WILDLIFE HABITAT ASSESSMENT AT THE GEYSERS GEOTHERMAL FIELD

Janet F. Hurley
University of California
Berkeley, California

Abstract.

In 1976, a cooperative team began a comparative study of wildlife populations in developed and undeveloped areas at The Geysers Geothermal Field. This portion of the study analyzes habitat variation and derives habitat relationship models for small mammals. Developed and undeveloped plots were compared in five habitat types. (Developed plots were subject to disturbance from geothermal development, while undeveloped plots were free from this disturbance.) Natural habitat variation was described by measurements of vegetative structure and composition, ground cover type, and topography and solar radiation. Because geothermal development produces high noise levels from steam wells and construction operations, measurements of noise level were used to assess the geothermal influence on each plot. All habitat and small mammal measurements were replicated on 10 sampling units in each study plot.

Noise levels were consistently higher in developed than in undeveloped plots. Some developed plots showed alterations in shrub cover and ground cover that were attributed to geothermal development, but in general the developed and undeveloped plots of the same habitat type were similar in vegetative structure. Plant species composition depended on location of the plot. Of the eight small mammal species captured, the deer mouse (Peromyscus maniculatus) and the pinyon mouse (P. truei) comprised 80 to 95 percent of the catch in each plot. However, the dominance relationships of these two species seemed to be affected by geothermal development, with the pinyon mouse dominating in undeveloped plots and the deer mouse dominating in developed plots. Discriminant analysis was used to develop models of small mammal species relationships as influenced by vegetation and noise level.

INTRODUCTION

As habitat modification through human development of landbased resources accelerates, biologists increasingly need to examine relationships between wildlife species and their habitats. Knowledge of wildlife-habitat relationships is needed both for impact assessment and for management through vegetation manipulation and other means. For many species, the precise information that allows a manager this control is lacking. Furthermore, the task of gathering and analyzing data for unstudied field situations is awesome.

These problems were faced by a cooperative team studying the distribution and abundance of wildlife at The Geysers Geothermal Field. The Geysers Wildlife Study began in 1976 with the objective of comparing wildlife populations in developed and undeveloped areas so that differences attributable to geothermal development could be assessed.

The portion of the study described in this paper provides a detailed analysis of habitat variation, both naturally-occurring and related to geothermal development. Two problems were addressed in this habitat survey: (1) to provide an analysis of habitat variation within the developed and undeveloped plots established for sampling of wildlife populations, and (2) to apply these data in an analysis of habitat relationships for one animal group, small mammals. The second problem was undertaken to demonstrate the use of multivariate analytical techniques and modern computer capabilities in this type of research.

ACKNOWLEDGMENTS

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DESCRIPTION OF STUDY AREA

The Geysers Known Geothermal Resources Area (KGRA) is located in Sonoma, Lake, and Mendocino counties of northern California. The wildlife study area comprises about 42 square miles (109.2 sq km) of the Big Sulphur Creek watershed in northeastern Sonoma County; this represents about one-third of the KGRA. Commercial geothermal development began on Big Sulphur Creek in the late 1950's.

The topography is dominated by east-west ridges formed by the canyons of Big Sulphur Creek and its tributary, Squaw Creek. Slopes range from 30 to 70 percent in the study areas, and elevations range from 1000 to 3600 feet (300 to 1080 m).

Plant communities in the Big Sulphur Creek watershed form a mosaic that is influenced by topography, exposure, and soil type. Of the nine vegetation types mapped from an aerial photographic survey in September 1975 (Comarc Design Systems 1976), five were selected for analysis during the habitat study. These types are: mixed evergreen forest, oak woodland, oak savanna, mixed chaparral, and chamise chaparral. Wildlife and habitat data were collected from one developed and one undeveloped plot within each habitat type. Complete descriptions of the habitat types and the 10 study plots are given by Hurley (1977) and Meneghin et al. (1977).

METHODS

Habitat characteristics were compared for developed and undeveloped plots in five habitat types. The habitat characteristics that were measured included structure and composition of trees and shrubs, ground cover type, noise level, and topography and solar radiation. These measurements were associated with small mammal live-trapping data collected at the same locations. Field work for the habitat survey was conducted from October 11 to November 12, 1976. The small mammal data were collected for four seasons (spring, summer, fall, and winter) beginning in spring 1976.

Study Design

In order to make full use of the multivariate analytical techniques made possible through computer analysis, it was necessary that each set of habitat and small mammal data be associated with the same "piece of ground." Furthermore, it was necessary that many replicates or sampling units be available for analysis. It was not sufficient to merely average the measurements over 25 stations in each plot, for example, as this would give only 10 sampling units, one for each study plot.

To provide a sufficient number of samples, each study plot was divided into 10 sampling units. This resulted in 100 sampling units available for multivariate analysis. For any given variable, means for the 10 plots could be obtained by averaging the values for the 10 sampling units in each plot.

Each sampling unit contained 300 feet (90 m) of belt transect for shrub cover and ground cover measurements, and five point stations located in 75-foot (22.5 m) intervals along the centerline of the transect (Figure 1). Each point sampling station was located at a small mammal trap site, and was used for sampling of tree species composition and measurement of noise levels.

Location of the sampling units was determined by the established small mammal trap lines (Meneghin et al. 1977), which this habitat survey followed. The small mammal trap lines consisted of two lines of 25 stations each in each study plot. Locations are shown in Figure 2.

Data Collection and Analysis

Data analysis was based on a matrix of variables for each of the 100 sampling units. That is, each sampling unit was given a value for each of the variables describing habitat and small mammal parameters. Field methods for this data collection are described briefly; complete methods are given by Hurley (1977).

Vegetation structure and composition.

The physical parameters of the vegetation (height, density, and relative cover) were measured by several methods. For trees, either the point-centered quarter method (Mueller-Dombois and Ellenburg 1974) or the areal method (James and Shugart 1970) were employed at each point sampling station to give density (number of trees per acre) and dominance (basal area per acre). The point-centered quarter method was used in dense forest stands, and the areal method was used in open stands where a complete sample could not be obtained by the first method (see Figure 1). Relative cover of the tree canopy was measured by sighting upward through an ocular tube (James and Shugart 1970).

