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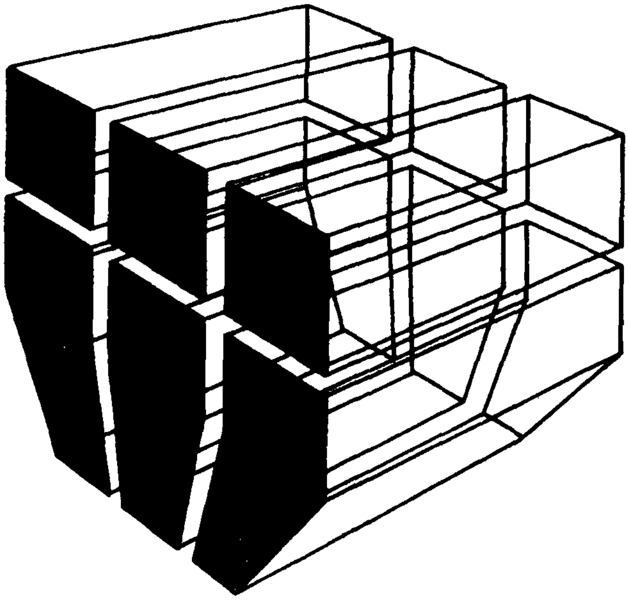
ECOLOGICAL ASSESSMENT OF THE EFFECTS OF ARMY TRAINING ACTIVITIES ON A DESERT ECOSYSTEM: NATIONAL TRAINING CENTER, FORT IRWIN, CALIFORNIA

by
Anthony J. Krzysik

This report describes a study conducted at Fort Irwin, California, to assess the effects of large-scale Army training maneuvers and war game scenarios on the installation's desert ecosystem. Additional objectives of the study were to develop rigorous methodologies for quantifying environmental impact assessments, to describe species/habitat associations, and to quantitatively summarize the relative relationships of experimental and control sites on the basis of vertebrate community structure.

The data obtained showed that creosote bush cover or volume was the best indicator for monitoring ecosystem degradation. The Brewer's and sage sparrows, the little pocket mouse, and the southern grasshopper mouse were identified as sensitive indicators of disturbances. The absence of black-throated sparrows and LeConte's thrashers indicate severely degraded habitats. The presence of the desert kangaroo rat is associated with very low shrub and ground cover and loose, sandy substrates—both characteristic of heavily trained areas. Several analytical approaches were developed to evaluate environmental impacts: *a priori* orthogonal contrasts, *a posteriori* range tests, canonical analysis of discriminance, and principal components analysis.



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This report describes a study conducted in the spring of 1983 at Fort Irwin, California, to assess the effects of large-scale Army training maneuvers and war game scenarios on the installation's desert ecosystem. Additional objectives of the study were to develop rigorous methodologies for quantifying environmental impact assessments, to describe species/habitat associations, and to quantitatively summarize the relative relationships of experimental and control sites on the basis of vertebrate community structure.

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The field studies were conducted on five sites: two were controls while the others represented three gradations of environmental impacts. The data collected on habitat structure, birds, and small mammals were subjected to rigorous univariate and multivariate analyses and the results evaluated.

The data obtained showed that creosote bush cover or volume was the best indicator for monitoring ecosystem degradation. The Brewer's and sage sparrows, the little pocket mouse, and the southern grasshopper mouse were identified as sensitive indicators of disturbances caused by Army training activities. The absence of black-throated sparrows and LeConte's thrashers indicate severely degraded habitats. The presence of the desert kangaroo rat is associated with very low shrub and ground cover and loose, sandy substrates--both characteristic of heavily trained areas.

Several analytical approaches were developed to evaluate environmental impacts. *A priori* orthogonal contrasts were recommended as the most valid approach, and *a posteriori* range tests (multiple comparisons) were shown to be useful for examining within and between habitat heterogeneity. Canonical analysis of discriminance was useful for selecting linearly independent subsets of habitat (environmental) variables from the original data set. Principal components analysis, which extracted weighted linear combinations of habitat variables, was an effective dimension reduction technique for ordinating species in habitat space.

Species/habitat associations for the bird and small mammall communities were described using a quantitative multivariate framework. A method was developed that corrected for unequal species sample sizes, and also associated species-abundance patterns with specific habitat features (Refs. 67,68).

Canonical analyses of discriminance were used to classify the five sites in a three-dimensional space defined by species-abundance patterns. The bird community proved to be a good indicator for classifying study sites on the basis of environmental impacts. The structure of small mammal communities was also a good indicator, but was not as effective, since kangaroo rats benefited from several aspects of habitat disturbance.

FOREWORD

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Dr. R. K. Jain is Chief of USA-CERL-EN. COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INRODUCTION

Background

Most early studies of deserts were descriptive, autecological, or centered on physiological adaptations (Refs. 105, 80, 54, and 9).* When ecology entered the MacArthurian era, attention focused on vertebrate community structure. Desert ecosystems have played an important role in these studies, particularly in studies of mammals (Refs. 101, 17, 81, 94, 122, 64), but also of lizards (Refs. 91, 92, 20, 29), snakes (Ref. 19), and birds (Ref. 125). Recently there has been a great deal of interest in the impact of off-road vehicles (ORVs) on desert communities (Refs. 22, 132, 21, 75, 78, 12, 134).

The desert environment of the Army National Training Center at Fort Irwin, CA, is an important natural resource for the Army's training mission. However, increased levels of training and the resulting ecological impact on fragile communities is a growing concern. Fort Irwin is located in the central Mojave Desert (35°38'-35°8' N, 116°56'-116°19' W) south of Death Valley in San Bernardino County, southeastern California. The fort, which occupies 260 245 ha, has been in operation periodically since 1940, but training efforts have intensified since the late 1970s.

