions	63%	19
Small heteromyids	60%	18
Reptiles	36%	11
Large heteromyids	20%	6
Insects	17%	5
Lagomorphs	7%	2
Birds	7%	2

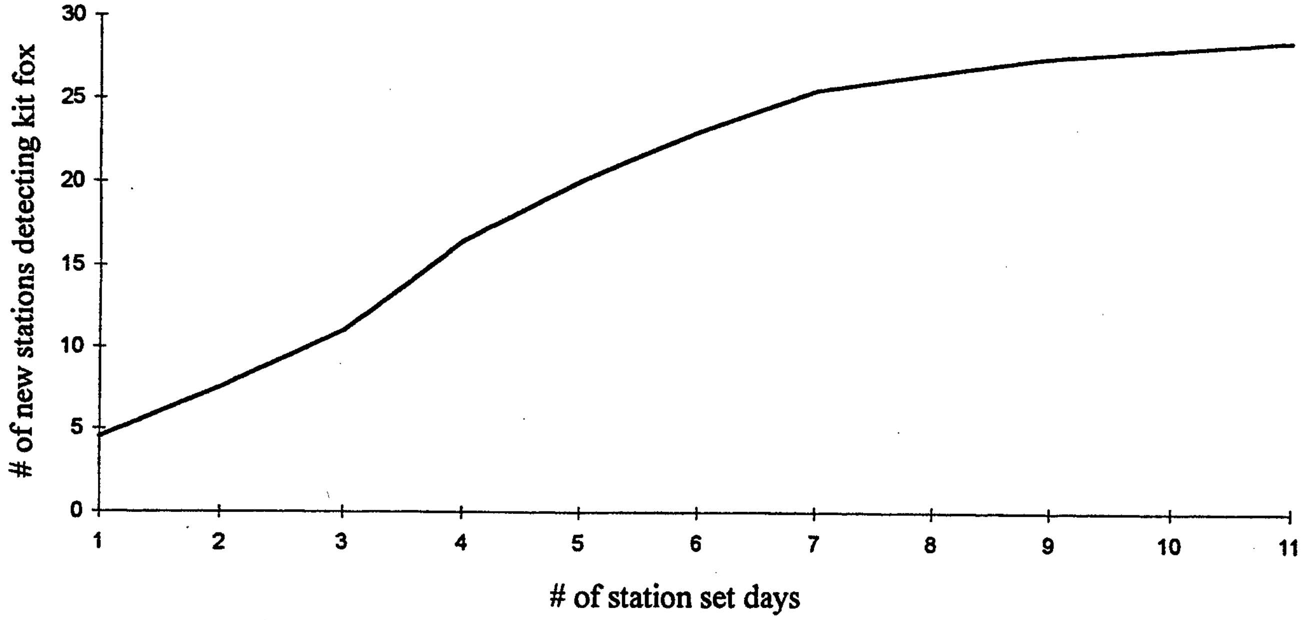


Figure 6-17 Optimum sampling curve for the number of new camera stations detecting kit fox.

Measures of success for the April 1993 camera survey are presented in Table 6-9. Of all photographs of identifiable animals (16 of 64 pictures), kit foxes were seen in 25%. On the control site, 54.2% of identifiable animal photos (13 of 24) were of kit foxes, while on the exposed site only 7.5% (3 of 40) were of kit foxes. The percentage of kit fox photographs was biased because some individuals triggered stations repeatedly, while others did not. A more valid measure of success was the number of stations that detected kit foxes at least once, overall 21.1% of camera stations (8 of 38). On the control site 26.3% of the stations detected kit foxes (5 of 19) while 15.8% of stations on the exposed site detected kit foxes (3 of 19). Thirty-one percent of all identifiable animal photos were of gray foxes, all in the exposed site. Figure 6-18 shows the locations where the gray fox photos were taken. This survey suggested that gray foxes might compete with kit foxes, at least within close proximity to the hills. Figure 6-19 shows the distribution of species detected during the January 1994 camera survey. Success at detecting animals was calculated as the ratio of animal photos to the total number of photos taken (Table 6-10). For both the control and exposed site combined, the detection rate was 58.1% (143 of 246 photos). The rate was significantly higher on the control site (64.9%; 85 of 131) than on the exposed site (50.4%; 58 of 115; $X^2 = 4.68$, $p = 0.031$), although the difference was not large (14.5%).

Table 6-9 *Percent success for the April 1993 camera station survey.*

	Exposed Site	**Control Site**	**Both Sites**
Kit Fox Photos / Identifiable Animal Photos[a]	7.5%	54.2%	25.0%
Kit Fox Photos / Available for Photo[b]	1.5%	6.4%	3.9%
# of Stations with Kit Fox / # of Stations[c]	15.8%	26.3%	21.1%
Gray Fox Photos / Identifiable Animal Photos	50.0%	0.0%	31.3%
Gray Fox Photos / Available for Photo	9.8%	0.0%	4.9%
# of Stations with Gray Fox / # of Stations	36.8%	0.0%	18.4%
Kit and Gray Fox Photos / Identifiable Animal Photos	57.5%	54.2%	56.3%
Kit and Gray Fox Photos / Available for Photo	11.2%	6.4%	8.8%
# of Stations with Kit and Gray Fox / # of Stations	47.4%	26.3%	34.2%

[a] Identifiable Animal Photos—Any exposure with an animal in the photograph.
[b] Available for Photo—Number of nights the camera was armed.
[c] # of Stations—Number of camera stations available.

Several factors led to lower detection rates. The 110 instamatic cameras used at each camera station allowed only one triggering after they were set. Therefore, if an animal molested the camera without first taking the bait, the camera could be triggered without photographing it. This often occurred when birds used the trigger arm as a perch. A flimsy wire perch was added above the trigger arm to keep birds from triggering the camera. Rodents, foxes, and other large predators molested stations in more destructive ways. Camera stations were often found torn apart, with cameras, wire and batteries covered with tooth marks. No solution was discovered for this problem.

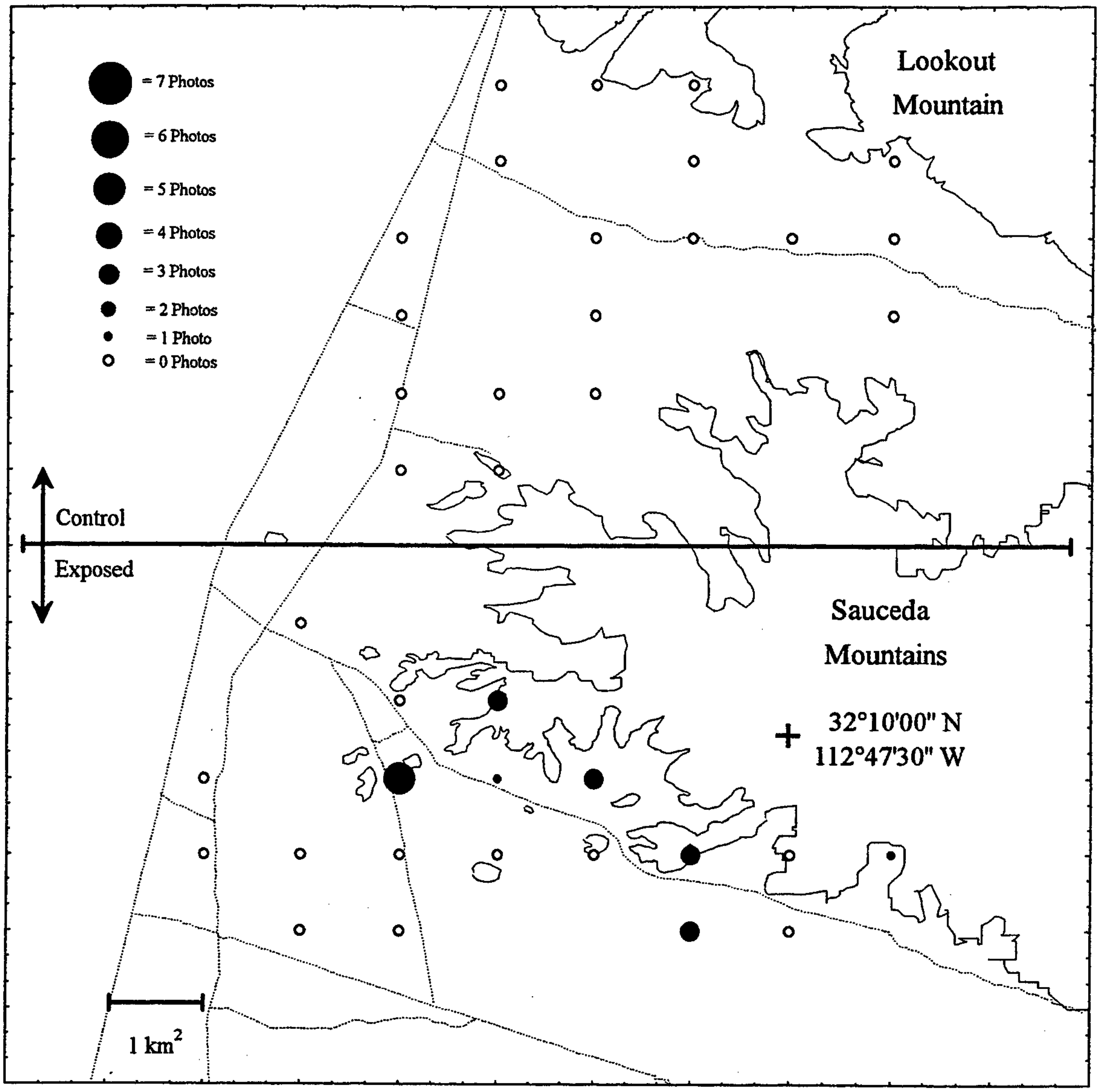


Figure 6-18 Map of the study area showing the number of photographs (represented by dot size) acquired for gray fox during the April 1993 camera station survey.

Of all photos identifiable as an animal in the January 1994 survey (92 of 143 photos), kit foxes were seen in 65%. On the control site 85.9% (73 of 85) were of kit foxes, while on the exposed site only 34.5% (20 of 58) were of kit foxes. The difference was significant ($X^2 = 37.83$, $p \ll 0.001$).

Kit foxes were detected at 72.9% of the camera stations (35 of 48) during the January 1994 survey (Figure 6-20). Significantly more control site stations (23 of 24) detected kit foxes than exposed site stations (12 of 24; $X^2 = 10.55$, $p < 0.0012$). All but one station on the control site detected kit foxes, while only half the stations on the exposed site did. Four stations on the exposed site detected gray

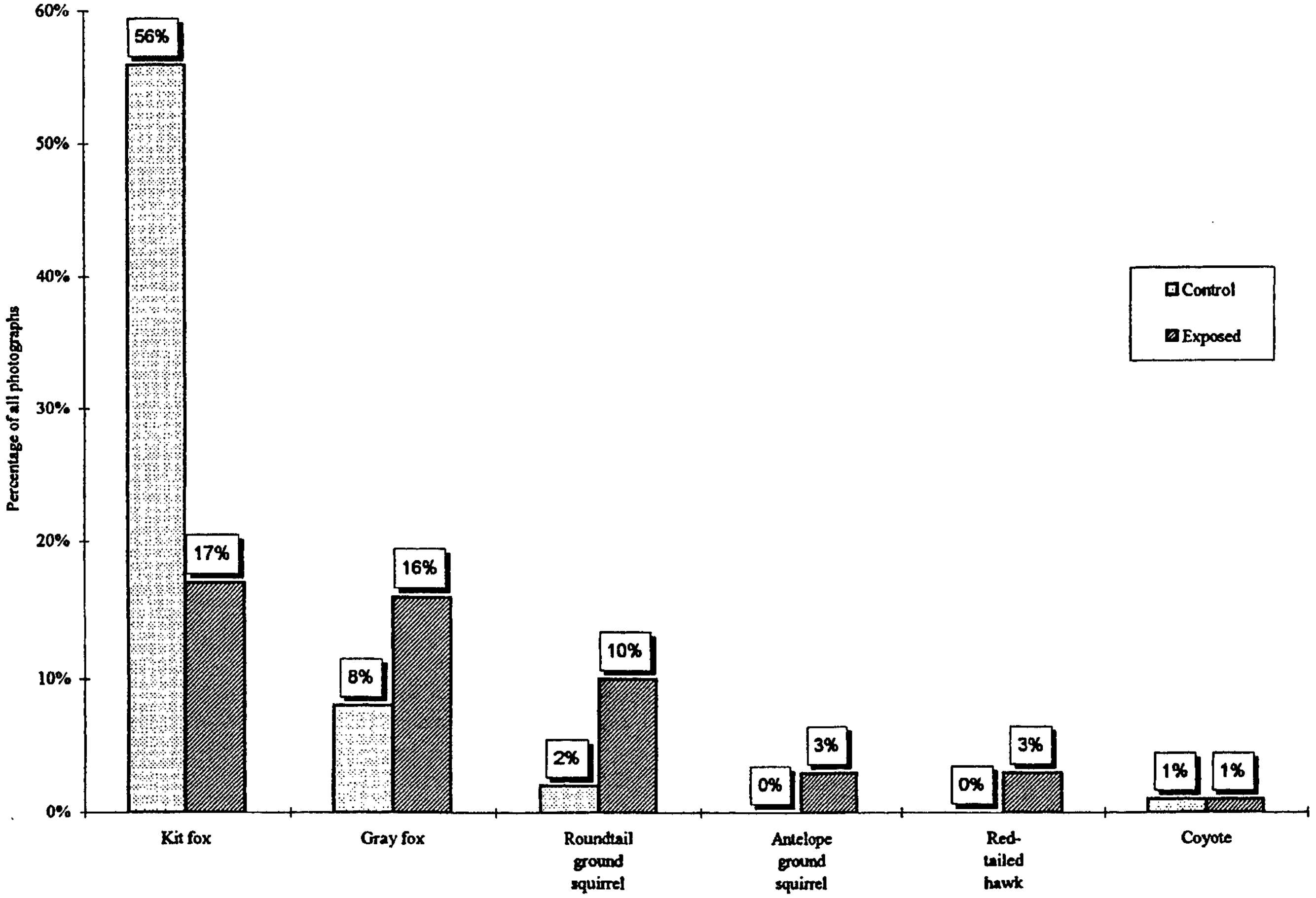


Figure 6-19 *Percent species distribution of photographs taken during the January 1994 camera station survey.*

foxes but not kit foxes. All four of these stations were within 120 meters of a hill (Figure 6-21). Gray foxes may have excluded kit foxes by triggering cameras before kit foxes could locate them. Gray foxes inhabit hilly areas, while kit foxes spend their time on the alluvial flats, and there were more hills in the exposed area. Of the 30 gray fox detections for both sites, 90% were at stations less than 500 m from a hill and 80% were at stations within 200 m of a hill. The placement of camera stations on the control and exposed sites was similar in that both sites had 8 stations within 200 m of a hill. The evidence was consistent with the presence of a population of gray foxes in the hilly regions of the exposed area and another in the Lookout Mountain area in the branch of the Saucedas north of the control area.

In addition to competition with gray foxes, another factor may have biased the estimates of relative density in January 1994. The kit fox population declined rapidly at the beginning of 1994. This decline was seen as a drop in trapping success as well as high mortality among radio-collared individuals.

Table 6-10 Percent success for the January 1994 camera station survey.