Relative shrub cover for each sampling unit was obtained by measuring the linear footage of the shrub canopy intercepted within arm's length on both sides of the transect line. Because not all transects were exactly 300 feet in length, shrub cover was expressed as a percent of the total line length.

Each tree and shrub species was given a relative abundance value. For trees, relative

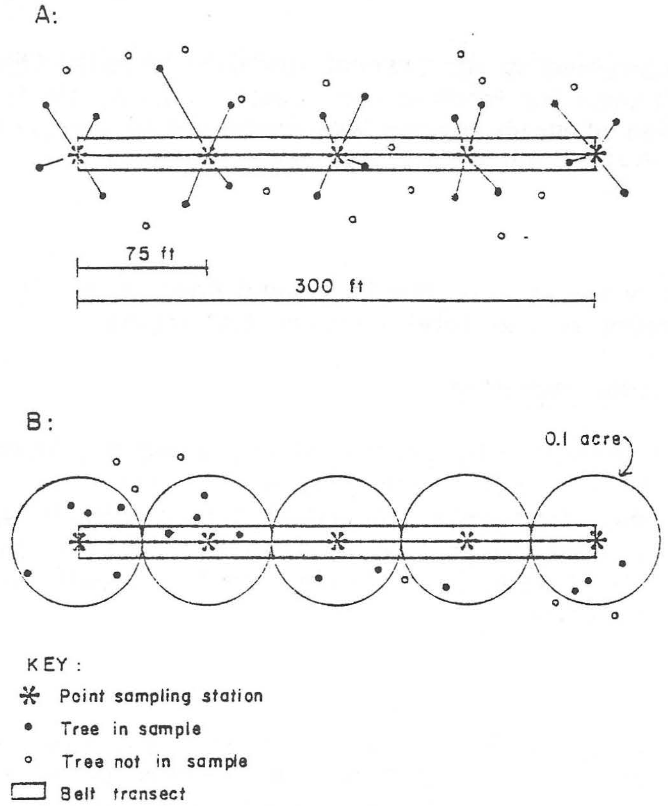

FIGURE 1. Schematic diagram of the sampling unit, showing belt transect for shrub and ground cover sampling, and point stations with two methods of tree sampling. "A" refers to the point-centered quarter method (Mueller-Dombois and Ellenburg, 1974) and "B" shows the areal method (James and Shugart, 1970).

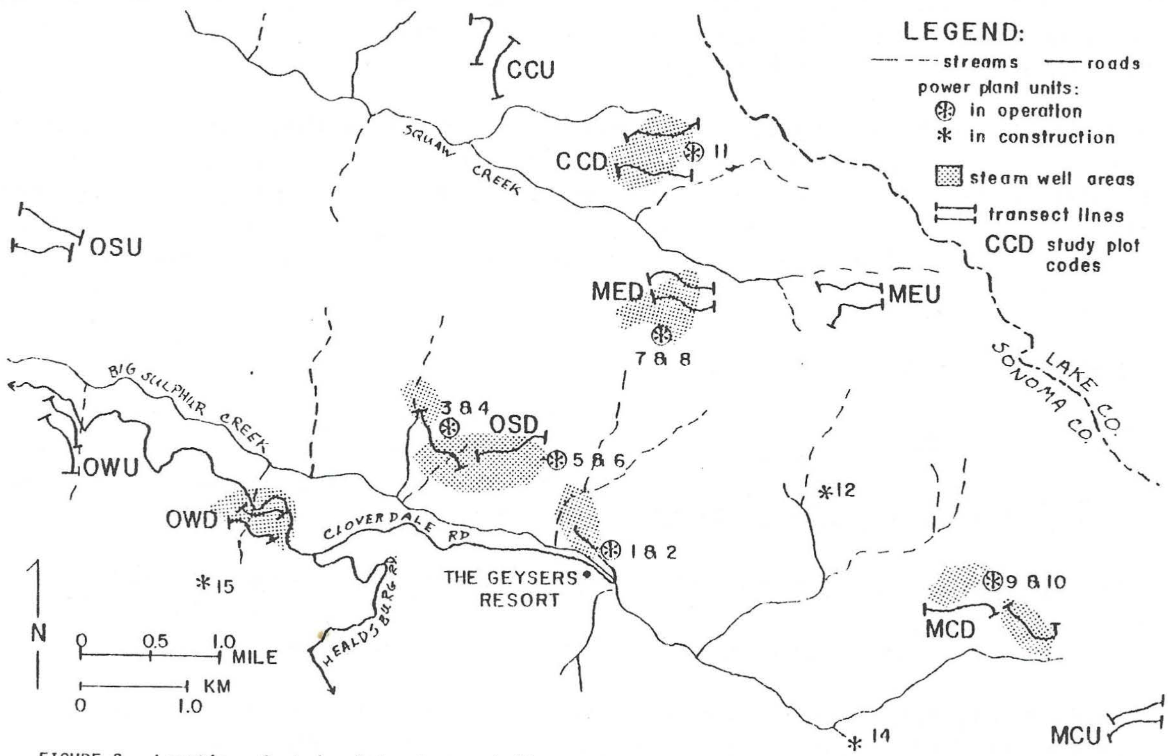

FIGURE 2. Location of study plots, transect lines, steam well areas, and power plant units within the developed portion of the Geyers KGRA. The first two letters of the plot codes indicate habitat type: ME, mixed evergreen forest; OW, oak woodland; OS, oak savanna; MC, mixed chaparral; CC, chamise chaparral. "D" indicates a developed plot; "U" indicates an undeveloped plot.

abundance was expressed by the percent importance value (Mueller-Dombois and Ellenburg 1974), which sums the relative dominance, relative density, and relative frequency. Relative abundance of shrub species was expressed as the percent of the total transect line length occupied by each shrub species.

Ground cover.

Relative abundance for each of the 14 ground cover types (Hurley 1977) identified was expressed as percent of the total transect line length.