The predominant environmental damage occurs during large-scale war game scenarios involving several thousand participants. As of 1983, these exercises operated year-round on a 2 weeks on-off schedule. However, in early 1985 the training rotations intensified to the point that there was only about 5 days between scheduled training maneuvers. The extensive use of tactical vehicles includes tracked vehicles (tanks, self-propelled howitzers, and armored personnel carriers) and a wide assortment of four-wheel drive trucks, jeeps, and motorcycles. Tracked vehicles, despite their high weights (62 tons for an M1 tank), possess low unit loading (about 1.8 kg/cm^2 for the M1), and therefore compact soil less than trucks. However, tracked vehicles disrupt soil surface integrity and shuffle substrate layers, especially when they make sharp turns.

A more thorough understanding of the effects of Army training in this desert requires more detailed knowledge of ecological processes. This study was motivated by several factors related to expanding the Army's knowledge about the central Mojave Desert ecosystem:

1. Habitat disturbances on a large scale over extensive areas of desert provide a unique experimental setting for quantifying species-habitat associations.

2. The flora, fauna, and habitat structure of the Mojave Desert is reasonably simple, and is therefore easier to study and analyze than "richer" ecosystems since the data structure may be less complex and redundant.

*References cited in parentheses appear on pp 119 through 127.

3. The scarcity of references in the literature clearly demonstrates that the central Mojave Desert has not been well studied compared to other western deserts or even other parts of the Mojave. This is particularly true with regard to the effects of ORVs and habitat changes on animal communities. This lack of data can be attributed to the remoteness of the region and the fact that much of the land is controlled by the Department of Defense and therefore closed to the public.

4. Research dealing with the effects of ORVs on desert communities is important for several reasons:

a. ORV enthusiasts are lobbying and pressuring the Bureau of Land Management to make more land available for ORV recreation.

b. Arid ecosystems are environmentally fragile.

c. Desert successional dynamics are not understood.

d. Impact recovery rates of deserts are very low (some communities may never return to their original preimpact structure).

5. An investigation into the environmental effects of Army training activities on a desert ecosystem would complement parallel USA-CERL studies in other ecosystems (Refs. 110, 109, 108, 33, 34).

Objective

The objectives of this study were to (1) assess, in an analytical framework and on a firm statistical basis, the effects of large-scale Army training maneuvers and war game scenarios on the desert ecosystem at Fort Irwin and identify specific habitat (environmental) variables to quantify these impacts; (2) develop rigorous, robust analytical methodologies for quantifying environmental impact assessments; (3) analytically decipher, describe, and summarize species-habitat associations; (4) quantitatively summarize the relative relationships of experimental and control sites on the basis of vertebrate community structure.

The information obtained will provide guidelines for managing desert nongame species and ecological communities. The approach used in this study can be applied directly to any ecosystem with any type of impacts.

Approach

Field studies were conducted at Fort Irwin between 28 March and 4 May 1983 to quantify cause-effect relationships between Army training activities and Mojave Desert ecological associations. The study sites selected represented three gradations of environmental impact, as judged by soil and shrub disturbance. Two unimpacted sites were selected as controls for statistical comparisons. Data were collected on habitat structure, birds, and small mammals. The data were subjected to rigorous univariate and multivariate analytical/statistical procedures and the results evaluated.

8, 9, and 10. With few exceptions, there was little variability among transects within a site. (Note that the two statistical procedures are in very close agreement.)

The data show that Army training activities significantly increase the percentage of surface sand (particle size < 3 mm) while decreasing the percentage of larger particles--coarse sand (3 mm to < 1 cm) in valleys, and gravel (1 to 8 cm) on alluvials (Table 2, $P < 0.001$).

Forb cover (nonwoody annual and perennial vegetation, excluding grasses and ferns) was characteristic of the alluvial control site and the high desert. Impacted sites possessed much less forb cover than their respective control sites ($P \leq 0.008$).

Although grass was distributed throughout the study sites, it was closely associated with valleys and the impacted alluvial. Grass cover was low in the high desert and very high on a single valley control transect. This same transect correspondingly possessed very low forb cover.

There was much more bare ground at impacted sites in comparison to their respective controls ($P < 0.001$). The two control sites had a similar percentage of ground cover. The first two transects in the high desert and the control sites had a similar degree of ground cover, but the other two transects were similar to the impacted sites. There was a great deal of barren desert pavement on the last two transects.

Although litter was more abundant on the controls than on the impacted sites (Figure 19), several transects on the controls had very low values, making statistical interpretation tenuous. This may result from the high percentage of ground cover masking the litter layer during sampling; transects AC3 and VC1 were among those with the highest ground cover.

Canonical analysis of discriminance (CAD) was initially used to select a subset of habitat variables from the original 58 variables. Table 3 summarizes this analysis (Appendix E defines the variables). Figure 20 shows the power of these variables to discriminate among the five study sites (+ indicates group centroids). Note that CDF I in Figure 20, which accounts for 78.5 percent of the data variance, reflects the degree of habitat disturbance, and is based mainly on the cover of creosote bush and burroweed. CDF II represents a combination of substrate and vegetation characteristics such that unimpacted or slightly disturbed habitats have a positive score for valleys and a negative score for alluvials/high desert. Disturbed sites score along the null axis. CDF III is not ecologically interpretable--a common problem of CAD. Nevertheless, even this axis extracts a combination of original variables that divide the sites into two groups.

Principal components analysis (PCA) was performed on a subset of 25 habitat variables (Ref. 68). Table 4 is the matrix of habitat variable loadings on the first four principal components (Appendix E defines the variables). The numbers represent regression weights, as well as correlation coefficients, since this is an orthogonal factor matrix. Table 5 summarizes the principal components analysis by showing how the first four principal components partition the major portion of the variance present in the original data set. These components account for 78.2 percent of the variance associated with the original 25 habitat variables.

PC I represents a gradient from tall and dense cover of creosote bush and burroweed (also forbs and coarse sand) contrasting a high variability of creosote bush size (crushed or trampled shrubs) associated with sandy substrates. This gradient reflects the degree of habitat disturbance in the Mojave Desert.

Army training activities significantly decreased creosote bush and burroweed density, but not the density of subdominants (12 species total).