	Exposed Site	Control Site	Both Sites
Identifiable Animal Photos[a] / All photos[b]	50.4%	64.9%	58.1%
Kit Fox Photos / All Photos	17.4%	55.7%	37.8%
Kit Fox Photos / Identifiable Animal Photos	34.5%	85.9%	65.0%
Kit Fox Photos / Available for Photo[c]	7.6%	27.7%	17.6%
# of Stations with Kit Fox/ # of Stations[d]	50.0%	95.8%	72.9%
Gray Fox Photos / All Photos	15.7%	7.6%	11.4%
Gray Fox Photos / Identifiable Animal Photos	31.0%	11.8%	19.6%
Gray Fox Photos / Available for Photo	6.8%	3.8%	5.3%
# of Stations with Gray Fox / # of Stations	33.3%	16.7%	25.0%
Kit and Gray Fox Photos / All Photos	33.0%	63.4%	48.8%
Kit and Gray Fox Photos / Identifiable Animal Photos	65.5%	97.6%	83.9%
# of Stations with Kit and Gray Fox / # of Stations	83.3%	100.0%	97.9%

[a] Identifiable Animal Photos—Any exposure with an animal in the photograph.
[b] All Photos—Any exposure not triggered by field personnel.
[c] Available for Photo—Number of nights the camera was armed.
[d] # of Stations—Number of camera stations available.

These mortalities were probably the result of disease based on the capture of a few individuals that were obviously ill. The evidence from trapping surveys was consistent with movement of the contagion from south to north, from exposed area to control area, and the January camera survey may have begun after the disease had already affected the southerly population but before it entered the northern population.

The results of the August 1994 camera survey are presented in Table 6-11. Due to the hot summer temperatures, stations were rebaited late in the day to reduce desiccation of the bait. One camera was stolen on the control site on the 19th day of sampling, so one randomly-selected exposed station was removed from the analysis. Figure 6-22 shows the results, by species, for all photos acquired during the August effort. A total of 45 photographs of animals was collected, 20 on the exposed site and 25 on the control site. No kit foxes were detected on the exposed site, and only two photographs on the control site were of kit foxes. Numbers of gray fox photographs were similar to those collected in January, but were collected from both areas, with six from the exposed site and four from the control.

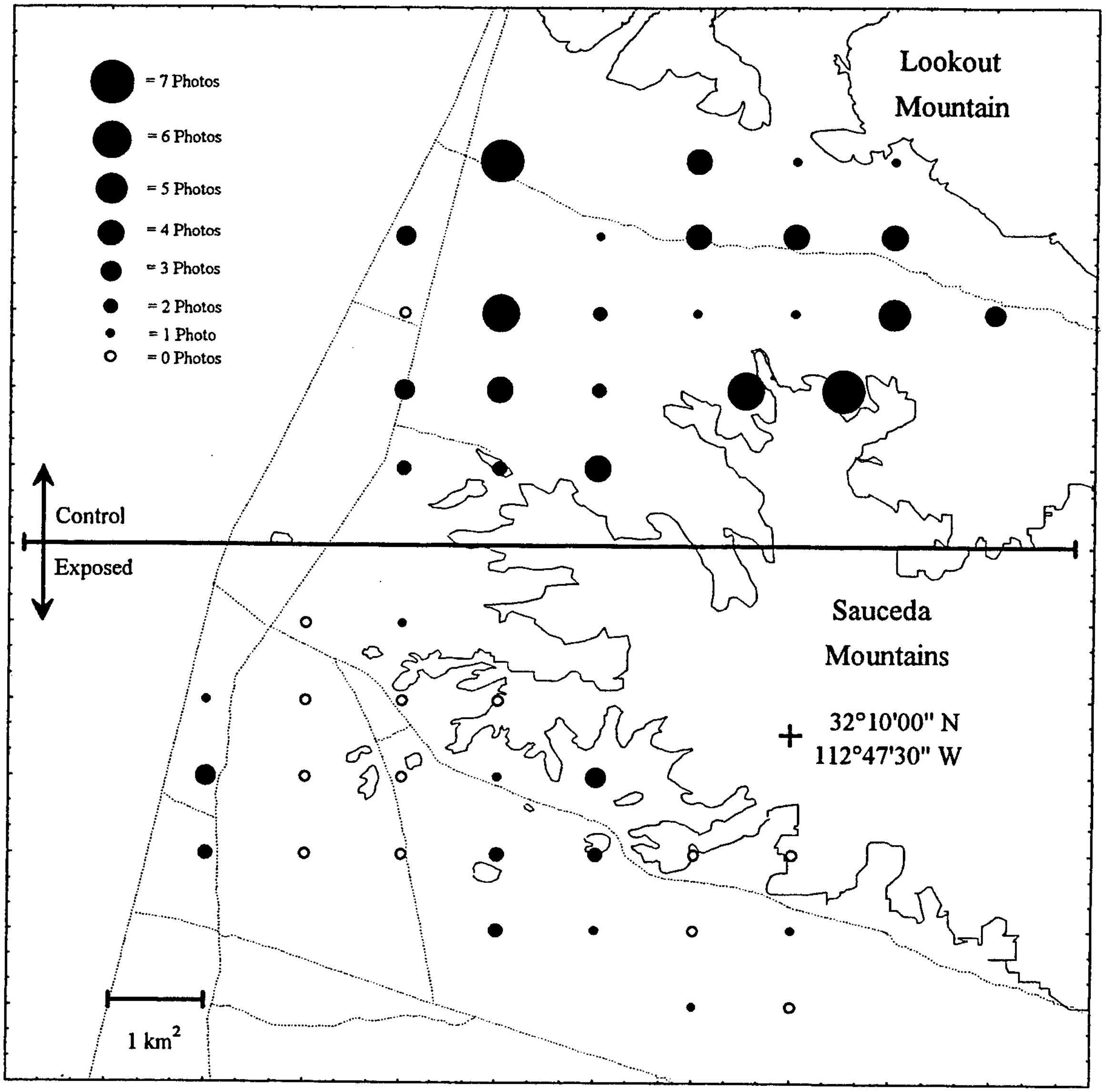


Figure 6-20 Map of the study area showing the number of photographs (represented by dot size) acquired for kit fox during the January 1994 camera station survey.

The remaining 32 photos were of ground squirrels and one coyote.

During the January camera survey, 37.8% of all photos were of kit foxes, compared with only 1.2% in August. The cameras were triggered repeatedly by ground squirrels in August. Fifty-seven percent of all photographs from the exposed site and 52% of all photographs from the control site were triggered during the day, presumably by ground squirrels. Seventy-one percent of all photographs with animals in them from both sites were of ground squirrels. Squirrels were very aggressive about taking the bait. They often crawled into the backpacks of field personnel to get at the bait while the camera station was

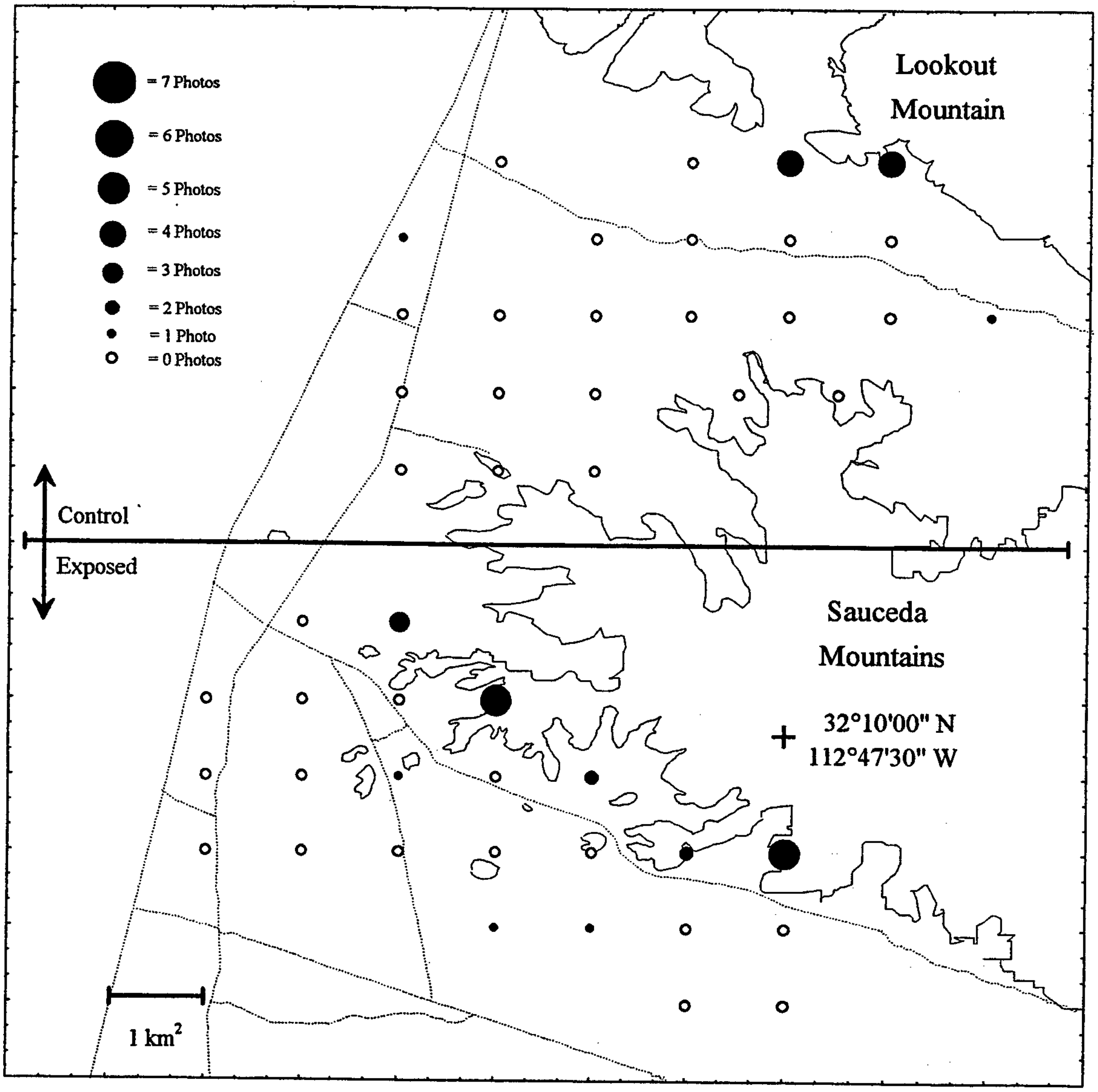


Figure 6-21 Map of the study area showing the number of photographs (represented by dot size) acquired for gray fox during the January 1994 camera station survey.

being serviced. This behavior was not seen during 1992, 1993 or January 1994, and was best explained by the limited rainfall in 1994, which led to reduced availability of fodder and water.

6.2.8 Results of Short-Interval Telemetry During Range 2 Shutdown

Over 300 locations were collected using short-interval telemetry. The median travel rate between successive 10-minute points for all foxes combined was 0.79 km/hr (n = 323). The maximum travel rate recorded was 4.88 km/hr. There was no significant difference between fox travel rates on the exposed (0.77 km/hr, n = 274) and control sites (0.91 km/hr, n = 49; Mann-Whitney U = 5874, p = 0.163).

Table 6-11 Percent success for the August 1994 camera station survey.

	Exposed Site	Control Site	Both Sites
Identifiable Animal Photos[a] / All photos[b]	23.0%	31.6%	27.1%
Kit Fox Photos / All Photos	0.0%	2.5%	1.2%
Kit Fox Photos / Identifiable Animal Photos	0.0%	8.0%	4.4%
Kit Fox Photos / Available for Photo[c]	0.0%	0.8%	0.4%
# of Stations with Kit Fox[d] / # of Stations			
Gray Fox Photos / All Photos	6.9%	5.1%	6.0%
Gray Fox Photos / Identifiable Animal Photos	30.0%	16.0%	22.2%
Gray Fox Photos / Available for Photo	2.5%	1.7%	2.1%
# of Stations with Gray Fox / # of Stations			
Kit and Gray Fox Photos / All Photos	6.9%	7.6%	7.2%
Kit and Gray Fox Photos / Identifiable Animal Photos	30.0%	24.0%	26.7%
# of Stations with Kit and Gray Fox / # of Stations	0.0%	8.7%	4.3%

[a] Identifiable Animal Photos—Any exposure with an animal in the photograph.
[b] All Photos—Any exposure not triggered by field personnel.
[c] Available for Photo—Number of camera "set" nights.
[d] # of Stations—Number of camera stations available.

There was no difference between travel rates before the range was closed for maintenance (0.80 km/hr, n = 32) and during the maintenance period (0.75 km/hr, n = 242; U = 1407, p = 0.271).

One fox was tracked during nighttime sorties prior to range shutdown. The animal traveled at a rate higher than average and with greater variability in its rate of travel (0.94 km/hr, n = 9). This sample is too small to draw any conclusion about the effect, but its behavior was consistent with increased activity during the overflight.

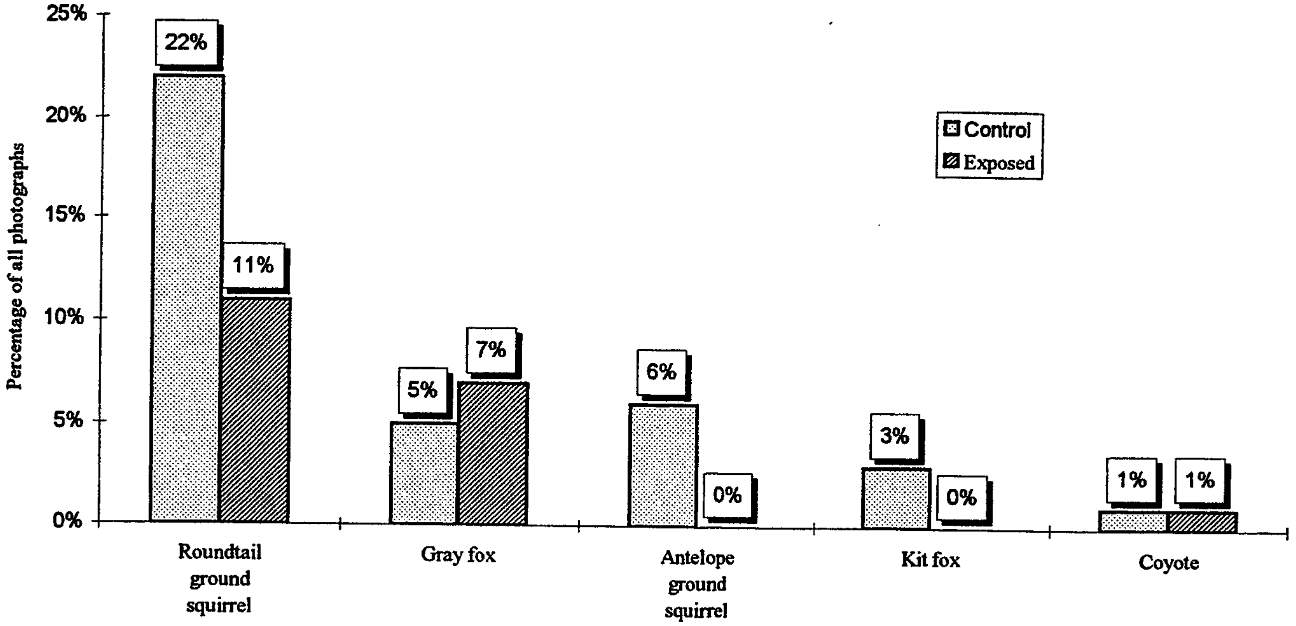


Figure 6-22 Percent species distribution of photographs taken during the August 1994 camera station survey.