Topography and solar radiation.

Topography was represented by percent slope, which was read from a topographic map on which the sampling units were plotted. Aspect was also recorded. The solar radiation index was read from published tables (Frank and Lee 1966). For each combination of slope and aspect at a given latitude, the solar radiation index is the fraction of theoretical solar beam irradiation that would be received by a horizontal plane at the same latitude.

Noise level.

Elevated noise levels in developed areas were expected to be a major effect of geothermal development. Noise levels in decibels were recorded at the third point station of each sampling unit for the complete noise spectrum (decibels A-weighted and decibels linear) and for six frequency bands chosen to represent the audible ranges of most birds and mammals. In addition, a subjective noise score was recorded from the impression of noise level heard by the field assistants at each point station.

Small mammal abundance.

Two 9-inch (23.5 cm) Sherman live traps were set at each of five trap stations in each sampling unit. The traps were set for three consecutive nights in each season (spring, summer, fall, and winter).

For this analysis, small mammal captures were summed over the four seasons for each sampling unit, and the number of captures per 120 trap-nights was used as an index of abundance. Relative abundance for each small mammal species was computed as the total number of captures for that species divided by the total captures for all species in the sampling unit. A separate analysis of the small mammal data is given in Meneghin et al. (1977).

Analysis of Data

Computer analysis was done by SPSS: Statistical Package for the Social Sciences (Nie et al. 1975). Means and standard deviations of the variables by study plot were used for graphical analyses to be described later. Multivariate analysis was done with the program DISCRIMINANT in SPSS (Klecka 1975).

The theory of discriminant analysis has been discussed by Gilbert (1973), Klecka (1975), and Pimentel (1976). Applications of this technique to ecological field studies have been shown by Green (1971), James (1971), and Whitmore (1975).

In this study, discriminant analysis was used to determine the most important habitat parameters for distinguishing areas of small mammal abundance from areas of their absence. This was done by assigning each sampling unit to a discriminant group on the basis of the abundance value for a given species. For example, in the analysis of deer mouse (Peromyscus maniculatus) abundance, group 1 consisted of all sampling units with low abundance (10 or fewer captures per 120 trap-nights), group 2 contained all sampling units with moderate abundance (11 to 24 captures), and group 3 contained all sampling units with high abundance (25 or more captures). These group limits differed for each species, but in all cases were chosen so that the number of sampling units was approximately equal for the three groups.

Selected habitat variables were then entered into the analysis to produce a discriminant function that mathematically separated the groups by use of a weighting coefficient for each variable. The standardized value of the coefficient indicated the relative importance of the variable in separating the groups (Kelcka 1975). For example, suppose shrub cover and grass cover were the most important of 25 variables in an analysis. If group 1 sampling units were associated with abundant shrub cover but scarce grass cover, while group 3 sampling units were associated with scarce shrub cover but abundant grass cover, then it may be inferred that good habitat for the species in question is characterized by grasslands with an absence or scarcity of shrubs.

Similar analyses were repeated for each of the small mammal species collected during the study. At least 10 variables were entered into each analysis. The full discussion is given by Hurley (1977).

RESULTS

Evaluation of Study Plots

The study plots were selected from an a priori classification of vegetation types. It was necessary both to examine this classification and to verify that the plot pairs fit the assumptions of the comparative study design. That is, developed and undeveloped plots of the same habitat type should be similar for all habitat characteristics except those related to the effects of geothermal development.

The selected plots were ordinated along an inferred moisture gradient (Figure 3),using the Bray-Curtis ordination method (Bray and Curtis 1957) applied to the mean relative abundance for each tree and shrub species in the plots. This ordination fit the expectation that a moisture gradient would be evident in the similarity relationships of these vegetation types. Topographic moisture gradients are known to be a primary determinant of plant community formation (Muller-Dombois and Ellenburg 1974, Whittaker 1975).

In the strictest sense, the gradient analysis and its underlying theory of individualistic response are incompatible with the concept of classification (Pielou 1977). However, the classification was employed as a means of stratifying the data collection, and no assumptions regarding theoretical correctness were made. In fact, the ordination and the structural analyses described below indicate that the plot means were sufficiently different so that stratification was valid for study purposes, even though the individual sampling units may be continuously distributed along the gradient.

Habitat variation between developed and undeveloped was compared by three procedures. Structural variation was compared by use of the profiles shown in Figure 4. In these profiles, mean values for each study plot were expressed as percent of the