Figure 7 shows mean shrub size (diameter and height) at the five study sites. Figures 8, 9, and 10 summarize intra- and intersite variability and the *a posteriori* range tests for statistical evaluation. These figures are interpreted in the same manner as Figures 4, 5, and 6. Although there was a great deal of variability in mean diameter and mean height, both within and between study sites, impacted sites consistently had statistically significant shorter and smaller-diameter creosote bush and burroweed. Statistically significant smaller (both height and diameter) shrubs of these species were found in the severely impacted area (a valley) compared to the moderately impacted area. This is even more significant if one considers that the valley control site had the tallest and broadest creosote bush and burroweed. Figure 10, which evaluates combined data from 12 subdominant species, is not easily interpreted. More data is needed so that each species can be evaluated separately. Intrasite variability in subdominants at L and AC, but surprisingly not at M, was due to an intertransect difference in species compositions. Although the severely impacted site had the shortest subdominant shrub individuals, there is no overall pattern that would clarify the effects of environmental impacts.

Table 1* shows *a priori* orthogonal contrasts, which are more reliable than *a posteriori* range tests. This analysis reached identical conclusions and substantiates the statistical inferences of the range tests.

Shrub volume (m^3/ha) summarizes shrub biomass, since its measure includes density, diameter, and height (Figure 11). Note that the scale on the ordinate changes by a magnitude of five between each of the three shrub groups. Several features of this figure are worth reemphasis: (1) the predominance of creosote bush as the main three-dimensional structural component of the Mojave Desert ecosystem; (2) the close inverse relationship of creosote bush volume to the degree of environmental impact; (3) the sensitivity of burroweed to environmental disturbance and its scarcity in the high desert; (4) the greater abundance of subdominant shrub species on alluvials and the high desert than in valleys, which, as a group, was only slightly affected by disturbance (grouping may mask species changes); and (5) the similarity of the lightly impacted high desert to the control sites.

Figure 12 shows the contribution to shrub cover of each of four shrub height categories at half-meter intervals. Vegetation layers greater than 1 m consisted of creosote bush, since the other 13 species of shrubs were usually less than 0.5 m high and always less than 1 m. Figure 13 summarizes the relative relationships of the four shrub heights among the five study sites. The 25 percent line would be the loci of points if the four categories possessed equal shrub cover at each site. These figures show that: (1) creosote bush grows taller in valleys than on alluvials (the high desert was intermediate); (2) shrubs more than 1 m tall dominated woody cover in lightly or unimpacted sites, while shrubs less than 1 m high dominated impacted Mojave Desert landscapes; (3) the moderately impacted alluvial site came closest to possessing equal shrub height categories or high vertical heterogeneity (site M was consistently close to the 25 percent line).

Figures 14 and 15 show the substrate characteristics and ground cover at the five study sites. Table 2 summarizes the statistical analysis. Figures 16 through 19 compare intrasite and intersite variability. The format used is identical to that in Figures 4, 5, 6,

*Tables begin on page 41.

4 DATA ANALYSIS

Habitat Structure

Figure 1* shows the cover (m^2/ha) of the eight most abundant woody species at each of the five study sites. (Appendix D lists all the species and their scientific names.) Two species--creosote bush (*Larrea tridentata*) and burroweed (*Ambrosia dumosa*), also known as burrobush or white bur-sage--are codominants and constitute most of the woody vegetation. Figure 2 is comparable data showing shrub density (number of individuals/ha) as the habitat parameter. Although creosote bush, which was larger in diameter and height, dominated shrub cover, the smaller burroweed was more abundant.

The relative magnitude of Army training activities shows a close inverse relationship to the cover and density of these dominant shrub species. Burroweed may be more sensitive to disturbance than creosote bush. It also possesses a low density in the lightly impacted high desert, where it is patchily distributed, generally being found along washes. Intersite differences in subdominant shrub species were observed, but more extensive field work is needed to substantiate and define the ecological relevance of the patterns.

The high desert and alluvials possessed more cover of subdominant shrub species than valley sites. Turpentine broom (*Thamnosma montana*) was restricted primarily to the high desert. Desert cassia (*Cassia armata*) and Mormon tea (*Ephedra* spp.), were predominantly found at the moderately impacted alluvial. Spiny hopsage (*Grayia spinosa*) and goldenhead (*Acamptopappus sphaerocephalus*) were found only in unimpacted sites. Cheesebush (*Hymenoclea salsola*) was most abundant at heavily impacted sites, but was also found in unimpacted areas, being strongly associated with washes (areas of environmental disturbance).

Cacti individuals were scarce, and only four species were observed (see Appendix D). Several Joshua trees (*Yucca brevifolia*) were present at the high desert site.

Figure 3 shows the percent species composition of shrubs at the five study sites. The data suggest that environmental impacts in valleys decreased the dominance of burroweed and increased the relative importance of other shrub species (primarily cheesebush). The importance of subdominant species to shrub biomass also increased slightly when alluvials were impacted.

Figures 4, 5, and 6 statistically summarize the variability of shrub densities within and between study sites. These data represent the statistical validation of the intersite comparisons given in Figure 2. The loci represent the mean number of shrub individuals per hectare; the numbers refer to individual transects within a study site. The vertical lines connecting transect means and the horizontal lines connecting study sites are enclosing means that are statistically similar based on the indicated *a posteriori* range tests at the indicated level of significance. A discussion of range tests is provided on p 21. Note that the sites are ordered horizontally by the magnitude of their means, and that variability between sites is greater than within sites. There was statistically significant intrasite variability for creosote bush at the alluvial control site, for burroweed at the moderately impacted alluvial site, and for subdominants at the severely impacted site.

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*Figures begin on p 62.

The literature provides additional information (Refs. 28, 120, 52, 86, 44, 93, 38, 3, 35, 106) and an excellent review of statistical designs and data handling as applied to environmental assessments (Ref. 45).