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7 DISCUSSION

7.1 ACOUSTIC MONITORING

This study was conducted under the training racetracks of the Barry M. Goldwater Air Force Range (BMGAFR), in an area receiving levels of exposure somewhat above those likely to be encountered under a Military Training Route. It therefore provides a conservative, worst-case scenario for exposure. In order to compare the most intense events in the exposed area with a matched control area, the mean of the 30 loudest ASELs, event rates, and 24HL values were compared. A few of the sampling grid locations had all 30 of their highest events greater than 110 dB: stations lying under the low-altitude entry to the range and under the pop-up point, the point at which aircraft climbed rapidly on their approach to a bombing target. The highest ASEL recorded in this area was 115.5 dB and 10% of the ASELs were in excess of 100 dB. The mean sound level for the loudest 30 events recorded at all stations on the exposed site was 103.4 dB. The mean number of overflights greater than 80 dB MXFA recorded on the exposed site was 30.22 flights/day. The average of the maximum 24HLs for the exposed site was 68.8 dB.

The control site received noise levels at least an order of magnitude lower than the exposed area. No ASEL was in excess of 100 dB. The mean sound level for the loudest 30 events recorded at each site was 87.3 dB. The event rate was 0.99 flights/day > 80 dB MXFA, less than 1/10th of the rate on the exposed area. The average of the maximum 24HLs for the control site was 51.4 dB.

Many of the species on the BMGAFR spend the day in burrows or dens, which might have protected them from aircraft noise. In fact, ASELs in small mammal burrows averaged only 3 dB lower than at 1.2 m above the surface. Significant attenuation was seen only above 1,300 Hz. The small mammals that were the focus of this study, heteromyid rodents, hear well down to 100 Hz, and were therefore likely to hear aircraft sounds well in their burrows. Without knowing how kangaroo rats perceive loudness, it is difficult to predict what levels will be disturbing. However, based on their auditory threshold function, A-weighting should be a robust predictor of effects. In that case, kangaroo rats are likely to be wakened more often and to experience greater irritability than their undisturbed counterparts (Kryter, 1985). Kit fox dens conferred greater protection, with levels attenuated significantly above 500 Hz. Measurements of kit fox hearing indicated that foxes did not hear especially well at low frequencies.

7.2 LABORATORY STUDIES

Hearing of one heteromyid species, the kangaroo rat, was measured *in situ.* Auditory brainstem responses (ABRs) were used to measure the hearing of nine kangaroo rats in each area. A significant

2% difference in latency was uncovered between the two areas. This difference was small and was best explained by individual differences in the small sample of individuals tested (Figure 4-11). A single profoundly deaf individual was encountered on the exposed site in good condition and apparently healthy. The hearing loss was profound enough that it was most likely the result of previous illness or a congenital or genetic defect, because the noise levels on the BMGAFR are not great enough to produce deafness or profound auditory deficit in laboratory animals. Population parameters of small mammals were examined by establishing 1.1-ha live-trap grids on the exposed and control areas. Three of five trapping grids established in the exposed area were attacked by predators, probably kit foxes. Therefore, final comparisons were made between three trapping grids in the control area and two trapping grids in the exposed area (February 1993 to September 1994).

7.3 SMALL MAMMAL SURVEYS

7.3.1 Plant Community Structure

Overall, plant species diversity was found to vary significantly among exposed and control plots, with Grids A-C having greater diversity than Grids D-F, which, in turn had greater diversity than Grids H and I. When only perennial species were considered, Grids D-F had greater diversity than the exposed plots. Judging from the vegetation on the exposed and control sites, it appears that the control grids probably received somewhat higher annual rainfall than the exposed grids. This conclusion was based on the species composition in the vicinity: There were greater numbers of small trees and generally a denser vegetation on the control grids.

Adjacent to the control grids are some small hills that probably cause the precipitation to be enhanced by an orographic lifting effect. The exposed grids are considerably farther from the hills, so they do not receive much orographic effect. Presumably, the better moisture conditions at the control site support a greater diversity of perennial species than at the slightly dryer exposed area.

In good rainfall years, such as 1992, the perennial diversity at all sites was supplemented by the rapid growth of annual species. Exposed Grids A-C had a greater overall species diversity than the control sites in 1992, even though the perennial species diversity was higher on the control sites. Precipitation in 1994 was considerably less than in 1992 and this probably contributed to the lower diversity on Grids H and I because the growth of annual species was greatly reduced at all locations in 1994. This illustrates the importance of variation in annual precipitation on plant species diversity, which undoubtedly affects animal populations.

Rodent species diversity in arid ecosystems has been shown to be correlated with plant diversity and productivity on both a regional and local geographic scale (Beauchamp, 1983; Brown, 1973, 1975; Hafner, 1977; Price, 1978; Rosenzweig and Winakur, 1969; Rosenzweig *et al.*, 1975). However, statistically significant differences in plant community diversity among the study plots in the present study did not translate into consistent differences in either mammal species composition or in patterns of population demography among plots. This is illustrated by the observation that Grids H and I had the lowest overall plant diversity and the lowest perennial plant diversity, yet these plots possessed diverse, abundant rodent communities that closely resembled those found on plots having more diverse plant communities. Despite among-plot differences in plant species diversity, the overall aspect of the vegetation on all plots was very similar: All the plots were typical of the Lower Colorado River Valley subdivision of the Sonoran Desert, with S. barbatus and L. divaricata being the dominant annual and perennial plant species.

7.3.2 General Rodent Community Patterns

Studies of rodents in desert habitats of North America have contributed greatly to advances in population and community ecology, and extensive information is available concerning the ecology of species in the heteromyid genera Dipodomys, Perognathus, and Chaetodipus (Genoways and Brown, 1993). Variation in population density through time and space in these species is primarily a result of interactions between limiting factors in the environment and the life history characteristics of the organisms themselves (Brown and Harney, 1993).

Heteromyid rodent populations are thought to be largely limited by food availability. Fluctuations in population density are driven by temporal changes in plant productivity, which, in turn, is a function of precipitation (Rosenzweig, 1968). Reproduction in most desert rodent species is closely correlated with patterns of precipitation (Beatley, 1969, 1976; Kenagy and Bartholomew, 1985; Reynolds, 1958) and appears to be at least partly cued by the ingestion of substances in new plant growth (Bradley and Mauer, 1971; McClenaghan, 1987; Reichman and Van de Graaff, 1975; Soholt, 1977; Van de Graaff and Balda, 1973).

Local fluctuations in population density are moderated by a suite of life history traits that promote adult survival during periods when conditions are unfavorable at the expense of rapid juvenile recruitment when conditions are more favorable (Brown and Harney, 1993). Heteromyids are relatively long-lived when compared to other small rodents, with individuals living up to five years in the field (Brown and Zeng, 1989; Conley *et al.*, 1977; French *et al.*, 1967; McClenaghan, 1984; Zeng and Brown, 1987). Adult survivorship is enhanced through the use of cached food, torpor, and highly developed predator avoidance strategies (*e.g.*, bipedality). Increased adult survivorship requires a tradeoff with reproduction, and heteromyids display modest reproductive potential when compared to other rodents. Litter sizes in heteromyids are small, ranging from two offspring in some species of Dipodomys to four offspring in some species of Perognathus and Chaetodipus (Jones, 1993). In addition, individuals usually produce only one or two litters in a season (Bradley and Mauer, 1971; Smith and Jorgensen, 1975). Gestation periods are of moderate length (20-30 days; Jones, 1993) and growth and development are relatively slow (Eisenberg, 1963b; Lackey, 1967).

In the present study, patterns of changes in nearly all community and population parameters were strongly coupled to changes in environmental factors. Mean numbers of species on both control and exposed plots fluctuated seasonally, with peaks being observed from spring to late fall followed by lows during the late fall and winter. Decreases in species number and diversity resulted from P. amplus and C. penicillatus entering torpor as ambient temperatures decreased in the fall; these species become inactive and were not trapped on the study plots from October through February. Changes in rodent biomass on control and exposed plots over the course of the study illustrate the strong influence that local patterns of precipitation have on rodent communities. Biomass increased by nearly an order of magnitude over the first two years of the study in response to two years of above-normal precipitation. Peaks in biomass in the fall of 1993 were followed by a decrease through the summer of 1994, as more-or-less average rainfall fell during the winter of 1993-94.

Changes in population parameters for individual rodent species on the study plots generally conformed to those described for heteromyid rodents as a group. Nonetheless, D. merriami, P. amplus and C. penicillatus displayed rather different patterns of changes in abundance over the study. Like biomass, abundance of D. merriami increased greatly over the first two years of the study before declining during 1994. This pattern contrasts with that observed for P. amplus, where peak densities in the summer of 1992 were followed by declining densities over the remainder of the study. Abundance for C. penicillatus was low on all plots and only very small seasonal fluctuations in abundance were observed for this species.

Reproductive activity in all three species was greatest during the spring and summer and was followed by increased rates of recruitment into the populations. In D. merriami, males with scrotal testes were found in all months of the year, while the presence of reproductive females was almost entirely limited to spring and summer. This pattern has previously been reported in other studies of kangaroo rats (McClenaghan, 1984; McClenaghan and Taylor, 1993). Reproductive activity in P. amplus and C. penicillatus was much more constrained temporally for both males and females of those species. Reproductive activity for all three species was greatly reduced in the spring and summer of 1994 in response to reduced rainfall during winter 1993-94.

The effects of reduced reproductive activity during the spring and summer of 1994 can also be seen in seasonal patterns of recruitment in all three species. When among-year heterogeneity in recruitment rates within seasons was assessed, eight of twelve comparisons for spring and summer were statistically significant; the general pattern on both control and exposed plots was toward reduced recruitment in the spring and summer of 1994.

Changes in body weight were similar among all three species, with the largest individuals being present in the spring as breeding season commenced and the smallest in the fall for *P. amplus* and *C. penicillatus*, and in the winter for *D. merriami*. In all three species, males were consistently heavier than females within the same season. Sexual dimorphism in body size has previously been documented for both *D. merriami* and *P. amplus* (Best, 1993).

Patterns of survivorship in this study were complicated by the predator disturbances that eventually led to the discontinuation of trapping on Grids A-C in late 1992. However, when data from the undisturbed control grids are considered, survival rates comparable to those reported for heteromyids in other studies are found. Monthly survival rates for *D. merriami* on control plots were 0.82 for both males and females. This is comparable to the values of 0.85 and 0.87 reported for populations of *D. merriami* and *D. agilis* in southeastern San Diego County, California (McClenaghan, 1984). McClenaghan and Taylor (1993) observed monthly survival rates of between 0.79 and 0.87 for three populations of *D. stephensi* from Riverside County, California. Survival rates on control grids for *P. amplus* were 0.66 for males and 0.63 for females, and 0.62 for male and 0.66 for female *C. penicillatus*. McClenaghan (1983) reported a mean monthly survival rate of 0.79 for *Chaetodipus fallax* in San Diego County, California.

7.3.3 Comparisons of Patterns on Control and Exposed Plots

The primary objective of this study was to determine whether jet overflights have significant, detectable demographic effects on nocturnal rodent communities and their component species populations. Negative effects of jet overflights might manifest themselves at the population level as changes in reproductive activity, lower survivorship, increases in emigration or some combination of these effects. These impacts densities might not appear as differences in animal density due to compensation by density-dependent changes in patterns of survivorship and reproduction.

The design of this study was complicated by perturbations introduced by predator activity on exposed Grids A-C. Nonetheless, comparisons were possible, and some important patterns emerged. Before the predator disturbances, mean species number on control and exposed plots were equivalent, while estimates of total rodent biomass on control Grids D-F were greater than on exposed Grids A-C. However, with the replacement of Grids A-C by Grids H and I, which were better matched to the control sites in vegetation diversity, rodent species number and biomass on the exposed and control plots became statistically indistinguishable. This suggest two points. The correlation between vegetation diversity and small mammal density was not good, suggesting that, on a local level, the plant community characteristics were not a particularly powerful predictor of small mammal community characteristics. Local precipitation and its influence on annual plant productivity was probably a more important predictor.

Rodent population sizes on exposed and control areas were estimated in this study by direct enumeration (Krebs, 1966). Hilborn *et al.* (1977) have shown that the accuracy of density estimates obtained by direct enumeration is a function of the trappability of species being studied. Generally, trappability of 0.70 or more is needed for direct enumeration to be accurate (Hilborn *et al.*, 1977). Overall trappabilities for rodent species on control and exposed grids met this criteria. Trappabilities for D. merriami was 0.84 on control plots and 0.88 on exposed plots. For P. amplus, trappability was 0.68 on control plots and 0.86 on exposed plots. Lastly, trappability was 0.72 on control plots and 0.67 on exposed plots for C. penicillatus. The somewhat lower values for pocket mice reflect the fact that animals known to be alive were often not captured in the spring because they had not yet emerged from hibernation. Likewise, fall trappabilities for these species were reduced as animals began entering hibernation. Overall trappabilities on control and exposed plots were significantly different for D. merriami and P. amplus, with greater trappabilities on the exposed plots. This difference was consistent with the hypothesis that under good conditions, trappabilities were somewhat reduced. This may in turn have been the consequence of saturation of the trapping grids during peak abundance (abundances were higher than anticipated from a perusal of the existing literature).

Population densities for the three most abundant species on the study plots, D. merriami, P. amplus and C. penicillatus, were not different between control and exposed areas (Figures 3-5). As with biomass, significant differences in D. merriami abundance were observed only early in the study when Grids A-C were compared to Grids D-F, almost certainly the result of differences in vegetation diversity. No significant differences between control and exposed densities were observed over the last 20 months of the study. Similarly, no significant differences in abundance between control and exposed plots were seen for either P. amplus or C. penicillatus over the last 18 months of the study. This is consistent with the one report of small mammal densities near an airfield as compared with nearby unexposed areas (Chesser *et al.* 1975). Absolute density does not appear to be affected by aircraft noise.

When proportions of animals in breeding condition on control and exposed plots were compared, the data failed to support the hypothesis that jet noise adversely influenced reproduction in rodent populations. While significant heterogeneity in reproductive activity within seasons was observed for all three common species, there was no consistent trend suggesting lowered reproduction on exposed plots. For

D. merriami, there were seven significant comparisons, but in three of those comparisons, levels of reproductive activity on exposed plots were significantly greater than those on control plots. This finding would not be expected if jet noise were adversely affecting reproduction, but it would be consistent with a density-dependent response to increased mortality.

For P. amplus, there was a single comparison (spring 1993) with a higher proportion of males in reproductive condition on control grids than on exposed grids. Likewise, a single comparison (males in the spring of 1994) indicated greater reproductive activity on control plots than on exposed plots for C. penicillatus. It is significant that none of the comparisons in which reproduction was greater on the control plot was a comparison involving females. Given the high energetic investment that female mammals make in reproduction (*e.g.*, gestation and lactation) compared to males, the effects of adverse environmental conditions on reproduction should be seen in females before they are seen in males. That the reverse was seen in the present study suggests that a factor (or factors) other than differences in sound regimes on the two groups of plots was responsible for differences in reproductive activity in all three species.

Breeding activity was assessed on the basis of external characteristics (*e.g.*, size of mammae) in this study. While these data describe temporal patterns in the intensity of reproductive activity on the study plots, they are not accurate estimators of the rates at which new individuals are added to populations by reproduction. That is to say, they do not necessarily reflect reproductive rates. Data measuring reproductive rates would have to come from an examination of differences in litter sizes. Note that these measurements are difficult to obtain in populations of small fossorial mammals without undue levels of disturbance (*e.g.*, opening burrows). Thus, whether reproductive rates differ on exposed and control plots awaits further investigation, perhaps with an optical device that can be inserted in burrows.

Recruitment accounted for the young added to the population during the late spring and late summer. When seasonal rates of recruitment for the three species were considered, there was a consistent trend towards greater recruitment on exposed plots than on control plots. Recruitment was significantly greater on exposed plots in six out of ten seasons for D. merriami, three out of ten seasons for P. amplus, and for two out of seven seasons for C. penicillatus; only in a single comparison (C. penicillatus in summer 1994) was recruitment on control plots significantly greater than recruitment on exposed plots.