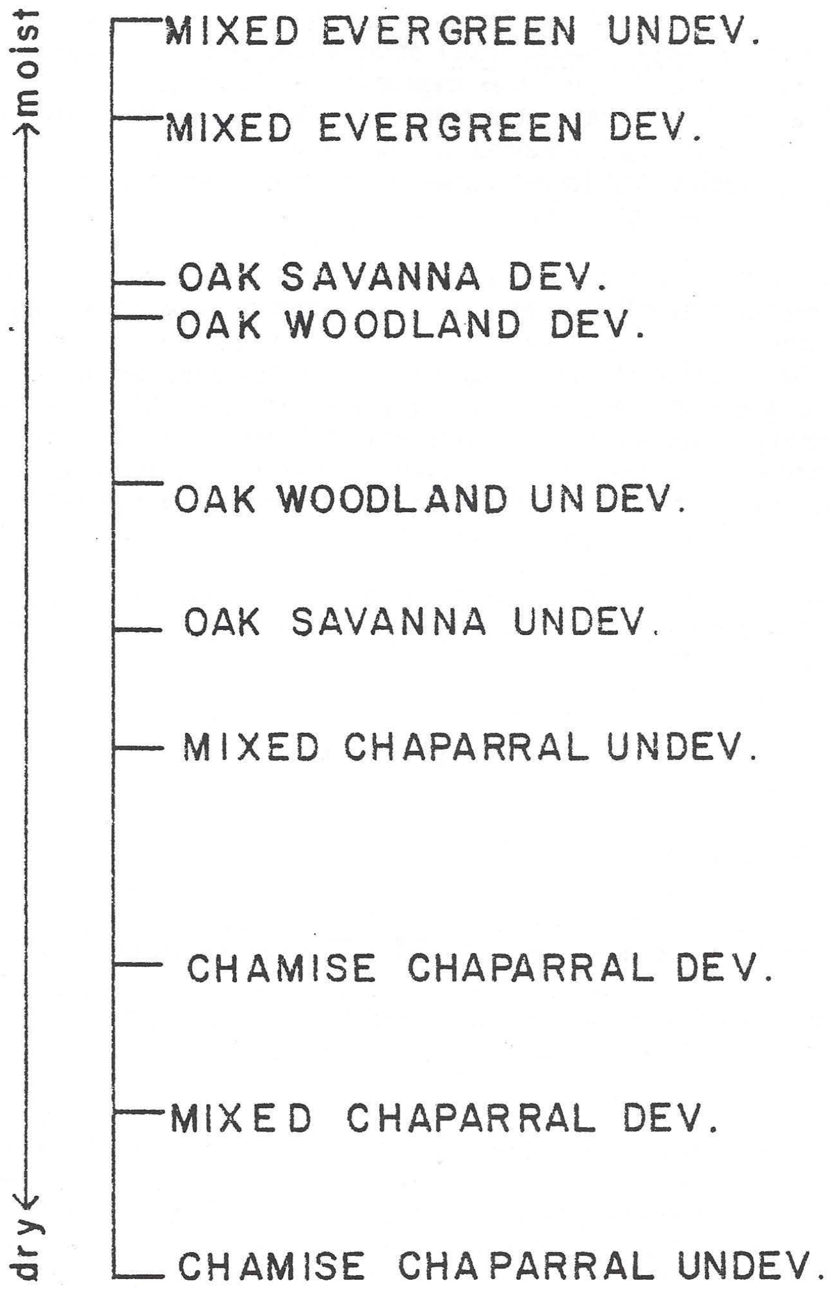

FIGURE 3. One-dimensional ordination of the 10 study plots based on similarity of tree and shrub species.

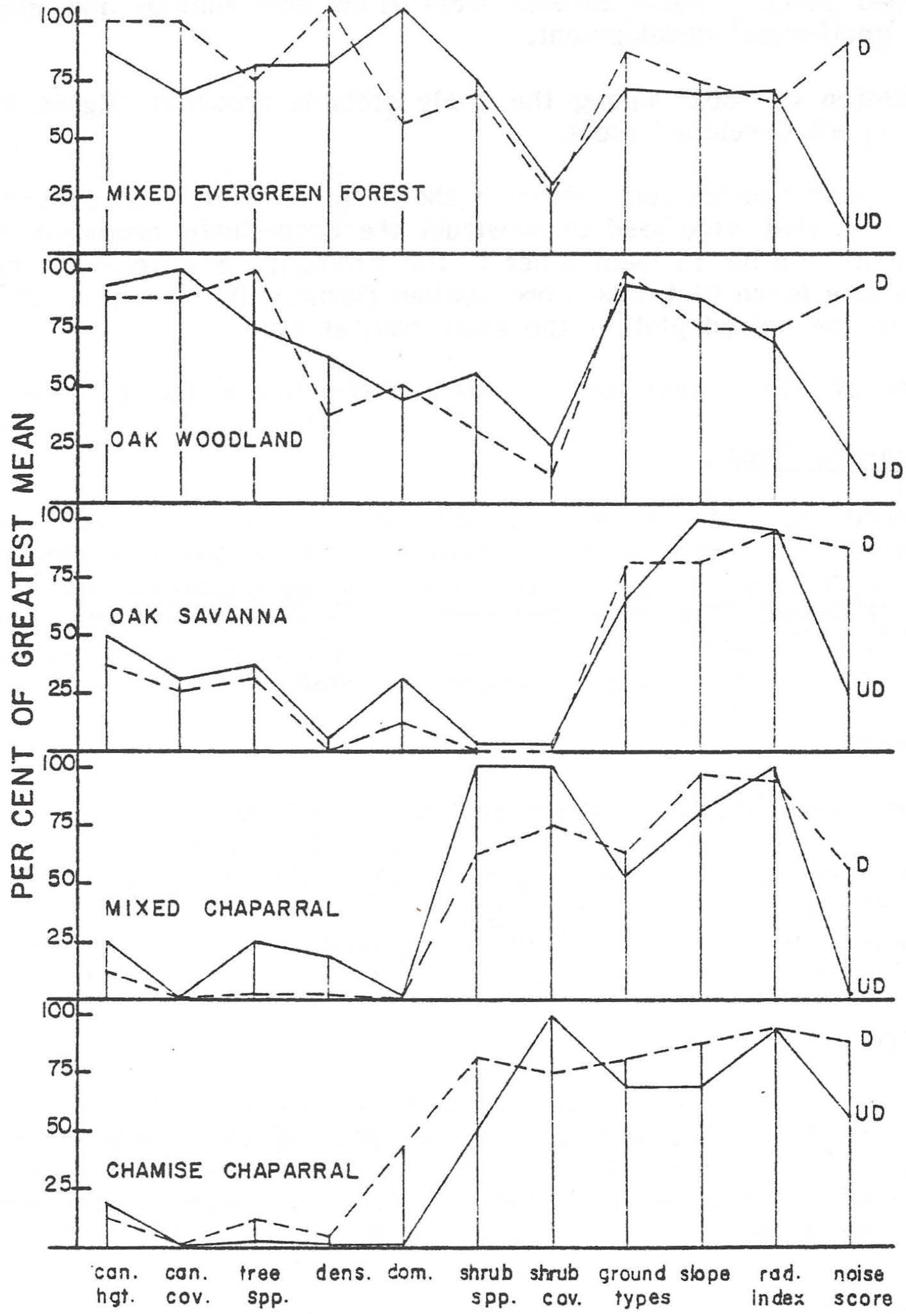

FIGURE 4. Habitat profiles of structural variables ant the noise score for the 10 study plots. In each plot, a given variable is expressed as a percentage of the greatest mean for that variable among the 10 plots. D = developed plot, UD = undeveloped plot.

greatest mean for a given variable among all the study plots. The variables along the x-axis were considered to describe the structure of the vegetation and topography; on noise variable, the subjective noise score, was included to show the relative amount of variation contributed by noise as compared to the other parameters. The major trends indicated by the profiles are that shrub cover tends to be reduced in the developed chaparral plots, and that the number of ground cover types is increased in all developed plots. These effects stem from construction and clearing activities related to geothermal development.