All univariate and multivariate statistical analyses were performed using the SPSS statistical package (Ref. 89).

$$R^2 = \frac{SS_{REG}}{SS_y}$$ [Eq 12]

Based on Eqs 10, 11, and 12, and applying hierarchical multiple regression analysis, solutions to the following partitioned sums of squares can be obtained:

Total sums of squares $SS_y\,(R^2_{x,s,xs})$ [Eq 13]

Sums of squares due to x and s $SS_y\,(R^2_{x,s})$ [Eq 14]

Sums of squares due to s (adjusted for x) $SS_y\,(R^2_{x,s} - R^2_x)$ [Eq 15]

Sums of squares due to x (adjusted for s) $SS_y\,(R^2_{x,s} - R^2_s)$ [Eq 16]

Sums of squares due to interaction $SS_y\,(R^2_{x,s,xs} - R^2_{x,s})$ [Eq 17]

Sums of squares of residuals $SS_y\,(1 - R^2_{x,s,xs})$ [Eq 18]

Dividing the solutions of Eqs 13 through 18 by the appropriate degrees of freedom produces the desired mean squares (MS). Statistical significance is based on the F-test, where,

$$F = \frac{MS_i}{MS_{residuals}},$$

as in ANOVA; i refers to Eqs 13 through 17 above. Eq 17 is particularly interesting, since a significant interaction term shows that the slopes of the regression lines are heterogeneous (significantly different). The literature provides excellent discussions of analysis of covariance (Refs. 115, 88).

Multivariate Analyses

The multivariate strategy used in this study and its justification is detailed elsewhere (Refs. 67, 68). Principal components analysis (PCA) was used as a dimension reduction technique to extract small correlated subsets of variables that nevertheless retained a substantial portion of the original data variance. PC analyses were performed on Pearson correlation matrices. All solutions were varimax rotated. In this way, individual bird or mammal species were positioned relative to one another in a three-dimensional space. This space was defined by specific-habitat (environmental) variables closely associated with species-habitat preferences. A hybrid ordination was used to completely eliminate multivariate spatial distortions caused by unequal species sample sizes (Refs. 67, 68).

Canonical analysis of discriminance (CAD) was used to discriminate or analytically separate the five study sites in a three-dimensional space defined by habitat variables or bird or mammal species abundance patterns. This type of analysis quantitatively assesses or characterizes habitats on the basis of their faunal compositions.

procedure is *a priori* orthogonal contrasts (Ref. 116). This procedure allows independent (orthogonal) contrasts to be made of treatment pairs selected before the experimental results are known (e.g., in this report, the severely and moderately impacted sites were compared to their respective controls). Unequal sample sizes were adjusted so that the weighted sum of cross-products was equal to zero. Mean squares were pooled for variance estimates, and Bartlett's test was used to evaluate homoscedasticity.

A posteriori range tests (multiple comparisons) were used to compare transect and intersite means relative to one another. Although they lack the power and resolution of orthogonal contrasts (since statisticians have had difficulties developing exact probabilities for α and β errors), they were included so that intrasite and intersite variability could be examined. There are seven commonly used methods; since each could be used with a wide range of α's, the possible combinations are staggering. Three tests have been used for this study: Duncan, SNK, and Scheffe (listed in order of minimizing α error). The SNK (0.05) represents a good compromise in considering α and β errors. The Scheffe test is very conservative, minimizing α error, but increasing the chances of β error. In other words, when this test shows a significant difference between two or more means, one is pretty certain that this is indeed the case; however, interpretational discretion must be used when the test suggests "no significant difference." Sokal and Rohlf (Ref. 116) clearly discuss α and β errors and pertinent ANOVA principles.

Analysis of Covariance

The analysis of covariance was based on the following regression model:

$$Y' = A + B_n X + \sum_{i=1}^{n-1} B_i S_i + \sum_{i=1}^{n-1} B_{i+n} S_i X \qquad \text{[Eq 10]}$$

where:

Y' = least squares estimate of the dependent variable

A = intercept

B = slope

n = number of sites being compared

X = the metric independent variable (covariate)

S = the categorical variable for sites, coded by dummy variables.

In regression, the total sums of squares can be partitioned into two parts: a component that is explained by the regression, and a component that is unexplained (the error or residuals).

$$SS_y = SS_{REG} + SS_{RES} \qquad \text{[Eq 11]}$$

The percent of sums of squares that is explained by regression is equal to the square of the multiple correlation coefficient.

3 STATISTICAL ANALYSIS METHODS

Variable Transformations

The validity of most statistical procedures rests on many assumptions: randomness, independence of sampling errors, homogeneous sample variances, normal distribution of variables, linear variable relationships, and sample means uncorrelated with the variance or standard deviation. Typical biological data incur these problems, especially skewness and heteroscedasticity. Also, larger means are usually associated with larger standard deviations, and low-frequency events follow a Poisson distribution. In a Poisson distribution the mean and variance are equal. Linear relationships and normal distributions are the exceptions. Appropriate transformations of the original raw data values vastly improve the fit of environmental variables to parametric assumptions. Transformation utility is generally based on experience. A good foundation and review is provided in Sokal and Rohlf (Ref. 116). Appendix C gives the transformations used for all the habitat (environmental) variables.

Calculations of basic descriptive statistics (means, standard deviations, etc., as well as regression parameters) were performed on the original variables.

Analysis of Variance

The focal point of the statistical inference is based on use of transect replicates; thus, within treatments (or controls), variability can be analytically contrasted to the variability between treatments and respective controls--the basis for analysis of variance (ANOVA). *Although such an experimental design is mandatory, it is frequently ignored in* environmental impact assessments. Impacted sites cannot be differentiated from controls unless the inherent environmental variance present in the experimental entities is known.

Fundamentally, ANOVA produces a test statistic (F) which is the ratio of intertreatment variance of sample means to the variance within treatments. The magnitude of F is a direct measure of the probability of F occurring by chance alone. Generally, the accepted margin for error is 5 percent. Two or more sample means (treatments) will be accepted as being significantly different if the calculated F is larger than a value based on the theoretical F-distribution at the 0.05 level (each sample size and number of treatments has a separate F-distribution). Of course, five out of 100 comparisons will be in error (e.g., treatment means are, in reality, from the same population, and the calculated "high value" of F arose by chance alone). This is called α error, or Type I. If the chances for α error are reduced by lowering the acceptance level to, say, 1 percent, the chances of making β error (Type II) increase (finding that the treatment means are not significantly different when, in reality, they belong to different populations). Experience and the experimental setting guides the choice of significance levels. For this study, the tendency has been to minimize α error, which increases the confidence one has in statistically judging impacted sites as being different from their respective controls.