Several factors might account for the pattern of higher recruitment on exposed plots. Greater recruitment might be expected on exposed plots if these plots had higher reproductive rates than control plots. Also, higher recruitment rates might be expected on exposed plots if they typically had greater rates of population turnover: for example, higher rates of immigration to offset higher losses due to emigration and/or mortality.

Body weight did not seem to be influenced by the presence or absence of jet noise in the three most common rodents species. While body weights varied significantly over time in these species, the repeated measures ANOVA indicated that mean body weights for exposed and control plots were not statistically different for any of the species examined. This indicates that neither condition nor growth was affected over the course of the study. These results are consistent with laboratory work suggesting that rodent growth is not affected by noise until much higher exposure levels are reached (Borg, 1981; Gamble, 1982).

There are several lines of evidence suggesting that the rates at which individuals were lost from populations were greater on exposed plots than on control plots. First, there was a consistent pattern of reduced survival rates on exposed plots for both males and females in two of the three species examined. In D. merriami, overall monthly survival rates for males and females on exposed plots (0.724 and 0.745, respectively) were significantly lower than those for males and females on control plots (0.822 and 0.825, respectively). This difference amounted to around 12% of the normal (control) condition. Similarly, overall monthly survival for exposed-plot males (0.499) and females (0.488) were significantly lower than for control-plot males (0.658) and females (0.630) in P. amplus, by around 30%. Survival rates for both sexes in D. merriami and P. amplus on exposed plots were still statistically lower than their counterparts on control grids after the data from the predator-disturbed plots were removed from the analysis.

In support of this contention, an examination of the life span data indicates a trend in all three species for individuals on exposed plots to have shorter life spans in the trappable population. These differences were statistically significant for D. merriami and P. amplus. These shorter life spans probably account for the reduced monthly survival rates observed in D. merriami and P. amplus on exposed plots.

The mild increase in recruitment observed in the exposed areas could have balanced greater losses, leading to comparable densities. Several plausible explanations are suggested for the observed differences between control and exposed areas in recruitment, loss rates, and life spans. The most obvious of these explanations is that jet noise on exposed plots resulted in lowered survival rates and life spans for D. merriami and P. amplus. As attractive as this hypothesis might be, other factors could have explained some or all of the differences. In designing this study, it was hoped that the only significant environmental difference between the control and exposed areas would be the presence/absence of jet noise. However, ecological systems are very complex, and control of all relevant experimental variables would have been impossible. Other, more subtle ecological differences could have existed between control and exposed areas that influenced differences in survival rates and longevity. In particular, differences in available resources were probable based on the vegetation surveys conducted, which indicated that available rainfall was probably greater on the plots in the control area.

The importance of resource competition in structuring desert rodent communities is well known, and interspecific competition in such communities has been widely studied by mammalian ecologists (see Brown and Harney, 1993, for a review). At the population level, intra- and interspecific competition for resources undoubtedly affects survival rates. Whether resource availability and the intensity of competition were the same on control and exposed plots during this study is not known. In addition, survival rates for rodent populations are obviously influenced by levels of predation, which, in turn, are a function of predator densities. Densities of predators could also have been different, for example, because the surveys for carnivores did not account for densities of snakes.

A better way to determine whether aircraft noise was the relevant factor would have been to alter noise exposure in both areas, exposing the control site and leaving the exposed site free of overflights. A partial experiment of this sort was conducted in July and early August 1994. Range 2 was shut down during a six week period. The duration was too short to see population-level effects on small mammals, particularly because conditions were poor and rodent densities were already declining significantly. Longer alterations in flight patterns or playback experiments would provide a better test.

If the effects observed are assumed to be the result of aircraft noise exposure, the consequences to rodent communities and their component species populations were small in magnitude. While there was a statistically significant difference in survival rates and life spans between exposed and control plots for D. merriami and P. amplus and the difference might be attributable to jet noise, the biological significance of these differences was unclear because these species compensated for lower survivorship by having higher recruitment rates in the exposed area. All three species on control and exposed plots were indistinguishable based on density, proportions of reproductively active individuals, and mean body weights. Likewise, species diversity and rodent biomass on communities exposed to jet flyovers were not different from those seen for control communities.

The mild increase in recruitment observed in the exposed areas could have balanced lower survival and greater losses, leading to comparable densities in the two areas. Several plausible explanations are suggested for the differences between control and exposed areas in recruitment, loss rates, and life spans. An obvious explanation was the presence of jet noise, but other factors could have explained some or all of the differences. Vegetation surveys indicated that available rainfall was probably greater on the plots in the control area, hence food may have been somewhat more available. The differences in vegetation between the two areas were greatest during good years, when annual vegetation was abundant, and this is when survivorship in the control area was highest. The corresponding increase in recruitment in the exposed area was probably a density-dependent response to the lower survival of individuals under slightly poorer conditions. The most parsimonious explanation for the differences in rodent survivorship and recruitment was the difference in the vegetation.

In addition, there may have been differences in predator activity between the two areas. Owls and snakes, which are usually the most important predators of heteromyid rodents, were not censused, but another important predator, the kit fox, was censused throughout the study. Bait-stations equipped with cameras were used to determine relative densities of kit foxes and other canids in the two study areas. In April 1993 and January 1994, camera station surveys showed greater numbers of kit foxes in the control area and larger numbers of gray foxes in the exposed area.

7.4 KIT FOX SURVEYS

Based on trapping surveys, radio tracking and camera station surveys, numbers of kit foxes and home range sizes were similar between the exposed and control areas. However, fox mortality differed between the two areas and was somewhat correlated with home range size. The most interesting mortalities were those that occurred in the winter of 1994. Three lines of evidence suggested that disease contributed to the abrupt decline in fox density in January and February 1994 and that this disease spread from the south, including the exposed area, to the north. First, several diseased animals were trapped in the exposed area during this period, although none had been seen during the previous three years. Second, camera station surveys during January showed much lower numbers of kit foxes. Of all photos identifiable as an animal in January 1994, 85.9% (73 of 85) were of kit foxes, while on the exposed site only 34.5% (20 of 58) were of kit foxes. Thirdly, trapping effort in January found many fewer foxes in the exposed area than in the control.

If the contagion began in the exposed area as opposed to some location further south, one explanation might have been immune suppression caused by increased wakefulness, irritability or other disturbance caused by aircraft noise. This could also be put forward as an explanation for the lower survivorship of small mammals in the exposed area. Immune suppression is not the most parsimonious explanation for the effects, but it merits investigation in the future because it is entirely consistent with the available data and with what is known about the effects of noise from the laboratory.

Although differences were uncovered between kit fox and small mammal populations between the control and exposed areas, none was at odds with the most parsimonious natural explanations. If the effects observed are assumed to be the result of aircraft noise exposure, the consequences to rodents and fox populations were smaller in magnitude than the natural variability observed during the course of the study. While there was a statistically significant difference in survival rates and life spans between exposed and control plots among rodents, species compensated for lower survivorship by having higher recruitment rates in the exposed area. Lower reproductive rate is one of the consequences of noise exposure in humans and laboratory animals (Kryter, 1985; Gambel, 1982), and as animals avoid areas with uncomfortably high levels of noise exposure; therefore, the marginal increase in recruitment in the exposed area is not entirely consistent with expected noise-related effects. The rodent species examined on control and exposed plots were indistinguishable based on density, proportions of reproductively active individuals, mean body weights, species diversity and biomass. Differences did not appear during a stressful year, but during a year of plenty. Therefore, if the differences were the result of aircraft exposure, the long-term effects would be seen not as differences in population density, but as small genetic differences. The consequences of the differences are thus difficult to interpret, even if they are found to be the result of aircraft exposure.

Future studies should focus on observations and experimental manipulations to detect the subtle differences suggested by this study. These should include:

- Measurements to determine whether emigration and reproductive output of kit foxes and their prey are altered by the presence of aircraft;
- An experiment that alters flight patterns to determine whether the natural differences observed could be altered;
- Measurements of physiological factors that might result in increased mortality in both foxes and small mammals, particularly factors that are reliable indicators of significantly-suppressed immune function;
- Measurements of hearing in a large number of individuals, to determine whether auditory effects could be shown at a population level, particularly in a small subset of the population that might have especially sensitive hearing;
- Monitoring of the genetic composition of populations, to determine whether individuals susceptible to noise are selected out. These measurements would have to be preceded by studies to determine the normal variability and drift in undisturbed populations and to determine which genes lead to susceptibility to noise disturbance. Without better evidence for proximate effects of noise, such an effort is probably premature.

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Appendix A. Animal species listed as being present on the Luke Air Force Range. Species seen by observers during the present study are indicated with 'Yes' in the last column. Species known to be present by their spoor or remains are indicated with 'Present'. Bat species were unlikely to be identified in the field and are listed for convenience only.

Key to Codes for Frequency of Occurrence:
C=Common or abundant; LC= Locally common;
U=Uncommon; R=Rare;
H=possibly present; range not well-known.

Key to Codes for Habitat Type:
OW= Open water; DR= Desert riparian
CD= Creosote desertscrub;
MSD= Mixed Sonoran desertscrub.

Key to Seasonal Distribution (lowercase letters):
p=permanent resident; s=summer resident;
w=winter resident; t=transient;
i=irregular; cas=casual visitor; a=accidental visitor;
*=breeding occurs or is suspected to occur.

SPECIES	**Frequency of Occurrence/ Seasonality**	**Preferred Habitat Type**	**Seen by Observer in Study Area ?**
Order Insectivora			
Desert shrew	R	OW, DR	-
Notiosorex crawfordi			
Order Chiroptera			
California leaf-nosed bat	C	OW, MSD	-
Macrotus californicus			
Long-toungued bat	C	OW, DR, MSD	-
Choeronycteris mexicana			
Mexican long-nosed bat	C	OW, DR, MSD	-
Leptonycteris nivalis			
Yuma myotis	LC	OW, MSD	-
Myotis yumanensis			
Cave myotis	LC	OW, DR, MSD	-
Myotis velifer			
Western pipistrelle	C	OW, DR, CD, MSD	-
Pipistrellus hesperus			
Big brown bat	LC	OW, MSD	-
Eptesicus fuscus			

Northern yellow bat **Lasiurus cinereus**	U	DR, MSD	-
Spotted bat **Euderma maculata**	R	DR, MSD	-
Townsend's big-eared bat **Plecotus townsendii**	R	OW, DR, MSD	-
Pallid bat **Antrozous pallidus**	LC	OW, DR, MSD	-
Brazilian free-tailed bat **Tadarida brasiliensis**	R	OW, MSD	-
Big free-tailed bat **Tadarida femorosacca**	H	OW, MSD	-
Big free-tailed bat **Tadarida macrotis**	H	OW, MSD	-
Western mastiff bat **Eumpos perotis**	H	OW, MSD	-
Underwood mastiff bat **Eumops underwoodi**	H	OW, MSD	-
Order Lagomorpha			
Antelope jackrabbit **Lepus alleni**	R	DR, CD, MSD	-
Black tailed jackrabbit **Lepus californicus**	C	DR, CD, MSD	Yes
Desert cottontail **Sylvilagus audubonii**	C	OW, DR, CD	Yes
Order Rodentia			
Rock squirrel **Spermophilus variegatus**	R	MSD	Yes
Round-tailed ground squirrel **Spermophilus tereticaudus**	C	CD	Yes
Harris' antelope squirrel **Ammospermophilus harrisii**	LC	MSD	Yes
Botta's pocket gopher **Thomomys bottae**	LC	OW, DR, CD	Yes

Little pocket mouse **Perognathus longimembris**	LC	CD, MSD	Yes
Arizona pocket mouse **Perognathus amplus**	LC	CD, MSD	Yes
Desert pocket mouse **Chaetodipus penicillatus**	C	CD, MSD	Yes
Rock pocket mouse **Perognathus intermedius**	C	MSD	-
Bailey's pocket mouse **Perognathus baileyi**	LC	CD, MSD	-
Banner-tailed kangaroo rat **Dipodomys spectabilis**	H	CD, MSD	Yes
Desert kangaroo rat **Dipodomys deserti**	LC	CD	Yes
Merriam's kangaroo rat **Dipodomys merriami**	C	CD, MSD	Yes
Western harvest mouse **Reithrodonomys megalotis**	R	OW, DR, CD	-
Cactus mouse **Peromyscus eremicus**	C	OW, DR, CD, MSD	Yes
Canyon mouse **Peromyscus crinitus**	LC	MSD	-
Deer mouse **Peromyscus maniculatus**	R	OW, DR, CD, MSD	-
Southern grasshopper mouse **Onychomys torridus**	U	CD, MSD	Yes
White-throated woodrat **Neotoma albigula**	C	OW, DR, MSD	Yes
Arizona desert woodrat **Neotoma devia**	C	CD, MSD	-
Porcupine **Erethizon dorsatum**	H	DR, MSD	-
Order Carnivora			
Coyote **Canis latrans**	C	OW, DR, CD, MSD	Yes
Kit fox **Vulpes macrotis**	C	DR, CD, MSD	Yes

Gray fox. **Urocyon cinereoargenteus**	LC	OW, DR, CD, MSD	Yes
Family Procyonidae			
Raccoon **Procyon lotor**	H	OW, DR, MSD	-
Coati **Nasua nasua**	R	OW, DR, MSD	-
Ringtail **Bassariscus astutus**	LC	OW, DR, MSD	Yes
Family Mustelidae			
Badger **Taxidea taxus**	U	DR, CD	Yes
Western Spotted Skunk **Spilogale gracilis**	U	OW, DR	-
Striped Skunk **Mephitis mephitis**	LC	OW, DR	-
Hooded Skunk Mephitis macroura	U	OW, DR	-
Hognose Skunk **Conepatus leuconotus**	H	OW, DR, MSD	-
Family Felidae			
Mountain lion **Felis concolor**	R	OW, DR, CD, MSD	Present
Bobcat **Felis rufus**	C	OW, DR, CD, MSD	Yes
Family Equidae			
Burro **Equus asinus**	U	OW, DR, CD, MSD	-
Family Tayassuidae			
Collared peccary (javelina) **Tayassu tajacu**	U	OW, DR, CD, MSD	Yes

Family Cervidae			
Mule deer	C	OW, DR, CD, MSD	Yes
Odocoileus hemionus			
White-tailed deer	U	OW, DR, CD, MSD	-
Odocoileus virginianus			
Family Bovidae			
Desert bighorn sheep	U	OW, DR, MSD	Yes
Ovis canadensis mescicana			
BIRDS			
Order Podicipediformes			
Pied-billed grebe	Rt	OW	-
Eared grebe	Rt	OW	-
Order Pelicaniformes			
American white pelican	a		-
Brown pelican	a		-
Magnificent frigatebird	a		-
Order Ciconiiformes			
Great blue heron	Rt	OW	-
Snowy egret	Rt	OW	-
Cattle egret	Ut	OW, CD	-
Green-backed heron	Rt	OW	-
Black-crowned night heron	Rt	OW	-
Wood stork	a		-
Order Anseriformes			
Snow goose	a		-
Canada goose	cas		-
Green-winged teal	Uw	OW	-
Mallard	Rw	OW	-
Northern pintail	Rt	OW	-
Cinnamon teal	Ut	OW	Yes
Northern shoveler	Rw	OW	-