The distribution of noise among the study plots is shown in Figure 5. Noise levels are higher in all developed plots.

Variation in plant species composition is shown by the matrix of similarity coefficients, $C = 2w/(a + b)$, that were used to construct the Bray-Curtis ordination (Table 1). Plot pairs are most similar to each other if the similarity coefficient is close to 1.0. In several cases, a given plot was more similar floristically to a plot of another habitat type than to the paired plot of the same habitat type.

The results of these analyses are summarized below for the five habitat types:

Mixed evergreen forest.

The developed and undeveloped plots showed the greatest floristic similarity among the plot pairs. Both plots were dominated by canyon live oak (*Quercus chrysolepis*), madrone (*Arbutus menziesii*), Douglas fir (*Psuedotsuga menziesii*), and California nutmeg (*Torreya californica*). The developed plot had more trees per acre, but the trees had smaller diameters, on the average, than the undeveloped plot. Thus, the developed plot appeared to be at an earlier successional stage.

Oak woodland.

The two plots were similar in structure but differed greatly in species composition of the vegetation. The dominance of the developed plot was shared by black oak (*Quercus kelloggi*) and bay laurel (*Umbellularia californica*), but the undeveloped plot was stongly dominated by valley oak (*Quercus lobata*). Also, the shrub layer in the developed plot was dominated by poison oak (*Rhus diversiloba*) but manzanita (*Arctostaphylos* sp.) dominated in the undeveloped plot.

Oak savanna.

As in oak woodland, the oak savanna plots compared well in structure but not in species composition. The tree and shrub layers of the developed oak savanna plot were most similar to those of the developed oak woodland plot. Although they are on opposite sides of the canyon, these two plots are closer to each other than to the comparable undeveloped plots, which are several miles to the west.

Mixed chaparral.

The developed plot had about 25 percent less shrub cover per sampling unit than the undeveloped plot. This discrepancy may have resulted partly from shrub removal for geothermal development, and partly from past occurrance of fires. Chamise (*Adenostoma fasciculatum*) was the dominant species, comprising about 45 to 50 percent of the shrub cover.

Table 1. Matrix of similarity coefficients, based on tree and shrub relative abundance (mean for each species), for the ten study plots. Underlined values represent the similarity coefficient between developed and undeveloped plots of the same habitat type. Plot codes are given in Figure 1.

	MEU	OWD	OWU	OSD	OSU	MCD	MCU	CCD	CCU
MED	.846	.230	.138	.101	.121	.141	.315	.196	.107
MEU		.180	.144	.219	.135	.122	.320	.197	.046
OWD			.445	.575	.525	.211	.202	.314	.079
OWU				.514	.430	.198	.230	.210	.187
OSD					.589	.108	.217	.309	.109
OSU						.244	.097	.358	.122
MCD							.507	.691	.679
MCU								.623	.426
CCD									.555

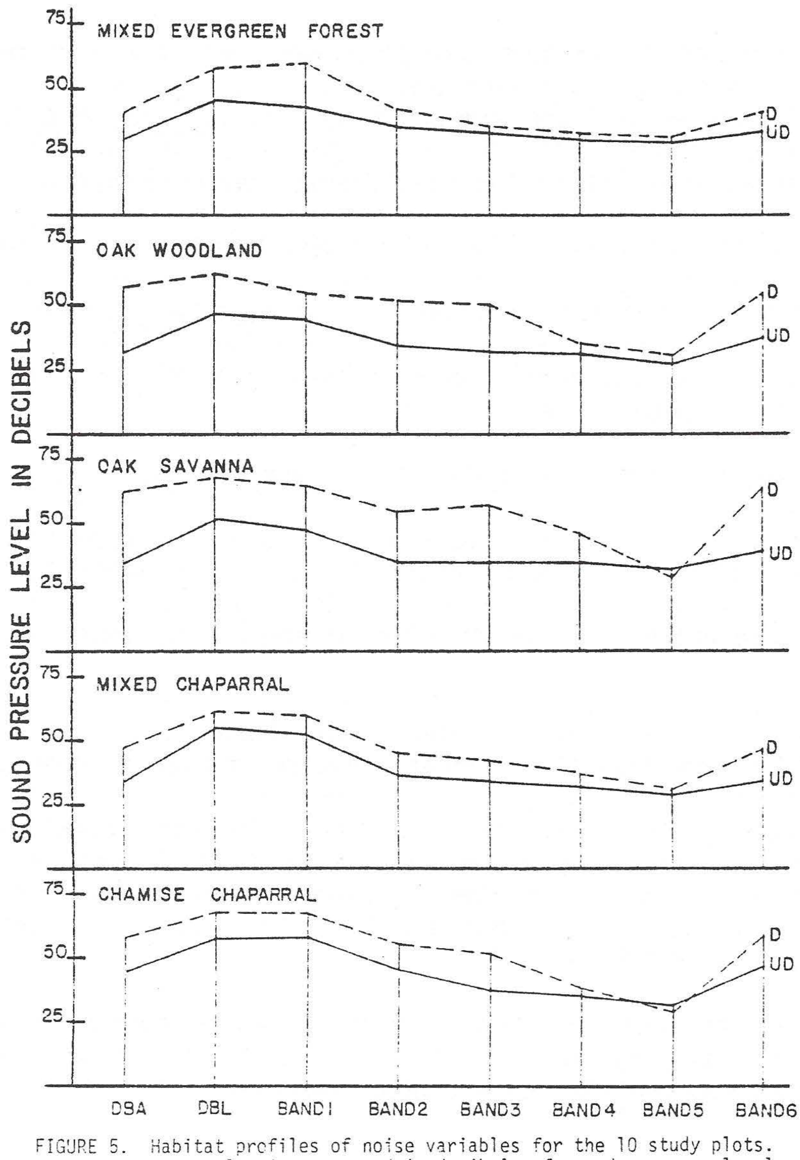

FIGURE 5. Habitat profiles of noise variables for the 10 study plots. Each value is expressed in decibels of sound pressure level. D = developed plot, UD = Undeveloped plot.