A common statistical abuse is to pair up all possible combinations of treatments and use a t-test (ANOVA of two groups) to compare each pair. For five treatments, there are 10 possible pairs of comparisons, $n(n-1)/2$. This is totally inappropriate, since the contrasts are not independent and the α error is much higher than anticipated from the t-table. After the experiment, the researcher must not look over the data and select "after the fact" a pair of treatment extremes for statistical validation. The correct coefficient of variation calculated from the four vegetation transects. The mean from all the bird transects at a given site therefore determined horizontal heterogeneity.

$$H_{xp} = (1/J_x) \sum_{j=1}^{J_x} SD_{xpj}/\bar{X}_{xpj} \qquad \text{[Eq 9]}$$

where:

H_{xp} = index of horizontal heterogeneity of parameter p (p = shrub diameter, height, or density.)

SD_{xpj} = standard deviation of parameter p in the j^{th} bird transect at site x

$\bar{X}_{xpj}$ = the mean of parameter p in the j^{th} bird transect at site x

J_x =as in Eq 3.

where:

V_{xs} = volume of species s at site x (m^3/ha)

H_{xsi} = height (m) of the i^{th} individual of species s at site x.

Ground cover was calculated as:

$$G_{xg} = (1/2J_x) \sum_{j=1}^{J_x} \sum_{k=1}^{4} P_{xgjk} \qquad \text{[Eq 6]}$$

where:

G_{xg} = percent ground cover of g (grass, forbs, or litter) at site x

J_x = as in Eq 3

P_{xgjk} = number of "hits" of g in the k^{th} shrub transect of the j^{th} bird transect at site x.

Substrate particle size distribution was calculated as:

$$S_{xp} = \sum_{j=1}^{J_x} \sum_{k=1}^{4} P_{xpjk} / \sum_{p=1}^{4} \sum_{j=1}^{J_x} \sum_{k=1}^{4} P_{xpjk} \qquad \text{[Eq 7]}$$

where:

S_{xp} = percent of surface substrate of particle size p at site x

P_{xpjk} = number of "hits" of particle size p in the k^{th} shrub transect of the j^{th} bird transect at site x.

Vertical heterogeneity was calculated as:

$$L_x = 1 / \sum_{i=1}^{4} p_{xi}^2 \qquad \text{[Eq 8]}$$

where:

L_x = index of vertical heterogeneity at site x

P_{xi} = proportion of shrub cover in the i^{th} layer at site x. The four height layers are: < 0.5 m, 0.5 to < 1 m, 1 to < 1.5 m, $\geq$ 1.5 m.

Horizontal heterogenity was defined as the *mean within transect heterogeneity* of three shub parameters: diameter, height and density. Within transects heterogeneity was the ground surface), sand (< 3 mm), coarse sand (3 mm to < 1 cm), gravel (1 to 8 cm), and rock (> 8 cm).

All habitat variable data were collected betrween 20 and 30 April 1983.

Shrub density was calculated as:

$$I_{xs} = (10^4/16J_x) \sum_{j=1}^{J_x} \sum_{k=1}^{4} N_{xsjk}/L_{xjk} \qquad \text{[Eq 3]}$$

where:

I_{xs} = density of species s at site x (shrubs/ha)

J_x = number of bird transects at site x

N_{xsjk} = number of individual shrubs in the k^{th} shrub transect of the j^{th} bird transect of species s at site x

L_{xjk} = length of the k^{th} shrub transect of the j^{th} bird transect at site x

Shrub cover was calculated as:

$$C_{xs} = (10^4/4) \sum_{i=1}^{N_{xs}} \pi(D_{xsi}/2)^2 / \sum_{j=1}^{J_x} \sum_{k=1}^{4} L_{xjk} \qquad \text{[Eq 4]}$$

where:

Cxs = cover of species s at site x (m^2/ha)

D_{xsi} = diameter (m) of the i^{th} individual of species s at site x

N_{xs} = sample size of species s at site x

J_x = as in Eq 3

L_{xjk} = as in Eq 3.

Shrub volume was calculated by modifying one of the terms of the shrub cover equation:

$$V_{xs} = (10^4/4) \sum_{i=1}^{N_{xs}} \pi H_{xsi} (D_{xsi}/2)^2 / \sum_{j=1}^{J_x} \sum_{k=1}^{4} L_{xjk} \qquad \text{[Eq 5]}$$

period of four nights between 2 and 24 April 1983. 164 to 210 traps were baited per night at each site, and the total trapping effort was 3121 trap-nights. An index of trapping success was used to standardize trapping effort per trap-line.

RELATIVE TRAPPING SUCCESS = CAPTURES x 1000/TRAP-NIGHTS.

Small mammal biomass was calculated as:

$$M_x = (1/41) \sum_{i=1}^{n_{xj}} \sum_{j=1}^{4} m_i \, C_{xij}/T_{xj} \qquad \text{[Eq 2]}$$

where:

M_x = mean relataive biomass of mammals at site x

m_i = mean weight of mammal species i (Appendix B)

C_{xij} = captures of species i at the j^{th} trap-line at site x

T_{xj} = trap-nights on the j^{th} trap-line at site x

n_{xj} = number of mammal species captured on the j^{th} trap-line at site x

Habitat Structure

Four vegetation transects were located along each bird transect. The origin of each was at the 100-, 300-, 500-, and 700-m loci of the bird transect. The compass bearing of the transect was randomly determined by casting dice and using a technique such that all integers between and including 0 through 359 had an equal probability of occurrence. Vegetation transects were 100- x 4-m (50- x 4-m transects were used when shrub density was high). Each woody plant (height $\geq$ 0.2 m) whose center fell within the transect was identified, and its average diameter (measured at its maximum horizontal projection) and maximum height were recorded to the nearest 0.1 m.