Gadwall	Rw	OW	-
American widgeon	Rt	OW	-
Ring-necked duck	Rw	OW	-
Redhead	a		-
Lesser scaup	Rt	OW	-
Common goldeneye	cas		-
Bufflehead	Rt	OW	-
Common merganser	cas		-
Red-breasted merganser	a		-
Ruddy duck	Rt	OW	-
Order Falconiformes			
*Turkey Vulture	Cp	DR, CD	Yes
Black vulture	cas		-
Osprey	cas		Yes
Bald eagle	a		-
Northern harrier	Uw	DR, CD, MSD	Yes
Sharp-shinned hawk	Ut, Uw	DR, MSD	-
Cooper's hawk	Uw	DR, CD, MSD	-
Harris's hawk	Rp	DR, MSD	-
Swainson's hawk	Rt	DR, CD, MSD	Yes
*Red-tailed hawk	Cp	DR, CD, MSD	Yes
Ferruginous hawk	Uw	DR, CD, MSD	-
*Golden eagle	Up	DR, CD, MSD	Yes
Crested caracara	a		-
*American Kestrel	Cp	DR, CD, MSD	Yes
Merlin	Rt, Rw	DR, CD, MSD	-
Peregrine falcon	cas		-
*Prairie falcon	Up	DR, CD, MSD	Yes
Order Galliformes			
*Gambel's Quail	Cp	DR, CD, MSD	Yes
Order Gruiformes			
Virginia rail	cas		-
Sora	Rt	OW, DR	-

Order Charadriiformes			
*Killdeer	Ut, Rw	OW, DR	-
Black-necked stilt	Ut	OW	-
American avocet	Rt	OW	-
Greater yellowlegs	Rt	OW	-
Solitary sandpiper	Rt	OW	-
Willet	cas		Yes
Spotted sandpiper	Ut, Rw	OW	-
Long-billed curlew	cas		-
Western sandpiper	Ut	OW	-
Least sandpiper	Ut	OW	-
Baird's sandpiper	Rt	OW	-
Pectoral sandpiper	a		-
Common snipe	Rt	OW	-
Long-billed dowitcher	cas		-
Wilson's phalarope	Ut	OW	-
Red-necked phalarope	cas		-
Red phalarope	cas		-
Ring-billed gull	cas		-
Black tern	cas		-
Order Columbiformes			
Band-tailed pigeon	cas		-
Inca dove	Rt	human settlements	-
Common ground-dove	Rs	DR, CD, MSD	Yes
*Rock Dove	Cp	introduced	-
*White-winged Dove	Cs	DR, CD, MSD	Yes
*Mourning Dove	Cp	DR, CD, MSD	Yes
Order Cuculiformes			
*Greater roadrunner	Up	DR, CD, MSD	Yes
Order Strigiformes			
*Common barn owl	Rp	DR, CD, MSD	Yes
Flammulated owl	a		-
*Western screech owl	Up	DR, MSD	-
Ferruginous pygmy-owl	Rp	DR, MSD	-

Burrowing owl	Rt	CD	-
Long-eared owl	Rw	DR, MSD	-
Short-eared owl	Rw	DR, CD, MSD	-
Northern saw-whet owl	a		-
*Great Horned Owl	Cr	DR, CD, MSD	Yes
*Elf Owl	Cs, Rw	DR, MSD	-
Order Caprimulgiformes			
*Lesser nighthawk	Us, Rw	OW, DR, CD, MSD	Yes
*Common poorwill	Us, Rw	OW, DR, CD	Yes
Order Apodiformes			
Vaux's swift	Ut	DR, CD, MSD	-
*White-throated swift	Us, Sw	OW, DR, CD, MSD	Yes
*Black-chinned hummingbird	Ut	DR, CD, MSD	-
Rufous hummingbird	Ut	DR, MSD	-
Allen's hummingbird	cas		-
*Anna's hummingbird	Rt, Rw	DR, MSD	-
Calliope hummingbird	Ct, Uw	DR, MSD	-
*Costa's hummingbird	Ct, Uw	DR, CD, MSD	Yes
Order Coraciiformes			
Belted kingfisher	Rt	OW, DR	Yes
Order Piciformes			
Lewis' woodpecker	a		-
*Gila woodpecker	Cp	DR, MSD	Yes
Yellow-bellied sapsucker	a		-
Red-naped sapsucker	Rt	DR, MSD	-
*Ladder-backed woodpecker	Cp	DR, CD, MSD	Yes
Red-shafted northern flicker	Cw	DR, CD, MSD	Yes
*Gilded northern flicker	Cp	DR, CD, MSD	-
ORDER PASSERIFORMES			
Family Tyrannidae			
Olive-sided flycatcher	Rt	DR, MSD	-
Western wood-pewee	Ut	DR, MSD	-
Willow flycatcher	Ut	DR	-

Least flycatcher	a		-
Hammond's flycatcher	Rt	DR	-
Dusky flycatcher	Rt	DR	-
Gray flycatcher	Ct, Rw	DR, CD, MSD	-
Western flycatcher	Ut	DR, MSD	-
Black phoebe	Rt, Rw	OW, DR	-
*Say's phoebe	Rs, Cw	DR, CD, MSD	Yes
Vermilion flycatcher	Ut	OW, DR	Yes
*Ash-throated flycatcher	Cs, Uw	DR, CD, MSD	Yes
*Brown-crested flycatcher	Us	MSD	-
Tropical kingbird	cas		-
*Western kingbird	Us	DR, CD, MSD	Yes
Family Alaudidae			
*Horned lark	Ur	CD	Yes
Family Hirudinidae			
Tree swallow	Ut	OW, DR, CD, MSD	-
Violet-green swallow	Ut	OW, DR, CD, MSD	-
*Northern rough-winged swallow	Ut, Rs	OW, DR, CD, MSD	-
Bank swallow	Rt	OW, DR, CD, MSD	-
Cliff swallow	Ut	OW, DR, CD, MSD	Yes
Barn swallow	Ut	OW, DR, CD, MSD	Yes
Family Corvidae			
*Common Raven	Cp	OW, DR, CD, MSD	Yes
Steller's jay	Ri	OW, DR, CD, MSD	-
Scrub jay	Ri	OW, DR, CD, MSD	-
Pinyon jay	a		-
Clark's nutcracker	a		-
Family Remizidae			
Verdin	Cp	DR, CD, MSD	Yes
Family Sittidae			
Red-breasted nuthatch	cas		-

Family Troglodytidae			
*Cactus wren	Cp	DR, CD, MSD	Yes
*Rock wren	Cp	DR, CD, MSD	Yes
*Canyon wren	Cp	DR, MSD	Yes
Bewick's wren	Uw	DR, MSD	-
House wren	Ut, Uw	DR, MSD	-
Family Muscicapidae			
Golden-crowned kinglet	a		-
Ruby-crowned kinglet	Cw, Ct	DR, MSD	-
Blue-gray gnatcatcher	Rw	DR	-
*Black-tailed gnatcatcher	Cp	DR, CD, MSD	Yes
Western bluebird	Ri	DR, CD, MSD	Yes
Mountain bluebird	Uw	DR, CD, MSD	Yes
Townsend's solitaire	Uw	DR, CD, MSD	-
Swainson's thrush	Ut	DR	-
Hermit thrush	Um, Rw	DR	-
American robin	Uw	DR, CD, MSD	Yes
Family Mimidae			
*Northern mockingbird	Up	DR, CD, MSD	Yes
Sage thrasher	Um, Rw	DR, CD, MSD	Yes
*Bendire's thrasher	Rp	DR, CD	-
*Curve-billed thrasher	Cp	DR, CD, MSD	-
*Crissal thrasher	Up	DR	-
Le Conte's thrasher	up	CD, MSD	-
Family Motacillidae			
Water pipit	Rt	OW	-
Sprague's pipit	cas		-
Family Bombycillidae			
Cedar waxwing	cas		-
Ptilogonatidae			
*Phainopepla	Cp	DR, CD, MSD	Yes

Family Laniidae			
*Loggerhead shrike	Us, Ow	DR, CD, MSD	Yes
Family Sturnidae			
*European starling	Up	introduced	Yes
Family Vireonidae			
*Bell's vireo	Cs	DR	-
Gray vireo	Uw	DR, MSD	-
Solitary vireo	Ct	DR, MSD	-
Yellow-throated vireo	a		-
Warbling vireo	Ct	DR, MSD	-
Family Emberizidae			
Orange-crowned warbler	Rw, Ct	DR, CD, MSD	Yes
Nashville warbler	Ct	DR, CD, MSD	-
*Lucy's warbler	Us	DR, MSD	-
*Yellow warbler	Ct	DR, CD, MSD	Yes
Yellow-rumped warbler	At, Cw	DR, CD, MSD	-
Black-throated gray warbler	Ct, Rw	DR, CD, MSD	-
Townsend's warbler	Ut	DR, MSD	-
Hermit warbler	Ut	DR, MSD	-
Blackpoll warbler	a		-
MacGillivray's warbler	Ct	DR	-
Common yellowthroat	Rt	OW, DR, MSD	-
Wilson's warbler	Ct	OW, DR, CD, MSD	Yes
Yellow-breasted chat	Rt	OW, DR	-
Summer tanager	cas		-
Western tanager	Ct	OW, DR, CD, MSD	-
Northern cardinal	a		-
*Pyrrhuloxia	Up	DR	-
Black-headed grosbeak	Ct	DR, MSD	-
*Blue grosbeak	Rt, Rs	DR	-
Lazuli bunting	Ut	DR, MSD	-
Green-tailed towhee	Ct, Uw	DR, MSD	-
Rufous-sided towhee	Uw	DR	-
*Brown towhee	Up	DR, MSD	-
Cassin's sparrow	Rs, Rw	DR, MSD	-

Chipping sparrow	Ut, Rw	DR, CD, MSD	-
Brewer's sparrow	Cw	DR, CD, MSD	-
Black-chinned sparrow	Rt	DR, MSD	-
Vesper sparrow	Uw	DR, CD	-
*Lark sparrow	Ut, Rw	DR, MSD	Yes
Black-throated sparrow	Cp	DR, CD, MSD	Yes
Sage sparrow	Uw	CD, MSD	-
Lark bunting	Ow	DR, CD, MSD	Yes
Savannah sparrow	Uw	DR, CD, MSD	-
Grasshopper sparrow	Rw	DR, CD	-
Fox sparrow	Rw	DR	-
Song sparrow	cas		-
Lincoln's sparrow	Ut, Rw	DR, MSD	-
White-crowned sparrow	Cw	DR, CD, MSD	-
Slate-colored junco	a		-
Oregon junco	Uw	DR, CD, MSD	-
Gray-headed junco	Uw	DR, CD, MSD	-
Chestnut-collared longspur	cas		-
Red-winged blackbird	Rt	OW, DR	-
Eastern meadowlark	a		-
*Western meadowlark	Cw	CD, MSD	Yes
Yellow-headed blackbird	Rt	OW, DR	-
Rusty blackbird	a		-
Brewer's blackbird	Ut	OW, DR	Yes
*Bronzed cowbird	Us	DR	-
*Brown-headed cowbird	Ct, Us	DR, MSD	-
*Hooded oriole	Us	DR	Yes
*Northern oriole	Ct	DR	-
*Scott's oriole	Us	MSD	Yes
Family Fringillidae:			
Cassin's finch	cas		-
*House finch	Cp	DR, CD, MSD	Yes
Pine siskin	Rt	DR, MSD	-
*Lesser goldfinch	Rs, Uw	DR, MSD	-
Lawrence's goldfinch	Ri	DR, MSD	-
Evening grosbeak	cas		-

Family Passeridae			
* House sparrow	Cp	introduced	Yes
REPTILES AND AMPHIBIANS			
Order Anura:			
Couch's spadefoot toad **Scaphiopus couchi**	LC	OW, DR	-
Sonoran desert toad **Bufo alvarius**	C	OW, DR	Yes
Great Plains Toad **Bufo cognatus**	U	OW, DR	-
Red-spotted toad **Bufo punctatus**	C	OW, DR	Yes
Sonoran green toad **Bufo retiformes**	U	OW, DR	-
Canyon treefrog **Hyla arenicolor**	H	OW, DR	-
Northern casque-headed frog **Pternohyla fodiens**	H	OW, DR	-
Great-plains narrow-mouthed toad **Gastrophryne olivacea**	H	OW, DR	-
Order Chelonia:			
Desert tortoise **Gopherus agasizzii**	U	DR, CD, MSD	Yes
Order Sauria			
Western banded gecko **Coleonyx variegatus**	C	DR, CD, MSD	Yes
Desert iguana **Dipsosaurus dorsalis**	C	DR, CD, MSD	Yes
Common chuckwalla **Sauromalus obesus**	C	CD, MSD	Yes
Zebra-tailed lizard **Callisaurus draconoides**	C	CD, MSD	Yes
Colorado fringed-toed lizard **Uma notata**	LC	SAND DUNES	-

	C	DR, MSD	Yes
Common collared lizard **Crotaphytus collaris**			
Long-nosed leopard lizard **Gambelia wislizenii**	U	DR, MSD	Yes
Desert spiny lizard **Sceloporus magister**	C	DR, CD, MSD	Yes
Side-blotched lizard **Uta stansburiana**	C	DR, CD, MSD	Yes
Long-tailed brush lizard **Urosaurus graciosus**	C	CD	Yes
Tree lizard **Urosaurus ornatus**	C	DR	Yes
Desert horned lizard **Phrynosoma platyrhinos**	C	DR, CD	Yes
Flat-tailed horned lizard **Phrynosoma mcalli**	R	Yuma dunes	-
Regal horned lizard **Phrynosoma solare**	H	DR, MSD	-
Desert night lizard **Xantusis vigilis**	R	DR, MSD	-
Canyon spotted whiptail **Cnemidophorus burti**	H	DR, MSD	-
Western whiptail **Cnemidophorus tigris**	C	DR, CD, MSD	Yes
Gila monster **Heloderma suspectum**	U	DR, CD, MSD	Yes
			-
Order Serpentes:			
Western blind snake **Leptotyphlops humilis**	H	OW, DR, CD	-
Rosy boa **Lichanura trivirgata**	U	OW, DR, CD, MSD	Yes
Spotted leaf-nosed snake **Phyllorhynchus decurtatus**	LC	DR, CD	Yes
Saddled leaf-nosed snake **Phyllorhynchus brownii**	H	CD, MSD	-

Coachwhip **Masticophis flagellum**	C	DR, CD, MSD	Yes
Sonoran whipsnake **Masticophis bilineatus**	U	OW, DR, CD, MSD	Yes
Western patch-nosed snake **Salvadora hexalepis**	C	CD. MSD	Yes
Glossy snake **Arizona elegans**	C	DR, CD, MSD	-
Gopher snake **Pituophis melanoleucus**	C	OW, DR, CD, MSD	Yes
Common kingsnake **Lempropeltis getulus**	U	OW, DR, CD, MSD	-
Long-nosed snake **Rhinocheilus lecontei**	C	DR, CD, MSD	Yes
Black-necked garter snake **Thamnophis cyrtopsis**	H	OW, DR, CD, MSD	-
Checkered garter snake **Thamnophis marcianus**	H	OW, DR, CD, MSD	-
Ground snake **Sonora semiannulata**	H	DR, CD	-
Western shovel-nosed snake **Chionactis occipitalis**	LC	DR, CD, MSD	-
Sonoran shovel-nosed snake **Chionactis palarostris**	H	CD, MSD	-
Banded sand snake **Chilomeniscus cinctus**	U	DR, CD, MSD	-
Southwestern black-headed snake **Tantilla hobartsmithii**	H	DR, CD, MSD	-
Lyre snake **Trimorphodon biscutatus**	U	CD, MSD	-
Night snake **Hypsiglena torquata**	C	DR, CD, MSD	-
Western coral snake **Micruroides euryxanthus**	R	DR, CD, MSD	-
Western diamondback rattlesnake **Crotalus atrox**	C	DR, CD, MSD	Yes

Speckled rattlesnake **Crotalus mitchelli**	C	MSD	Yes
Sidewinder **Crotalus cerastes**	C	DR, CD, MSD	Yes
Black-tailed rattlesnake **Crotalus molossus**	U	DR, MSD	-
Tiger rattlesnake **Crotalus tigris**	R	DR, CD, MSD	-
Mojave Rattlesnake **Crotalus scutulatus**	C	DR, CD, MSD	Yes

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Appendix B. Summary of the A-weighting and sound exposure level calibration tests for the Larson-Davis model 820 integrating sound level meter and the Computer Engineering Limited model 493/2 integrating sound level meter.