Chamise chaparral.

The developed plot had about 20 percent less shrub cover per sampling unit than the undeveloped plot; this difference was attributed to clearing for development. The undeveloped plot was strongly dominated by chamise (80 per cent of shrub cover) and had few shrub species. The developed plot, with 50 per cent chamise and a much richer species composition, is perhaps best classified as mixed chaparral.

Despite the natural differences between paired plots, most of the variation between developed and undeveloped plots is contributed by development-related parameters: decreased shrub cover, altered ground cover, and increased noise level. On the whole, the plot selections fit the comparative design reasonably well.

Distribution of Small Mammals

Small mammals as a group may be more abundant in developed than in undeveloped plots (Figure 6). By habitat, the number of small mammal captures was significantly greater in mixed evergreen and chamise chaparral developed plots, slightly greater in oak woodland and oak savanna developed plots, and nearly equal in the two mixed chaparral plots.

The additional captures in the developed plots were not equally distributed among the species. The most striking differences occurred in the abundance of the two dominant species, the deer mouse and the pinyon mouse (*Peromyscus truei*). The deer mouse replaced the pinyon mouse as the dominant species in developed plots for all habitat types except oak savanna, where the deer mouse was dominant in both plots.

Captures of both species were higher in the developed mixed evergreen plot than in the comparable undeveloped plot (Table 2), but the difference in deer mouse captures was proportionately greater than in pinyon mouse captures. In all other habitats, the deer mouse was more abundant while the pinyon mouse was less abundant in developed plots. Furthermore, this increase in deer mouse captures was proportionately greater than the decrease in pinyon mouse captures.

Habitat Associations of the Pinyon Mouse and Deer Mouse

The absolute abundance of these two dominant species increased with shrub cover. Shrub cover and other measures of protection from predators have been associated with increased small mammal densities (Glanz 1976), and increased shrub volume indicates that more niches are available for occupation by small mammals (M'Closkey 1976).

The discriminant analyses based on relative abundance of the pinyon mouse and deer mouse (Figure 7) showed that the abundance groups of both species could be separated by the same variables. However, the two species select opposite ends of the habitat continuum implied by the discriminant function. The deer mouse reaches its highest relative abundance in areas with scarce shrub cover and high noise level. This contrasts with the pinyon mouse, which reaches its lowest relative abundance at this extreme of the function. The relative abundances of these two species are negatively correlated with each other ($r = -0.88$).

Discriminant analyses were also based on the absolute abundance (captures per 120 trap-nights) of the two species. In these analyses, the absolute abundance of the competing species was included as a habitat variable.

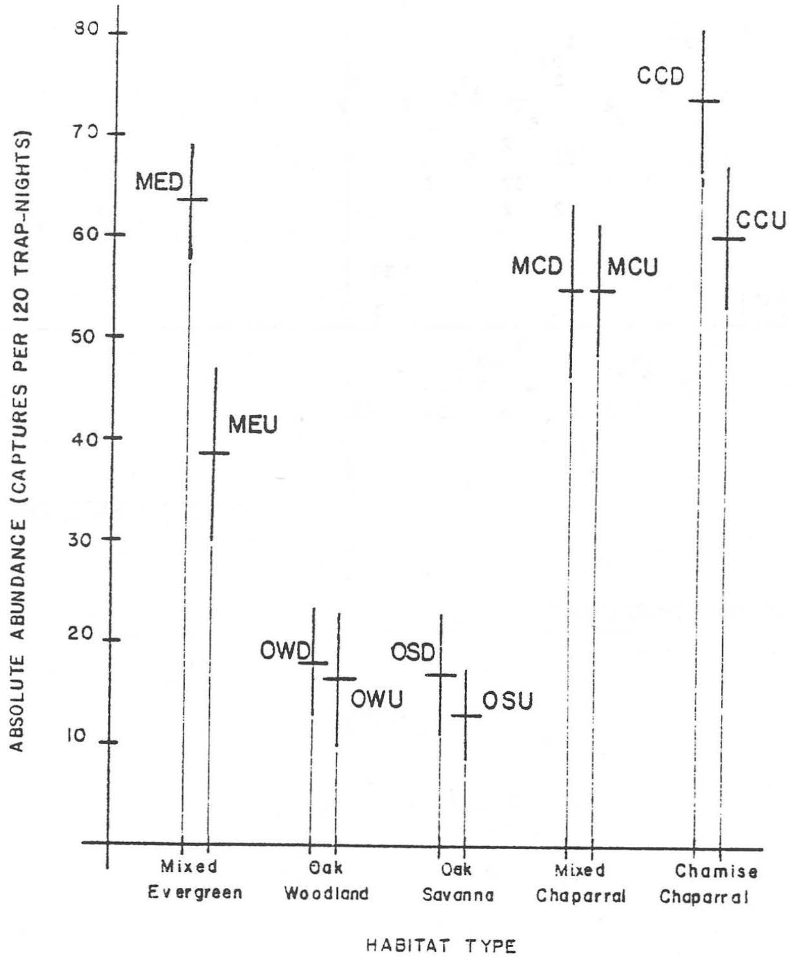

FIGURE 6. Absolute abundance (total number of captures in 120 trap-nights) for all small mammal species in the 10 study plots. N = 10 sampling units for each plot. Horizontal bars locate the plot means; dark vertical bars indicate plus or minus two standard errors.

Table 2. Abundance ratios for the two dominant small mammals, deer mouse and pinyon mouse. Each value is the ratio of species absolute abundance in a developed plot to species abundance in the undeveloped plot of the same habitat type.