Desert shrub individuals, particularly creosote bush, are not easily delimited (Refs. 39, 63). Creosote bush scrub consists of circular or semi-circular bands of clonal growth patterns. The center of the shrub dies, but is replaced on the periphery by new stem growth from the roots. The resulting growth pattern is a ring of circular or elliptical satellite clumps with a barren center (Refs. 118, 128). Therefore, delineation of shrub individuals was somewhat subjective. Shrubs were judged as individuals when their foliage was separated by at least 10 cm or when their respective radii were clearly outlined (e.g., burroweed foliage occurs in dense, compact spherical clusters). The use of cover (m^2/ha) as the measure of woody species dominance was more appropriate and less ambiguous than density (shrubs/ha), since cover includes both density and diameter. Cover was therefore independent of subjective observer judgments in selecting individuals.

Each vegetation transect was traversed; every 2 m, a sighting tube with crosshairs was used to record 50 "ground hits" from the following categories: grass, forb (nonwoody annual and perennial vegetation), litter (dry and decaying plant material lying on the that persistently occupied the same area (territory). Migrants or transients did not meet either of these criteria. A 1:1 sex ratio was assumed for all species. This may underestimate the density of horned larks, since this species is often polygynous (e.g., a male may possess two females in his territory). Species that possessed extensive home ranges or were represented by fewer than four individuals were not included.

A possible disadvantage of estimating breeding birds from transects is that the high ratio of perimeter length to transect area causes population sizes to be overestimated. The method used in this study was based on four very important considerations:

1. Any method of avian sampling in any habitat using visual and/or auditory cues drastically underestimates bird population sizes (Refs. 32, 95, 26).

2. Accurate relative numbers are more important than absolute numbers in species as well as study site comparisons.

3. Nesting females are generally more cryptic and shy than males (both visually and vocally), and both dimorphic and monomorphic species are present. Therefore, interspecies comparisons of relative numbers of birds is inaccurate if only birds that are flushed or seen on a transect are averaged in the combined censuses and used as population estimates.

4. The territory sizes of these species are reasonably small compared to the transect sizes.

Bird biomass was calculated as:

$$B_x = (1/J_x) \sum_{i=1}^{n_{xj}} \sum_{j=1}^{J_x} m_i \, P_{xij} \qquad \text{[Eq 1]}$$

where:

B_x = mean transect biomass of birds at site x

m_i = mean weight of bird species i (Appendix B)

P_{xij} = population estimate of species i on the j^{th} transect at site x

J_x = number of bird transects at site x

n_{xj} = number of bird species on the j^{th} transect at site x.

Small Mammals

Small mammals were collected using museum specials and rat traps (10 percent of the traps) baited with rolled oats and peanut butter. Because of severe time constraints, two different trapping grids had to be used; however, the two grids were expected to yield comparable results. At the severely and moderately impacted sites, four trap-lines were laid out directly over the center lines of the bird transects. The traps were placed at 15-m intervals. At the other three sites, the four trap-lines were also located in the central portion of the study area. Each line was 400 m long, with 80 m between trap-lines. The traps were placed at 10-m intervals. Trapping was generally conducted over a

2 DATA COLLECTION

Study Sites

The central Mojave Desert consists of broad valley plains (bajadas) located between rugged mountain ranges and of occasional high plateaus and dry lake beds (playas). At the base of the mountains are alluvial fans which gradually slope into the valleys. Alluvial substrates, formed by erosional breakdown of the mountains, are gravelly or rocky. Boulder fields or large rubble occasionally adjoin the mountains. The literature reviews the formation of the Mojave Desert and basic geological features (Refs. 27, 139), the paleobotany and evolution of Mojave Desert vegetation (Refs. 4, 5, 6, 7, 96), Mojave Desert boundaries, plant associations, and communities (Refs. 129, 103).

Study sites that represented Mojave's habitat types were carefully selected on the basis of several predetermined criteria. Habitat types must be: (1) relatively homogeneous and occupy large extensive areas, (2) characteristic of and representative of Fort Irwin as well as the central Mojave Desert, and (3) typically used for Army training maneuvers, including the use of tactical vehicles. Five study sites were chosen: three represented different levels of habitat disturbance (severely impacted, moderately impacted, lightly impacted), and two were unimpacted control sites.

Typically, vehicle traffic and training activities occur in the valleys, with impacts declining as one progresses into the alluvials toward the mountains. The closest edge of the severely impacted site (S) was located in a broad valley about 600 m from the main road. The moderately impacted site (M) was located on the alluvial about 3 km from the S site. The control sites (VC--valley control, AC--alluvial control) were located at Goldstone, an unimpacted portion of Fort Irwin, leased to the National Aeronautics and Space Administration/Jet Propulsion Lab for tracking satellites in deep space. A fifth, lightly impacted study site (L), was located on a high desert plateau.

Appendix A gives the map coordinates and elevations for all study sites. It also provides an estimate of tactical vehicle damage based on the percentage of paces in which vehicle tracks are encountered while walking a 600-m transect parallel to each bird transect.

Birds

Three to six 800- x 200-m (16-ha) strip transects were located in each of the five study sites (N = 23), and were censused five or six mornings between 2 and 26 April 1983. This is usually the peak breeding season in the central Mojave Desert. More transects were used in impacted sites because of the greater potential for heterogeneity, and smaller population densities. The transects were surveyed from daybreak (0500 hours) to about noon (1200). Transects were located and permanently identified using compass bearings from a Suunto sighting compass and easily recognizable permanent landmarks. Two-dimensional coordinates of individual birds seen or heard in the transects were recorded in a code that identified their species, sex (if possible), and behavior (flight origin and direction, foraging, perching, singing, or calling). Complete visual and auditory data were recorded for each transect.

The individual census days were color-coded on large master maps for each pair of transects, and the total number of breeding individuals, migrants, and transients of each species was estimated for each transect. Breeding birds were defined by singing males

Mode of Technology Transfer

This research contributes to the fundamental understanding of Army training impacts and their quantitative assessment and description. It is recommended that the results be used to develop more effective impact prediction methods and land maintenance technology.

PC II is predominantly associated with the cover of subdominant shrub species (species other than creosote bush and burroweed), but also with tall and intermediate-height shrubs and grass.