Computer Engineering Limited 493

Bin No.	1/3 Octave Frequency	A-weight sound level	Measured A-weight	Theoretical A-weight	A-weighted error	1-cycle ASEL	Measured difference from A-weight sound level	Theoretical difference from A-wgt sound level	ASEL error
40	10000	122.2	-2.8	-2.5	-0.3	69.3	-52.9	-38.9	-14.0
39	8000	123.6	-1.4	-1.1	-0.3	73.6	-50.0	-38.4	-11.6
38	6300	124.6	-0.4	-0.1	-0.3	77.4	-47.2	-37.7	-9.5
37	5000	125.4	0.4	0.5	-0.1	80.1	-45.2	-37.0	-8.2
36	4000	125.9	0.9	1.0	-0.1	88.7	-37.2	-36.1	-1.1
35	3150	126.2	1.2	1.2	0.0	90.1	-36.1	-35.2	-0.9
34	2500	126.3	1.3	1.3	0.0	91.3	-35.0	-34.3	-0.7
33	2000	126.2	1.2	1.2	0.0	92.3	-33.9	-33.4	-0.5
32	1600	126.0	1.0	1.0	0.0	92.9	-33.1	-32.6	-0.5
31	1250	125.6	0.6	0.6	0.0	93.6	-32.0	-31.7	-0.3
30	1000	125.0	0.0	0.0	0.0	94.0	-31.0	-30.7	-0.3
29	800	124.1	-0.9	-0.8	-0.1	94.1	-30.0	-29.8	-0.2
28	630	123.0	-2.0	-1.9	-0.1	93.9	-29.1	-28.8	-0.3
27	500	121.7	-3.3	-3.2	-0.1	93.7	-28.0	-27.7	-0.3
26	400	120.1	-4.9	-4.8	-0.1	93.2	-26.9	-26.7	-0.2
25	315	118.3	-6.7	-6.6	-0.1	92.5	-25.8	-25.6	-0.2
26	250	116.3	-8.7	-8.6	-0.1	91.6	-24.7	-24.4	-0.3
23	200	114.1	-10.9	-10.9	0.0	90.6	-23.5	-23.3	-0.2
22	160	111.6	-13.4	-13.4	0.0	89.3	-22.3	-22.1	-0.2
21	125	108.9	-16.1	-16.1	0.0	87.9	-21.0	-20.8	-0.2
20	100	105.9	-19.1	-19.1	0.0	86.2	-19.7	-19.5	-0.2
19	80	102.6	-22.4	-22.5	0.1	84.3	-18.3	-18.1	-0.2
18	63	98.9	-26.1	-26.2	0.1	92.3	-16.6	-16.5	-0.1
17	50	94.9	-30.1	-30.2	0.1	80.0	-14.9	-14.8	-0.1
16	40	90.4	-34.6	-34.6	0.0	77.7	-12.7	-12.9	0.2
15	32	85.7	-39.3	-39.4	0.1	75.2	-10.5	-10.6	0.1
14	25	80.5	-44.5	-44.7	0.2	73.0	-7.5	-7.9	0.4
13	20	74.8	-50.2	-50.5	0.3	69.8	-5.0	-4.8	-0.2
12	16	68.9	-56.1	-56.7	0.6	67.3	-1.6	-1.0	-0.6
11	12	63.3	-61.7	-63.4	1.7	64.9	1.6	3.3	-1.7
10	10	59.7	-65.3	-70.4	5.1	62.8	3.1	8.2	-5.1

Larson-Davis 820

Bin No.	1/3 Octave Frequency	A-weight sound level	Measured A-weight	Theoretical A-weight	A-weighted error	1-cycle ASEL	Measured difference from A-weight sound level	Theoretical difference from A-wgt sound level	ASEL error
40	10000	118.3	-1.7	-2.5	0.8	74.6	-43.7	-38.9	-4.8
39	8000	119.7	-0.3	-1.1	0.8	78.1	-41.6	-38.4	-3.2
38	6300	120.4	0.4	-0.1	0.5	80.6	-39.8	-37.7	-2.1
37	5000	121.1	1.1	0.5	0.6	83.4	-37.7	-37.0	-0.7
36	4000	121.3	1.3	1.0	0.3	84.5	-36.8	-36.1	-0.7
35	3150	121.6	1.6	1.2	0.4	87.4	-34.2	-35.2	1.0
34	2500	121.4	1.4	1.3	0.1	86.9	-34.5	-34.3	-0.2
33	2000	121.4	1.4	1.2	0.2	88.5	-32.9	-33.4	0.5
32	1600	121.1	1.1	1.0	0.1	88.0	-33.1	-32.6	-0.5
31	1250	120.8	0.8	0.6	0.2	88.4	-32.4	-31.7	-0.7
30	1000	120.0	0.0	0.0	0.0	88.5	-31.5	-30.7	-0.8
29	800	119.2	-0.8	-0.8	0.0	89.3	-29.9	-29.8	-0.1
28	630	118.2	-1.8	-1.9	0.1	89.5	-28.7	-28.8	0.1
27	500	116.9	-3.1	-3.2	0.1	88.8	-28.1	-27.7	-0.4
26	400	115.2	-4.8	-4.8	0.0	88.2	-27.0	-26.7	-0.3
25	315	113.3	-6.7	-6.6	-0.1	87.9	-25.4	-25.6	0.2
26	250	111.2	-8.8	-8.6	-0.2	86.9	-24.3	-24.4	0.1
23	200	109.0	-11.0	-10.9	-0.1	85.5	-23.5	-23.3	-0.2
22	160	106.6	-13.4	-13.4	0.0	84.3	-22.3	-22.1	-0.2
21	125	104.0	-16.0	16.1	0.1	83.2	-20.8	-20.8	0.0
20	100	100.7	-19.3	-19.1	-0.2	81.1	-19.6	-19.5	-0.1
19	80	97.2	-22.8	-22.5	-0.3	78.9	-18.3	-18.1	-0.2
18	63	93.5	-26.5	-26.2	-0.3	77.0	-16.5	-16.5	0.0
17	50	89.7	-30.3	-30.2	-0.1	72.4	-17.3	-14.8	-2.5
16	40	85.2	-34.8	-34.6	-0.2	71.9	-13.3	-12.9	-0.4
15	32	80.2	-39.8	-39.4	-0.4	69.5	-10.7	-10.6	-0.1
14	25	74.7	-45.3	-44.7	-0.6	66.8	-7.9	-7.9	0.0
13	20	68.3	-51.7	-50.5	-1.2	64.5	-3.8	-4.8	1.0
12	16	62.0	-57.8	-56.7	-1.1	62.9	0.7	-1.0	1.7
11	12	57.1	-62.9	-63.4	0.5	60.4	3.3	3.3	0.0
10	10	54.4	-65.6	-70.4	4.8	58.3	3.9	8.2	-4.3

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Appendix C. Summary of sound measurements collected from each sampling location.

File No.	Time	Year	System	Site	Easting Location	Northing Location	Mean ASEL > 80 dB
37	Late May	94	ANM	Exposed	325730	3612120	93.4
40	Late May	94	ANM	Exposed	325730	3612620	91.7
52	Early May	94	ANM	Exposed	325730	3613120	97.3
48	Late April	94	Larson-Davis 820	Exposed	325730	3613620	94.3
22	Early April	92	ANM	Exposed	326230	3613620	92.4
54	Early May	94	ANM	Exposed	326230	3612120	93.4
15	Early May	92	ANM	Exposed	326230	3612620	96.0
19	Early July	92	ANM	Exposed	326230	3613120	96.5
31	Early February	93	Larson-Davis 820	Exposed	326230	3613620	92.9
30	Early March	93	Larson-Davis 820	Exposed	326230	3614120	92.4
6	Late March	92	ANM	Exposed	326230	3614620	94.0
1	Late May	92	Larson-Davis 820	Exposed	326230	3615120	94.3
8	Late Februrary	92	Larson-Davis 820	Exposed	326230	3615620	97.0
27	Late March	93	ANM	Exposed	326230	3616120	93.0
13	Early May	92	ANM	Exposed	326230	3616620	91.9
55	Early May	94	ANM	Exposed	326730	3612120	93.4
34	Early April	93	ANM	Exposed	326730	3612620	99.1
33	Early April	93	ANM	Exposed	326730	3613620	94.6
25	Late March	93	ANM	Exposed	326730	3614120	90.0
49	Early October	93	Larson-Davis 820	Exposed	326730	3614620	97.2
17	Early July	92	ANM	Exposed	326730	3615120	94.1
18	Early July	92	ANM	Exposed	326730	3615620	92.9
28	Late January	93	Larson-Davis 820	Exposed	326730	3615620	92.0
46	Late July	93	ANM	Exposed	326730	3616120	92.4
51	Early May	94	ANM	Exposed	327230	3612120	102.4
14	Early May	92	ANM	Exposed	327230	3612620	100.5
50	Early May	94	ANM	Exposed	327230	3612620	91.8
53	Early May	94	ANM	Exposed	327230	3613120	89.4
21	Early April	92	ANM	Exposed	327230	3613620	98.6
26	Late March	93	ANM	Exposed	327230	3614120	91.4
38	Late May	94	Larson-Davis 820	Exposed	327230	3614120	90.8
39	Late May	94	ANM	Exposed	327230	3614620	89.6
29	Late Februrary	93	Larson-Davis 820	Exposed	327230	3615120	92.9
7	Late March	92	ANM	Exposed	327230	3615620	93.0
3	Late May	92	ANM	Exposed	327230	3616620	90.5
44	Late March	94	ANM	Exposed	327730	3612120	98.2
41	Late March	94	ANM	Exposed	327730	3612620	100.7
42	Late March	94	ANM	Exposed	327730	3613120	97.7
47	Late Februrary	94	ANM	Exposed	327730	3614620	91.9
35	Late November	93	ANM	Exposed	327730	3615120	91.4
43	Late March	94	ANM	Exposed	327730	3613620	92.0
16	Early May	92	ANM	Exposed	328230	3611620	93.3
56	Early April	94	ANM	Exposed	328230	3612120	99.0
12	Early May	92	Larson-Davis 820	Exposed	328230	3612620	96.4
57	Early April	94	ANM	Exposed	328230	3613120	91.0
9	Late April	92	Larson-Davis 820	Exposed	328230	3613620	90.6
58	Early April	94	ANM	Exposed	328230	3614120	88.4
20	Early April	92	Larson-Davis 820	Exposed	328230	3614620	91.1
5	Late May	92	ANM	Exposed	328230	3615620	93.3
11	Late April	92	ANM	Exposed	329230	3612620	91.9
10	Late April	92	ANM	Exposed	329230	3613620	93.5
2	Late May	92	ANM	Exposed	329230	3614620	93.1
45	Late July	93	ANM	Exposed	330230	3614620	89.5
23	Late May	93	Larson-Davis 820	Control	330850	3622000	90.9
4	Late May	92	CEL 438	Control	332850	3622000	86.0
36	Late November	93	Larson-Davis 820	Control	332850	3622000	87.4
32	Early April	93	Larson-Davis 820	Control	328850	3622000	88.1
24	Late March	93	Larson-Davis 820	Control	328850	3624000	92.6

File No.	No. Flights/Day	Index of Exposure	No. Events > 80 dB	Max ASEL	Min ASEL	Median ASEL
37	32.8	111.0	459.0	113.0	78.5	87.0
40	28.9	113.0	384.0	112.5	78.0	89.5
52	14.3	110.4	177.0	112.0	79.0	90.0
48	32.1	116.1	138.0	104.1	83.4	92.1
22	31.6	114.9	325.0	108.5	81.0	91.0
54	15.3	110.7	93.0	110.0	80.0	90.0
15	12.1	113.2	166.0	110.0	82.0	93.5
19	10.7	112.2	372.0	113.0	81.5	93.0
31	36.6	115.8	396.0	105.7	83.4	91.3
30	52.5	115.5	620.0	107.5	83.5	89.4
6	49.7	115.9	487.0	116.0	78.0	90.0
1	100.8	117.0	622.0	113.2	80.4	88.1
8	68.6	118.7	473.0	113.9	84.6	91.4
27	28.1	112.4	197.0	106.0	78.0	89.0
13	22.7	112.5	293.0	104.0	82.0	90.0
55	12.3	111.3	153.0	113.5	79.0	91.5
34	49.4	121.8	840.0	115.0	78.0	96.0
33	23.3	110.6	401.0	114.5	78.0	88.0
25	24.7	107.6	180.0	108.5	78.0	84.8
49	76.6	118.6	590.0	114.9	83.8	90.9
17	9.6	111.7	199.0	108.5	82.0	93.0
18	9.5	110.2	348.0	104.0	81.5	91.5
28	60.2	116.0	379.0	115.5	83.0	89.3
46	5.0	104.9	143.0	104.0	79.5	89.0
51	38.6	118.9	247.0	115.6	81.8	94.1
14	25.9	121.5	331.0	115.0	83.0	98.5
50	21.5	112.2	256.0	118.0	77.0	90.0
53	6.8	102.5	74.0	109.5	77.5	85.3
21	45.9	118.5	427.0	115.5	81.5	93.0
26	11.6	106.1	85.0	109.0	77.5	86.5
38	29.7	112.1	344.0	105.5	82.7	88.5
39	10.5	105.6	139.0	105.0	79.5	86.5
29	47.7	117.1	286.0	103.5	83.8	91.4
7	36.0	115.7	252.0	105.5	79.0	91.3
3	10.1	106.9	80.0	104.5	81.5	88.0
44	19.5	119.3	207.0	109.0	79.5	97.5
41	56.3	126.4	1132.0	113.5	77.5	100.0
42	40.3	119.9	306.0	111.0	78.0	95.0
47	3.9	102.0	42.0	107.0	78.5	87.3
35	24.5	110.8	414.0	107.5	78.0	88.0
43	40.1	112.4	811.0	114.0	77.5	87.5
16	11.5	112.5	161.0	100.5	81.0	93.0
56	42.8	121.7	308.0	114.0	78.0	96.5
12	47.9	120.0	651.0	109.7	80.6	94.3
57	24.0	110.2	173.0	109.0	77.0	87.5
9	62.0	115.0	620.0	113.9	81.1	88.2
58	18.2	107.7	202.0	102.0	78.0	86.3
20	87.5	115.5	901.0	109.7	81.3	87.2
5	6.5	108.0	51.0	106.0	82.0	91.0
11	11.0	109.8	97.0	102.5	83.0	90.5
10	9.9	111.1	70.0	107.0	81.5	92.3
2	3.7	107.0	29.0	105.0	84.0	92.5
45	0.8	94.1	35.0	105.5	79.0	86.0
23	0.7	95.7	18.0	101.3	83.4	88.3
4	2.2	95.7	17.0	92.5	78.9	83.5
36	0.2	88.8	2.0	90.2	83.3	87.4
32	1.4	97.1	21.0	97.2	81.4	86.7
24	0.5	98.6	4.0	96.0	85.5	92.9