Habitat type	Abundance Ratio (D : UD)	
	Deer Mouse	Pinyon Mouse
Mixed evergreen forest	3.1	1.2
Oak woodland	1.9	0.7
Oak savanna	1.6	0.1
Mixed chaparral	3.1	0.4
Chamise chaparral	1.8	0.7

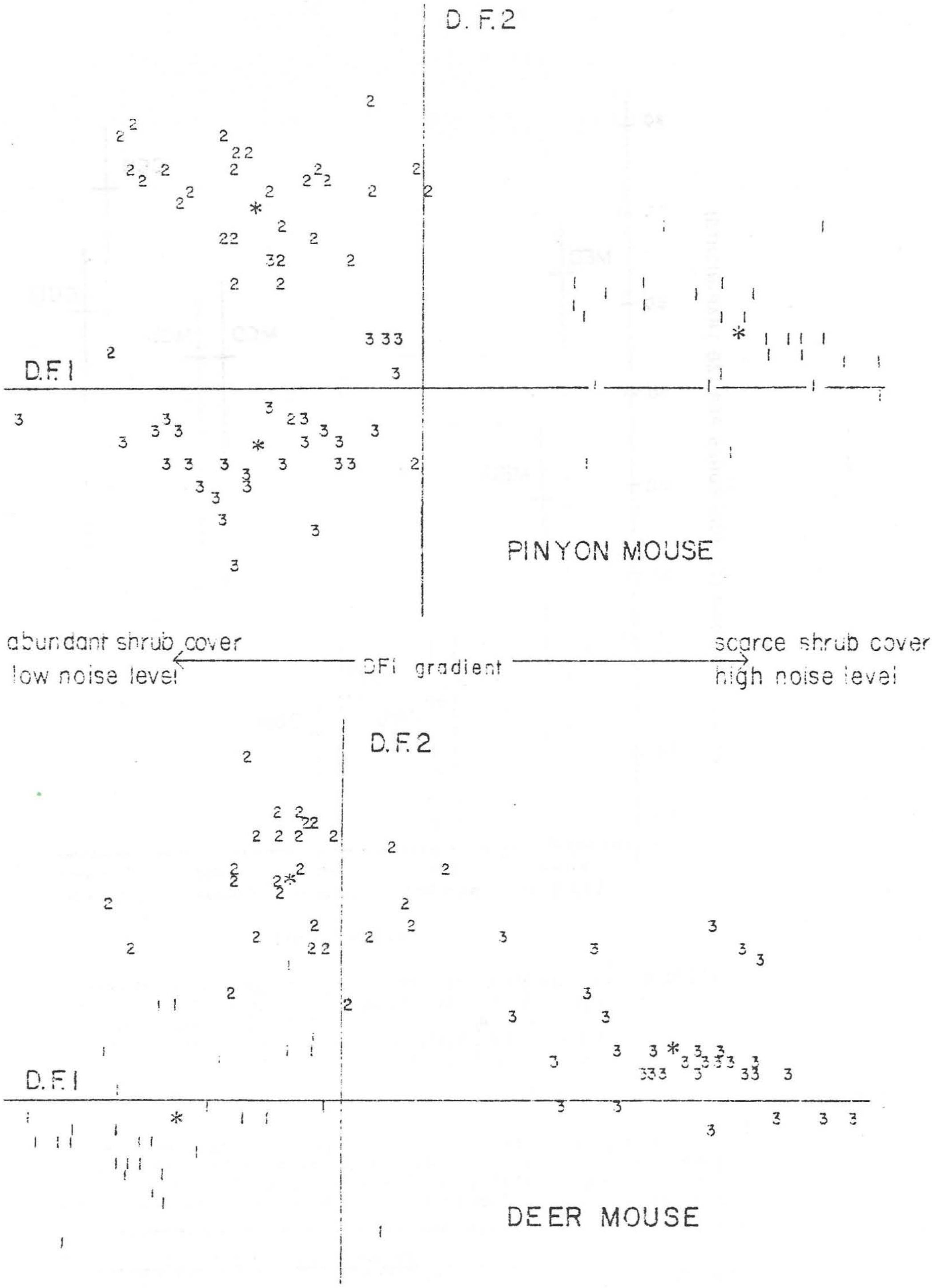

FIGURE 7. Dispersion of sampling units according to discriminant function scores for pinyon mouse and deer mouse relative abundance. Each sampling unit is located by a numeral indicating group; 1 = low, 2 = moderate, 3 = high relative abundance. Asterisks locate group centroids. The gradient trend of the first discriminant function is the same for both species.

In the analysis of absolute abundance, pinyon mouse groups were separated by shrub cover, grass cover, and medium-frequency noise level. In contrast, the most important variables separating the deer mouse groups were noise level and pinyon mouse abundance. The deer mouse reached its greatest absolute abundance in areas of high noise level and lowered pinyon mouse abundance.

The results of these analyses were synthesized in the hypothetical model shown in Figure 8. In this model, areas of pinyon mouse and deer mouse dominance are separated along a natural habitat continuum of shrub cover, presence or absence of trees, and grass versus leaf litter. The pinyon mouse is associated with abundant shrub cover, presence of trees, and leaf litter. The deer mouse dominates in grass or herbaceous cover with an absence of trees and shrubs. The "deer mouse" end of the continuum is represented in the undeveloped plots of this study by only one habitat type, oak savanna. The pinyon mouse tends to dominate in all other undeveloped plots, although patches within the plots may be more suitable for the deer mouse.

The effects of geothermal development may operate through two means; First, removal of shrub cover or alteration of ground cover may "move" an area further to the right of the continuum. Thus, a disturbed portion of the chaparral may become somewhat more suitable for the deer mouse. The second disturbance occurs with the influence of noise. As the pinyon mouse is reduced, presumably through its sensitivity to noise, the deer mouse population expands and thus becomes dominant, even in areas that may otherwise be suitable for the pinyon mouse.

DISCUSSION

The selection of study plots was largely validated by the habitat survey, but some important differences between paired plots were found. These resulted partly from use of a subjective procedure in locating the plots. However, study plot location was largely constrained by problems of accessibility, so it is doubtful that a perfect choice of paired plots could have been made.