PC III reflects a habitat gradient of gravelly-rocky subst-ates, shorter creosote bush, variability in burroweed size, and contributions from subdominant shrub cover and forbs, contrasting grass cover and sandy substrates. This is a substrate-size gradient with vegetation characteristics that contrasts alluvials and the high desert to valley floor habitats. The environmental interpretation of PC IV is less clear but may be associated with the high desert habitat.

Figure 21 ordinates the means and 95 percent confidence ellipses of transect principal components scores in principal component space of habitat variables. The variables associated with PC I reflect habitat disturbance, and thus quantitatively position the study sites relative to one another.

PC II was associated primarily with the cover of subdominant shrub species. Orientations and ecological relevance on this axis are weak, as expected. Twelve subdominant species were grouped, because individual sample sizes were inadequate. While some of these species appeared to be sensitive to impacts, others may increase in number at disturbed sites. Therefore, individual data elements within subdominant shrub parameters almost certainly reflect contrasting ecological attributes. When more data are gathered on the distribution of individual species, the habitat variable ensemble can be expanded to include separate contributions from each species, or at least statistically grouped clusters of ecologically similar entities. Such a treatment would greatly enhance ecological realism for interpreting principal component axes. The ellipse of the severely disturbed site (S) has a broad major axis along PC II. This is attributed to the high density of cheesebush along one of the transects (see Figure 6).

PC III represents an important environmental gradient, since it contrasts habitat variables associated with alluvials (e.g., gravel, rocks, forbs) with those characteristic of valleys (e.g., grass, sand). Note that the ellipse of the disturbed alluvial (M) drops on this axis. This is attributed to decreases in gravel and forbs and increases in grass and sand. The ellipse of the disturbed valley site (S) increases along this axis. This is due primarily to a decrease in coarse sand and grass.

The relationship between shrub height and diameter was investigated. The data were analyzed by shrub species and by site. Analysis showed that there was a highly significant positive relationship between shrub height and diameter ($P < 0.001$). Appendix F contains the Pearson product-moment correlation coefficients between shrub height and diameter.

The strong correlations suggested that regression equations should be developed for least squares estimates of creosote bush and burroweed cover from field data of shrub heights or, less importantly, shrub height estimates calculated from field data of shrub diameters. Appendix G gives the parameters for the 20 required regression equations.

Analysis of covariance (Appendices H and I) was used to evaluate slope homogeneity of these equations. This analysis is particularly significant when the designated independent variable yields the smaller residual sum of squares (diameter in this case). Note that the interaction terms are highly significant ($P < 0.0001$, Appendix H), so the slopes (regression coefficients, B) are heterogeneous. The impacted sites consistently had steeper slopes than the controls. Since the sum of squares of sites adjusted for diameter is highly significant ($P < 0.0001$) and shrub diameter must be positive (non-negative values), regression line elevations of the impacted sites are lower than those of the controls (intercepts, A). The lower elevations and steeper slopes for the impacted sites are quantitative evidence of crushed shrubs. Trampled shrubs over a wide range of diameters are necessarily shorter.

Birds

Figure 22 shows transect population estimates for breeding birds, migrants, and transients at each study site. Appendices J and K list all species recorded on the study transects, including their scientific names.

Horned larks selected a broad range of habitats (see Figure 23). Their population densities were statistically similar at all study sites, despite large differences in shrub cover, vegetation volume, ground cover, and substrate sizes. Transects AC3 and S1 each had six individuals, with ground cover 52 percent and 14 percent, respectively (the extremes found in this study). There was no significant difference between impacted and control sites ($P > 0.3$, Table 6).

Black-throated sparrows tolerated some degree of vegetation disturbance ($P = 0.48$--moderately impacted alluvial contrasted to respective control); however, only a single pair held a territory at the severely impacted site ($P < 0.001$--severely impacted site contrasted to respective control--see Table 6 and Figure 23).

Brewer's sparrows, sage sparrows, western meadowlarks, and a breeding pair of LeConte's thrashers were found only in lightly or unimpacted sites.
Of the migrants and transients, the white-crowned sparrows, chipping sparrows, and LeConte's thrashers tolerated moderately impacted areas, but were never observed at the severely impacted site. Sage sparrows preferred the valley control, and Brewer's sparrows preferred the high desert (Figures 22,23).

Figure 24 shows the ordination of the means and 95 percent confidence ellipses of avian principal component scores in principal components space of habitat variables. Tables 4 and 5 summarize the analysis. Appendix E defines the habitat variables. The analysis used to extract principal components was discussed in the habitat structure section. The PCA ordination of study sites was shown in Figure 21.

The large ellipses in Figure 24 for the chipping sparrow and the LeConte's thrasher reflect small sample sizes ($N = 4$ and 7, respectively). Therefore, sample sizes should be greater than 10.

PC I is the most informative axis for interpreting habitat selection by the Mojave avian community. This axis was considered an environmental impact gradient (see Figure 21A). Meadowlarks, sage, and Brewer's and white-crowned sparrows were associated with tall and dense cover of creosote bush/burroweed communities. Therefore, these species were very sensitive to vegetation disturbance. Black-throated sparrows predominantly selected intermediate heights and sparser cover of creosote bush/burroweed. LeConte's thrashers selected similar habitats, but showed a broad tolerance of shrub cover; however, the small sample size made interpretation difficult.

PC II--the presence of subdominant shrub species--was not an important habitat component of the avian community.

PC III (Figure 24B)--the alluvial-valley gradient--partitioned the bird community to some extent, but there was high variability along this axis. Black-throated, Brewer's, and chipping sparrows were partial to alluvials or high desert, while sage sparrows preferred the valley floor. Figure 24C summarizes the relationship between PC II and PC III.

Horned larks did not select or avoid any measurable feature of the habitat (mean near 0.0). No bird species was associated primarily with habitat features characteristic of impacted sites.

Figure 25 shows the means for each species' principal components scores within each of the five study sites. The predominant observable pattern is the complete ordination of the five study sites along PC I (habitat disturbance gradient) and PC III (substrate gradient or alluvial/high desert to valley bottoms), as shown in Figure 25B. This figure also suggests that horned larks may be associated with finer substrates. The large separation between horned larks and the single pair of black-throated sparrows at the severely impacted site (Figures 25A, 25C) resulted from the sparrow's territory being located on a transect containing an abundance of cheesebush; however, no relationship was assumed.