File No.	25% Quartile ASEL	75% Quartile ASEL	ASEL Std. Dev.	ASEL Range	Mean of 30 Loudest ASELs
37	83.0	94.0	7.72	34.5	108.2
40	84.5	93.5	5.83	34.5	103.9
52	85.0	99.0	8.92	33.0	108.2
48	87.9	96.2	5.70	20.7	101.2
22	87.0	94.5	4.91	27.5	101.3
54	85.0	93.5	6.66	30.0	101.8
15	89.6	98.0	6.14	28.0	104.0
19	89.0	98.5	6.38	31.5	107.4
31	88.1	95.0	4.79	22.3	101.6
30	86.2	93.5	5.31	24.0	104.3
6	85.0	95.5	6.96	38.0	107.2
1	83.7	95.1	7.81	32.8	109.4
8	87.5	98.8	7.22	29.3	109.7
27	83.5	96.5	7.25	28.0	102.0
13	87.0	94.0	4.43	22.0	99.2
55	86.5	94.5	6.22	34.5	103.0
34	87.0	102.5	8.73	37.0	111.1
33	83.5	95.5	8.04	36.5	108.4
25	82.5	89.3	6.52	30.5	101.3
49	86.8	97.7	7.72	31.1	111.5
17	88.8	96.0	5.15	26.5	101.6
18	87.9	95.0	4.68	22.5	100.4
28	86.6	93.0	4.88	32.5	104.4
46	85.0	95.0	6.22	24.5	101.6
51	89.5	107.8	10.11	33.8	112.2
14	93.5	103.0	6.64	32.0	109.5
50	85.5	93.1	5.49	41.0	104.7
53	82.5	88.5	6.03	32.0	97.5
21	89.5	99.5	7.68	34.0	111.3
26	83.0	90.5	6.98	31.5	100.0
38	85.0	92.3	4.93	22.8	100.4
39	82.8	91.5	5.61	25.5	97.2
29	88.4	94.5	4.53	19.7	100.4
7	85.5	95.5	6.02	26.5	102.0
3	86.0	91.0	4.58	23.0	96.3
44	92.0	100.8	7.05	29.5	105.5
41	92.0	104.0	8.35	36.0	110.9
42	86.5	101.5	8.23	33.0	107.4
47	83.6	92.5	7.08	28.5	101.6
35	84.0	92.5	6.35	29.5	103.0
43	83.5	93.0	6.65	36.5	108.1
16	90.0	95.0	3.88	19.5	97.9
56	88.5	101.6	8.25	36.0	109.3
12	86.1	99.3	7.63	29.1	106.0
57	84.5	93.0	5.86	32.0	99.7
9	83.9	92.6	5.39	32.8	104.3
58	83.5	89.5	4.89	24.0	96.4
20	83.6	93.1	5.96	28.4	103.8
5	87.8	94.5	5.38	24.0	97.8
11	86.5	94.5	4.65	19.5	96.9
10	88.1	95.0	5.03	25.5	98.1
2	87.0	94.0	4.93	21.0	94.8
45	82.8	90.8	5.81	26.5	93.3
23	85.7	91.4	5.04	17.9	90.9
4	81.5	88.9	4.67	13.6	84.9
36	85.6	88.9	4.88	6.9	88.0
32	82.8	90.0	4.43	15.8	88.0
24	91.3	93.9	4.46	10.5	85.5

File No.	No. of Weekday Hours Monitored	No. of Weekday Days Monitored	Max 24HL	Max 1HLHL	Mean MXFA > 80 dB
37	337.0	14.0	72.3	84.2	94.0
40	319.0	13.3	65.8	78.3	90.8
52	293.0	12.4	69.1	80.0	97.5
48	108.0	4.3	76.4	66.6	90.7
22	247.0	10.3	64.8	74.1	90.9
54	145.0	6.1	65.1	76.4	93.0
15	329.0	13.7	64.6	75.5	95.0
19	835.0	34.8	68.8	82.5	96.0
31	260.0	10.8	67.2	77.6	89.9
30	283.0	11.8	66.2	78.4	89.4
6	236.0	9.8	69.2	81.7	93.1
1	148.0	6.2	74.3	84.4	92.7
8	166.0	6.9	71.6	82.3	93.3
27	168.0	7.0	65.0	76.3	91.1
13	310.0	12.9	61.3	71.6	90.3
55	293.0	12.4	65.1	78.1	93.0
34	408.0	17.0	75.4	86.0	99.3
33	414.0	17.2	69.2	82.9	94.3
25	176.0	7.3	65.9	78.0	89.6
49	185.0	7.7	76.4	85.4	93.3
17	498.0	20.8	64.2	75.7	93.1
18	884.0	36.8	62.3	73.8	91.3
28	151.3	6.3	64.7	73.0	88.9
46	200.0	8.3	61.5	75.2	92.0
51	149.0	6.4	74.8	85.8	102.0
14	307.0	12.8	71.2	81.4	101.3
50	276.0	11.9	69.3		91.4
53	260.0	10.8	61.6	69.5	89.6
21	223.0	9.3	74.6	84.3	98.3
26	176.0	7.3	65.1	78.5	91.5
38	279.0	11.6	63.1	75.0	88.4
39	319.0	13.3	57.4	69.7	89.5
29	143.0	6.0	63.6	73.4	88.7
7	169.0	7.0	65.0	74.6	90.9
3	190.0	7.9	57.8	71.0	88.4
44	254.0	10.6	66.3	78.4	97.1
41	484.0	20.1	75.7	86.5	100.3
42	182.0	7.6	72.3	84.6	96.9
47	260.0	10.8	60.5	71.8	90.7
35	406.0	16.9	64.4	77.5	90.1
43	484.0	20.2	68.1	81.4	91.5
16	337.0	14.0	58.1	70.9	92.1
56	172.0	7.2	72.0	82.7	99.8
12	327.0	13.6	70.9	80.5	94.6
57	174.0	7.3	65.1	76.3	91.1
9	240.0	10.0	68.6	82.4	87.8
58	266.0	11.1	58.7	71.3	88.9
20	248.0	10.3	66.9	77.0	87.8
5	190.0	7.9	59.6	70.5	90.1
11	211.0	8.8	57.4	69.3	90.5
10	170.0	7.1	61.3	73.2	92.3
2	190.0	7.9	57.1	69.4	90.6
45	1014.0	42.3	56.5	64.3	90.0
23	600.0	25.0	54.6	68.1	90.1
4	191.0	7.9	55.8	68.3	85.7
36	270.0	11.3	44.8	67.6	83.6
32	359.0	14.9	48.0	61.9	85.2
24	196.0	8.2	48.6	60.5	87.6

File No.	Max MXFA	Min MXFA	Median MXFA	25% Quartile MXFA	75% Quartile MXFA	MXFA Std. Dev.
37	114.0	80.0	87.5	85.0	92.5	7.3
40	112.0	80.5	88.5	86.0	91.0	4.6
52	114.0	81.0	89.5	86.0	98.0	8.7
48	103.2	80.1	87.9	82.7	93.2	6.1
22	110.5	80.0	88.5	86.0	91.5	4.8
54	111.5	82.5	88.5	86.5	92.0	5.9
15	110.5	80.5	91.3	88.5	96.9	6.1
19	117.5	80.5	91.0	88.0	97.5	6.8
31	105.4	80.0	87.7	84.2	91.2	8.4
30	109.6	80.0	85.6	82.9	89.8	5.7
6	119.5	80.0	88.5	85.5	93.5	6.4
1	117.6	80.0	84.7	82.0	91.9	7.8
8	111.9	80.0	86.0	82.2	93.4	8.0
27	105.5	80.0	88.0	85.0	92.0	5.5
13	103.0	80.5	88.5	87.0	91.5	3.8
55	116.5	81.0	89.5	87.0	93.0	5.7
34	117.5	80.5	94.5	88.0	102.5	7.2
33	114.5	80.0	88.0	85.5	94.0	5.2
25	109.5	80.0	86.0	83.5	88.0	5.4
49	113.2	80.0	85.6	82.4	92.5	7.9
17	111.5	82.5	90.0	88.0	95.5	5.0
18	105.0	80.5	89.0	87.5	92.5	4.1
28	111.3	80.0	85.4	82.5	89.4	5.4
46	104.5	81.5	89.0	86.5	93.5	4.7
51	115.1	80.0	91.6	86.6	108.1	10.9
14	118.0	81.5	98.5	92.3	103.5	7.5
50	119.5	80.0	89.0	86.0	92.0	4.7
53	108.5	81.0	87.5	85.1	89.0	4.8
21	117.5	80.5	91.5	88.5	98.0	8.0
26	108.5	80.5	86.5	83.5	90.0	6.4
38	105.9	80.0	84.2	81.8	89.3	5.6
39	104.5	81.0	88.0	85.3	90.5	4.3
29	100.8	80.0	87.0	83.8	90.6	4.6
7	106.0	81.0	89.0	86.0	92.5	4.8
3	95.0	80.5	88.0	86.0	90.0	3.4
44	110.0	81.0	95.5	89.5	99.5	6.7
41	115.5	80.5	99.0	91.0	103.0	7.9
42	110.0	80.0	93.8	87.0	100.0	7.5
47	105.5	81.0	87.5	85.0	91.0	5.6
35	105.5	80.0	87.0	84.0	91.0	5.4
43	114.5	80.0	87.5	85.5	91.0	5.5
16	101.0	82.0	91.0	88.0	94.5	4.1
56	116.5	80.5	96.0	88.5	102.6	8.3
12	108.3	80.0	91.1	83.6	97.7	7.8
57	111.0	80.0	88.5	85.5	92.0	62.0
9	116.5	80.0	84.6	81.9	88.4	4.9
58	101.5	80.0	87.8	85.5	89.9	3.9
20	107.6	80.0	84.3	81.6	89.0	5.2
5	99.0	81.0	88.0	86.8	90.5	4.3
11	103.0	81.5	88.5	86.5	92.0	4.3
10	104.5	81.0	90.3	87.5	94.0	5.1
2	100.0	83.5	88.5	85.5	92.0	4.8
45	107.0	82.0	87.0	83.5	90.3	5.2
23	99.6	80.7	88.0	83.8	91.4	5.9
4	91.9	80.0	84.4	82.1	88.0	3.7
36	86.1	80.2	83.6	82.1	85.0	4.2
32	98.5	80.0	81.9	80.4	84.9	4.6
24	92.4	80.0	86.9	83.9	89.7	5.3

File No.	MXFA Range	Mean of 30 loudest MXFAs
37	34.0	109.1
40	31.5	103.0
52	33.0	109.3
48	23.1	98.3
22	30.5	101.7
54	29.0	102.2
15	30.0	103.5
19	37.0	109.5
31	25.4	100.2
30	29.6	103.7
6	39.5	108.5
1	37.6	110.3
8	31.9	108.0
27	25.5	100.2
13	22.5	97.8
55	35.5	105.9
34	37.0	112.0
33	34.5	108.8
25	29.5	101.0
49	33.2	109.8
17	29.0	101.8
18	24.5	99.6
28	31.3	102.5
46	23.0	100.2
51	35.1	112.3
14	36.5	111.7
50	39.5	105.7
53	27.5	99.3
21	37.0	112.2
26	28.0	99.7
38	25.9	99.8
39	23.5	96.0
29	20.8	96.5
7	25.0	100.2
3	14.5	91.4
44	29.0	105.2
41	35.0	111.8
42	30.0	106.7
47	24.5	100.2
35	25.5	101.1
43	34.5	108.1
16	19.0	97.5
56	36.0	111.1
12	28.3	105.5
57	31.0	101.1
9	36.5	104.4
58	21.5	95.7
20	27.6	101.1
5	18.0	93.2
11	21.5	95.6
10	23.5	97.0
2	16.5	92.1
45	25.0	94.2
23	18.9	89.8
4	11.9	84.5
36	5.9	84.1
32	18.5	86.4
24	12.4	81.2

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Appendix D. List of all plant species found on the small mammal trapping grids and species present for each grid in order of decreasing dominance.

Summary of plant species identified on the rodent sampling grids.

- Ambrosia deltoidea
- Ambrosia dumosa
- Amsinkia intermedia
- Camissonia boothii var. condensata
- Caulanthus lasiophyllus
- Cercidium microphyllum
- Chorizanthe brevicornu
- Chorizanthe rigida
- Corydalis aurea
- Cryptantha angustifolia
- Eriastrum sp.
- Eriogonum trichopes
- Geraea canescens
- Hesperocallis undulata
- Hilaria rigida
- Krameria grayi
- Larrea divaricata
- Lepidium lasiocarpum
- Lesquerella gordoni
- Monoptilon belliodes
- Nemacladus glanduliferus
- Opuntia leptocaulis
- Pectocarya heterocarpa
- Phacelia distans
- Plantago insularis
- Schismus barbatus
- Sphaeralcea ambigua
- Vulpia octoflora

Plant community characteristics for Grid A. Vegetation sampling was conducted in April, 1992. Species are arranged in ascending order of abundance, and points of occurrence for each species are given in parentheses as a percent.

Transect 1

Bare ground (39)
Schismus barbatus (23)
Pectocarya heterocarpa (14)
Larrea divaricata (13)
Chorizanthe brevicornu (5)
Monoptilon belliodes (5)
Eriogonum trichopes (4)
Chorizanthe rigida (3)
Krameria grayi (2)
Amsinkia intermedia (2)
Cryptantha angustifolia (2)
Lepidium lasiocarpum (1)
Camissonia boothii var. condensata (1)

Two most common perennials: L. divaricata and K. grayi
Two most common annuals: S. barbatus and P. heterocarpa

Transect 2

Bare ground (47)
Schismus barbatus (25)
Larrea divaricata (10)
Pectocarya heterocarpa (8)
Eriogonum trichopes (7)
Chorizanthe brevicornu (3)
Nemacladus glanduliferus (3)
Lepidium lasiocarpum (2)
Monoptilon belliodes (1)
Plantago insularis (1)
Chorizanthe rigida (1)
Krameria grayi (1)

Two most common perennials: L. divaricata and K. grayi
Two most common annuals: S. barbatus and P. heterocarpa

Plant community characteritics for Grid B. Vegetation sampling was conducted in April, 1992. Species are arranged in ascending order of abundance, and points of occurrence for each species are given in parentheses as a percent.

Transect 1

Bare ground (54)
Schismus barbatus (18)
Larrea divaricata (13)
Lepidium lasiocarpum (7)
Krameria grayi (7)
Pectocarya heterocarpa (5)
Plantago insularis (5)
Eriogonum trichopes (2)
Ambrosia dumosa (2)

Two most common perennials: L. divaricata and K. grayi
Two most common annuals: S. barbatus and L. lasiocarpum

Transect 2

Bare ground (60)
Schismus barbatus (26)
Larrea divaricata (11)
Eriognum trichopes (3)
Lepidium lasiocarpum (2)
Krameria grayi (2)
Plantago insularis (2)
Lesquerella gordoni (1)
Nemacladus glanduliferus (1)

Two most common perennials: L. divaricata and K. grayi
Two most common annuals: S. barbatus and E. trichopes

Plant community characteritics for Grid C. Vegetation sampling was conducted in April, 1992. Species are arranged in ascending order of abundance, and points of occurrence for each species are given in parentheses as a percent.