Nonetheless, some naturally-occurring habitat differences could influence the interpretation of animal distributions. For example, the strong dominance of chamise in the undeveloped chamise chaparral plot has no comparison, on an average basis, with any of the developed plots. Thus, the greater abundance of small mammals in the developed chamise chaparral plot may be related more to the richer species composition of that plot than to the effects of geothermal development.

This problem was partly resolved by use of discriminant analysis, in which the sampling units are grouped by high or low abundance of an animal species. The relative effects of chamise abundance, noise level, or any other habitat parameter on the species can be evaluated on a unit-by-unit basis. Thus, spurious correlations that may result from the subjective plot selection are reduced.

The discriminant analyses for the two dominant species, pinyon mouse and deer mouse, indicated a competitive interaction that appeared to be related to the effects of development. Thus, when other habitat factors were accounted for, the pinyon mouse was less abundant in sampling units with elevated noise levels. The deer mouse

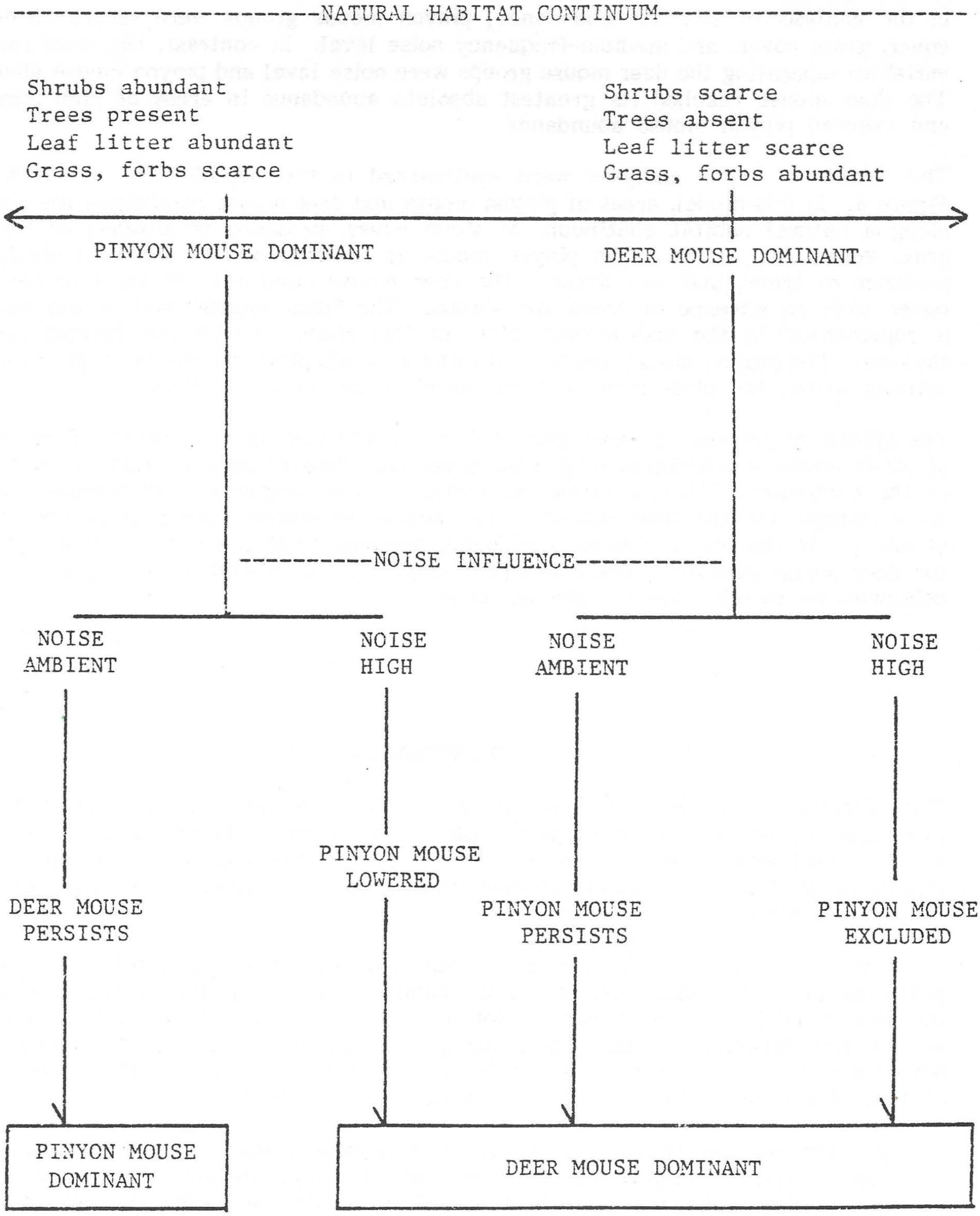

Figure 8. Hypothetical model of pinyon mouse - deer mouse relationships as determined by habitat and noise.

apparently responded to lowered pinyon mouse numbers by increasing beyond the typical population level of the undeveloped plots.

The habitat-relationship models that were developed for the dominant species illustrate some advantages of the multivariate approach to ecological field studies. Discriminant analysis and other multivariate techniques are powerful tools for discerning meaningful patterns within large quantities of field data. The results of this discriminant analysis, together with information from standard statistical methods, yielded hypothetical models that lend themselves to testing in experimental situations.

The use of multivariate analysis demands a careful approach to collection of the field data. This demand resulted in the development of a sampling unit for field use in this study. Replication of the sampling unit 10 times in each study plot not only assured that assumptions for discriminant analysis would be met, but also provided a very efficient means of organizing the field work. Also, the data matrix derived from the sampling unit replication allowed great flexibility in statistical analysis.

Multivariate analysis should receive wider use in ecological studies. More work needs to be done to (1) develop optimum sampling units for collection of data applicable to small mammals and other animal groups, (2) select the proper habitat parameters for each animal group and develop suitable ways to measure them, and (3) identify suitable packages of computer programs and train biologists in their use.

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