Transect 1

Bare ground (58)
Larrea divaricata (17)
Schismus barbatus (10)
Lepidium lasiocarpum (7)
Krameria grayi (4)
Ambrosia dumosa (4)
Lesquerella gordoni (4)
Eriogonum trichopes (1)
Monptilon belliodes (1)
Pectocarya heterocarpa (1)
Sphaeralcea ambigua (1)
Caulanthus lasiophyllus (1)
Phacelia distans (1)
Chorizanthe rigida (1)
Plantago insularis (1)

Two most common perennials: L. divaricata and K. grayi
Two most common annuals: S. barbatus and L. lasiocarpum

Transect 2

Bare ground (65)
Schismus barbatus (10)
Larrea divaricata (9)
Plantago insularis (5)
Krameria grayi (5)
Ambrosia dumosa (3)
Lepidium lasiocarpum (3)
Pectocarya heterocarpa (2)
Eriogonum trichopes (1)
Lesquerella gordoni (1)
Opuntia leptocaulis (1)

Two most common perennials: L. divaricata and K. grayi
Two most common annuals S. barbatus and P. insularis

Plant community characteritics for Grid D. Vegetation sampling was conducted in April, 1992. Species are arranged in ascending order of abundance, and points of occurrence for each species are given in parentheses as a percent.

Transect 1

Bare ground (57)
Schismus barbatus (16)
Larrea divaricata (11)
Nemacladus glanduliferus (5)
Camissonia boothii var. condensata (2)
Lepidium lasiocarpum (1)
Hesperocallis undulata (1)
Vulpia octoflora (1)

Two most common perennials: L. divaricata and H. undulata
Two most common annuals: S. barbatus and N. glanduliferus

Transect 2

Bare ground (70)
Larrea divaricata (17)
Schismus barbatus (10)
Ambrosia dumosa (3)
Krameria grayi (2)
Lesquerella gordoni (2)
Vulpia octoflora (2)
Plantago insularis (1)
Leaf litter (1)

Two most common perennials: L. divaricata and A. dumosa
Two most common annuals: S. barbatus and L. gordoni

Plant community characteritics for Grid E. Vegetation sampling was conducted in April, 1992. Species are arranged in ascending order of abundance, and points of occurrence for each species are given in parentheses as a percent.

Transect 1

Bare ground (61)
Schismus barbatus (28)
Larrea divaricata (8)
Pectocarya heterocarpa (2)
Plantago insularis (1)
Lesquerella gordoni (1)
Leaf litter (1)

The most common perennial: L. divaricata (no other perennial recorded)
Two most common annuals: S. barbatus and P. heterocarpa

Transect 2

Bare ground (48)
Schismus barbatus (16)
Larrea divaricata (15)
Hilaria rigida (10)
Lesquerella gordoni (5)
Ambrosia dumosa (4)
Ambrosia deltoidea (3)
Amsinkia intermedia (3)
Pectocarya heterocarpa (3)
Plantago insularis (3)
Corydalis aurea (2)
Vulpia octoflora (2)
Hesperocallis undulata (1)
Krameria grayi (1)
Caulanthus lasiophyllus (1)
Sphaeralcea ambigua (1)
Leaf litter (1)

Two most common perennials: L. divaricata and H. rigida
Two most common annuals: S. barbatus and L. gordoni

Plant community characteritics for Grid F. Vegetation sampling was conducted in April, 1992. Species are arranged in ascending order of abundance, and points of occurrence for each species are given in parentheses as a percent.

Transect 1

Bare ground (50)
Schismus barbatus (38)
Larrea divaricata (9)
Ambrosia dumosa (5)
Pectocarya heterocarpa (3)
Vulpia octoflora (2)
Lesquerella gordoni (1)
Leaf litter (1)

Two most common perennials: L. divaricata and Ambrosia dumosa
Two most comon annuals: S. barbatus and P. heterocarpa

Transect 2

Bare ground (25)
Schismus barbatus (49)
Larrea divaricata (15)
Ambrosia dumosa (10)
Cercidium microphyllum (7)
Lepidium lasiocarpum (6)
Pectocarya heterocarpa (4)
Hesperocallis undulata (2)
Lesquerella gordoni (1)
Caulanthus lasiophyllus (1)
Plantago insularis (1)

Two most common perennials: L. divaricata and A. dumosa
Two most common annuals: S. barbatus and L. lasiocarpum

Plant community characteritics for Grid H. Vegetation sampling was conducted in March, 1994. Species are arranged in ascending order of abundance, and points of occurrence for each species are given in parentheses as a percent.

Transect 1

Bare ground (53)
Schismus barbatus (9)
Plantago insularis (8)
Larrea divaricata (5)
Chorizanthe rigida (5)
Eriogonum trichopes (3)
Pectocarya heterocarpa (3)
Ambrosia dumosa (2)
Monoptilon belliodes (2)
Chorizanthe brevicornu (1)
Krameria grayi (1)
Cryptantha angustifolia (1)
Lepidium lasiocarpum (1)

Two most common perennials: L. divaricata and Ambrosia dumosa
Two most common annuals: S. barbatus and P. insularis

Transect 2

Bare ground (48)
Schismus barbatus (13)
Eriogonum trichopes (7)
Plantago insularis (6)
Larrea divaricata (3)
Pectocarya heterocarpa (2)
Amsinkia intermedia (2)
Monoptilon belliodes (1)
Cryptantha angustifolia (1)
Chorizanthe rigida (1)

Most common perennial: L. divaricata
Two most common annuals: S. barbatus and E. trichopes

Plant community characteritics for Grid I. Vegetation sampling was conducted in March, 1994. Species are arranged in ascending order of abundance, and points of occurrence for each species are given in parentheses as a percent.

Transect 1

Bare ground (47)
Schismus barbatus (18)
Larrea divaricata (16)
Lepidium lasiocarpum (2)
Plantago insularis (7)
Eriogonum trichopes (6)
Ambrosia dumosa (2)
Amsinkia intermedia (3)
Geraea canescens (2)
Most common perennial: L. divaricata
Two most common annuals: S. barbatus and P. insularis

Transect 2

Bare ground (46)
Schismus barbatus (19)
Plantago insularis (13)
Larrea divaricata (10)
Hilaria rigida (6)
Lepidium lasiocarpum (6)
Pectocarya heterocarpa (4)
Eriastrum sp. (3)
Eriogonum trichopes (2)
Cryptantha angustifolia (1)
Ambrosia dumosa (1)
Amsinkia intermedia (1)

Two most common perennials: L. divaricata and A. dumosa
Two most common annuals: S. barbatus and P. insularis

Appendix E. Summary of all kit foxes radio-collared or captured more than once with fate, cause of mortality (if known) and time of persistance (if known).

Exposed Site Animals

Animal ID	Sex	Dates of capture	Age* estimate	Radio-collar frequency	Date last known alive	Fate	Cause (if known)	Date discovered	Days known alive	Years known alive
3R	M	10/14/91 10/16/91	Yg. Ad. Yg. Ad.		10/16/91				2	0.01
5R	M	6/20/92 12/18/92 12/21/92 12/22/92	Yg. Ad. Pr. Ad. Pr. Ad. Pr. Ad.	29	10/10/93	Dead	Predation/ scavenged	1/23/94	477	1.31
22R	M	6/24/92 12/22/92	Pr. Ad. Pr. Ad.	47	10/10/93	Dead	Predation/ scavenged	1/23/94	473	1.30
24R	M	12/18/92	Pr. Ad.	32	5/23/93	Dead	Predation/ scavenged	10/5/93	156	0.43
31R	F	12/11/93	Pr. Ad.	77	12/11/93	Dead	Predation/ scavenged	1/21/94	10	0.03
42R	F	12/10/93 2/20/94	Pr. Ad. Pr. Ad.	65	3/26/94	Dead	Parasite?	3/26/94	106	0.29
50R	M	12/12/93	Pr. Ad.	98	12/12/93	Dead	Predation/ scavenged	1/21/94	0	0.00
56G	F	12/17/93	Pr. Ad.	53	11/1/94	Alive			319	0.9
58G	F	10/13/93 11/17/93	Yg. Ad. Yg. Ad.		11/17/93				35	0.10
60G	F	12/18/92	Pr. Ad.	17	1/22/94	Unknown			400	1.10
70G	M	12/10/93	Old Ad.	95	2/20/94	Unknown			72	0.20
75G	M	11/15/91	Pr. Ad.	11	6/28/92	Unknown			226	0.62
113B	F	10/16/91 11/14/91 11/16/91	Pr. Ad. Pr. Ad. Pr. Ad.	25	2/15/92	Dead	Predation/ scavenged	1/30/92	122	0.33

* Juv. = Ju Yg. Ad. = Young Adult Pr. Ad. = Pime Adult Old Ad. = Old Adult

Exposed Site Animals

Animal ID	Sex	Dates of capture	Age* estimate	Radio-collar frequency	Date last known alive	Fate	Cause (if known)	Date discovered	Days known alive	Years known alive
127B	F	12/18/92 12/20/92 12/21/92	Pr. Ad. Pr. Ad. Pr. Ad.	41	12/21/92	Unknown				
132B	F	11/15/91 12/8/91 1/18/92	Yg. Ad. Yg. Ad. Yg. Ad.	69	6/24/92	Dead	Predation/ scavenged	6/29/92	222	0.61
137B	F	9/22/91 12/8/91 1/18/92 12/23/92	Pr. Ad. Pr. Ad. Pr. Ad. Pr. Ad.	7	6/28/92	Released alive after uncollaring			280	0.77
148B	M	12/18/92 12/21/92 12/22/92 12/18/93	Yg. Ad. Yg. Ad. Yg. Ad. Old Ad.	35 and 41	7/25/94	Alive			584	1.60
158Y	M	3/20/93 3/27/94	Pr. Ad. Pr. Ad.	80	7/25/94	Alive			492	1.35
166Y	F	1/24/93 12/10/93	Pr. Ad. Pr. Ad.	84	12/15/93	Dead	Parasite?	1/21/94	325	0.89
167Y	F	5/27/93 10/13/93	Juv. Yg. Ad.		10/13/93				139	0.38
577R	M	1/24/94	Pr. Ad.	98.3	1/26/94	Dead		2/17/94	2	0.01

Animals that Moved from the Control Site to the Exposed Site

169B	F	11/14/93	Pr. Ad.							
169B	F	12/10/93	Pr. Ad.	86	12/12/93	Dead	Parasite?	1/21/94	28	0.08

* Juv. = Ju Yg. Ad. = Young Adult Pr. Ad. = Pime Adult Old Ad. = Old Adult

Animals that Moved from the Exposed Site to the Control Site

Animal ID	Sex	Dates of capture	Age* estimate	Radio-collar frequency	Date last known alive	Fate	Cause if mortality	Date discovered if dead	# of days alive	Years known alive
172Y	M	8/29/92	Yg. Ad.							
172Y	M	12/18/92	Yg. Ad.	38	10/14/93	Unknown			411	1.13
87G	F	12/22/92	Pr. Ad.	11						
87G	F	12/14/93	Old Ad.	62	7/29/94	alive			584	1.60

Control Site Animals

1Y	M	9/22/91 12/19/92 11/12 93 12/17/93	Pr. Ad. Pr. Ad. Pr. Ad. Old Ad.	2	1/31/94	Dead	Unknown	2/22/94	862	2.36
49R	M	12/14/93 1/27/94	Pr. Ad. Pr. Ad.		1/27/94				44	0.12
26R	F	12/17/93 1/28/94	Yg. Ad. Yg. Ad.	50	1/28/94	Dead	Parasite?	2/18/94	42	0.12
33R	M	12/14/93	Pr. Ad.	71	1/27/94	Unknown			44	0.12
34R	F	12/14/93	Pr. Ad.	74	12/14/93	Dead	Parasite?	1/26/94		
44R	M	12/17/93	Pr. Ad.	44	3/30/94	Dead	Parasite?	4/19/94	103	0.28
51G	F	10/12/91 2/17/92 2/23/92	Pr. Ad. Pr. Ad. Pr. Ad.	25	4/25/92	Dead	Unknown	6/12/92	196	0.54
68G	F	12/17/93	Yg. Ad.	32	12/17/93	Dead	Parasite?	1/24/94	0	0.00
72G	M	12/21/92 11/13/93 12/14/93	Pr. Ad. Pr. Ad. Old Ad.	63	12/14/93	Dead	Predation/ scavenged	1/26/94	358	0.98

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Control Site Animals

Animal ID	Sex	Dates of capture	Age* estimate	Radio-collar frequency	Date last known alive	Fate	Cause if mortality	Date discovered if dead	# of days alive	Years known alive
76G	F	12/19/92	Pr. Ad.	26	10/14/93	Dead	Predation/ scavenged	1/22/94	299	0.82
77G	M	12/20/92 11/10/93	Yg. Ad. Yg. Ad.	5	11/10/93	Released alive after uncollaring			21	0.06
87G	F	12/14/93	Old Ad.	62	7/29/94	alive			227	0.62
112B	F	11/10/92 1/12/93 1/14/93	Yg. Ad. Yg. Ad. Yg. Ad.		1/14/93				65	0.18
131B	F	1/24/93 12/14/93	Yg. Ad. Yg. Ad.		12/14/93				324	0.89
140B	M	12/19/92 11/12/93	Pr. Ad. Pr. Ad.	23	11/12/93	Dead	Parasite?	11/12/93	328	0.90
141B	F	12/19/92 1/24/93	Pr. Ad. Pr. Ad.	8	10/14/93	Dead	Predation/ scavenged	1/23/94	299	0.82
142B	M	12/19/92 12/21/92 11/12/93	Pr. Ad. Pr. Ad. Old Ad.	2	11/12/93	Released alive after uncollaring			328	0.90
144B	F	11/13/93 1/28/94	Pr. Ad. Pr. Ad.	74.5	1/28/94	Dead	Predation/ scavenged	2/18/94	76	0.21
155Y	F	2/17/92	Yg. Ad.	29	2/17/92	unknown			0	0.00
157Y	M	2/25/92 4/14/92	Yg. Ad. Yg. Ad.	97	4/30/92	Dead	Roadkill?	5/16/92	65	0.18
165Y	F	12/21/92 1/28/94	Yg. Ad. Yg. Ad.	14	1/28/94	Released alive after uncollaring			403	1.10
576R	M	1/27/94	Pr. Ad.	83.5	2/23/94	Dead	Predation/ scavenged	3/23/94	25	0.07

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Control Site Animals

Animal ID	Sex	Dates of capture	Age* estimate	Radio-collar frequency	Date last known alive	Fate	Cause if mortality	Date discovered if dead	# of days alive	Years known alive
578R	M	1/27/94	Pr. Ad.	71.4	2/27/94	Dead	Parasite?		31	0.08
579R	M	1/28/94	Pr. Ad.	20.4	2/21/94	Dead	Unknown		24	0.07
588R	M	1/27/94	Pr. Ad.	77.3	7/29/94	Alive			183	0.50
589R	F	1/27/94	Pr. Ad.	92.4	2/18/94	Dead		3/23/94	22	0.06
590R	M	4/28/94	Pr. Ad.	84.2	7/29/94	Alive			92	0.25

Area C Animals

8R	F	12/16/91 1/22/92	Yg Ad. Pr Ad.	2	2/15/92	Released alive after uncollaring			61	0.17
15R	F	12/14/92 1/20/92 2/14/93	Pr. Ad. Pr. Ad. Pr. Ad.	56	2/14/92	Released alive after uncollaring			62	0.17
62G	M	12/14/91 1/22/92	Yg. Ad. Yg. Ad.		1/22/92				39	0.11
63G	M	1/20/92 1/22/92	Yg. Ad. Yg. Ad.		1/22/92				2	0.01
128B	F	1/22/92	Pr. Ad.	97	1/22/92	Dead	Roadkill?	2/14/92	0	0.00
129B	F	1/20/92 1/22/92	Yg. Ad. Yg Ad.	60	2/15/92	Released alive after uncollaring			26	0.07
138B	M	12/14/91 12/16/91	Yg. Ad. Yg. Ad.		12/16/91				2	0.01
143B	M	12/16/91 1/22/92	Yg. Ad. Yg, Ad.		1/22/92				17	0.05
152Y	F	12/14/91 12/16/91	Old Ad. Old Ad.		12/16/91				2	0.01

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