Figure 26 shows the bird species centroids in discriminant space defined by principal component scores. The principal components represent linear combinations of the 25 habitat variables that define the study sites (Tables 4 and 5). Table 7 relates the first three canonical discriminant functions (CDF) to specific principal components. CDF I is related to shrub cover and height (PC I), and CDF II is related to vegetation and substrate characteristics of alluvials (PC II and PC III); CDF III represents a substrate gradient (PC III), effectively contrasting alluvials/high desert with valley floors.

The relative positions of species centroids gives the appearance of good separation in discriminant space. However, small sample sizes for several species, a great deal of habitat similarity for others, and broad habitat preference for two species all combine to produce a great deal of overlap in discriminant space. Figure 26 would be totally obscure if 95 percent confidence ellipses were drawn. Table 8 summarizes this problem. Only 27.2 percent of the individual birds were correctly identified to species based on their selection of habitat variables; the identification used classification equations derived from the canonical analysis of discriminance (CAD). If a correction was applied for sample size (e.g., probability of species membership is directly proportional to sample size), the correct classification of individuals belonging to abundant species was vastly improved; however, rarer species were consistently misclassified. Nevertheless, despite these limitations, Figure 26 is useful for visually assessing general habitat relationships among the Mojave Desert bird community.

CAD was used to discriminate study sites on the basis of bird community structure. Figure 27 depicts the group centroids and each bird transect of the five study sites in discriminant space as defined by bird species abundances. Tables 9 and 10 summarize the analysis. The first two canonical discriminant functions (CDF), which account for 94.1 percent of the variance, clearly separate the five sites. The basis of this separation is a linear combination of species abundance patterns unique to each site. Although some trends are evident (e.g., Brewer's sparrows prefer the high desert, sage sparrows are partial to the valley control site, and black-throated sparrows are common on alluvials), detailed ecological interpretation of the discriminant axes was not possible.

The overall pattern of CAD closely paralleled the principal components analysis (PCA) (Figure 25), as expected, on a mathematical as well as ecological basis. CDF I discriminated study sites on the relative degree of habitat disturbance, while CDF II separated alluvial sites from valley sites. It was not possible to ecologically interpret the location of the high desert site in discriminant space. This site was unique in its high population of both Brewer's sparrows and horned larks. All 23 transects were correctly assigned to their respective sites by classification equations.

Small Mammals

Figure 28 snows the relative trapping success along the four transects at each study site. The desert kangaroo rat (*Dipodomys deserti*) was restricted to two severely impacted transects, the southern grasshopper mouse (*Onychomys torridus*) mainly to the valley control, and the long-tailed pocket mouse (*Perognathus formosus*) mainly to the lightly impacted high desert site. Merriam's kangaroo rat (*D. merriami*) and the little pocket mouse (*P. longimembris*) were found at all study sites.

Densities of Merriam's kangaroo rat did not differ significantly among the five sites ($P = 0.28$) (see Table 11). *A priori* orthogonal contrasts comparing severely and moderately impacted sites with their respective controls yielded similar results ($P \geq 0.18$). However, the intrasite variability was high at S (absence of *D. merriami* on transects where its larger congener was trapped), and also at AC and VC. Since ANOVA is based on the F-ratio, high intrasite variance precludes reliable statistical inferences of intersite differences. Interestingly, however, trapping success for this species along individual trap-lines was generally more successful in impacted sites than in control sites.

Densities of the little pocket mouse decreased appreciably in severely and moderately impacted sites compared to the control sites ($P = 0.002$, Table 11).

Because of high intrasite variability in trapping success, the statistical inferences contrasted samples with heterogeneous variance (Bartlett's test, $P = 0.001$ and 0.02, Table 11), which violates one of the prerequisites for parametric tests. ANOVA is generally robust in this kind of analysis; nevertheless, another ANOVA was designed to reduce sample variance. Since adjacent trap-lines were presumed to be relatively similar, adjacent pairs were combined and another ANOVA was performed. Heteroscedasticity in this case was not statistically significant (Bartlett's test, $P = 0.07$ and 0.63). The results substantiated the previous analysis.

A posteriori range tests do not have the power or resolution of *a priori* tests, but close inspection revealed parallel trends (Figures 29 and 30). (Note the ambiguity in overlaps, which is typical of these tests.) Furthermore, since seven statistical models can be applied at an infinite range of significance levels, the options are vague.

Table 12 shows the matrix of habitat variable loadings on the first four principal components (Appendix E defines the variables). These values are both correlation coefficients and regression weights. Table 13 summarizes the principal components analysis (PCA) by showing how the first four principal components partition the major portion of the variance present in the original data set. PC I represents a gradient of heavy shrub cover (creosote bush and burroweed) to sparse shrub cover and sandy substrates--essentially an environmental impact gradient in the Mojave Desert. PC II represents a gradient of grass and sandy substrates to forbs and gravelly substrates. PC III contrasts coarse sand with gravel substrates. These three principal components accounted for 89.9 percent of the variability present in the original habitat variables. PC IV represents the cover of subdominant shrub species.

Figure 31 ordinates the means and 95 percent confidence ellipses of mammal principal component scores in principal components space of habitat variables. Figure 31A was most informative, since PC I and PC II accounted for 78.8 percent of the data variance. The grasshopper mouse was associated with dense shrub and grass cover and with coarse sand substrates. The little pocket mouse also preferred dense shrub cover and coarse sand.

Despite the small sample size, the desert kangaroo rat possessed a small ellipse, indicating that it was a habitat specialist. It was found only in transects with very sparse shrub and ground cover and sandy substrates. Interestingly, this species possessed a negative component on PC II (forbs and gravel). Several species of very abundant forbs were consistently associated with gravelly substrates on undisturbed alluvials and the high desert; however, a broad diversity of other forb species characterized the loose sandy substrates associated with severely disturbed desert soils. In these areas, tall bunch grasses and Russian thistle (*Salsola kali*) provided some stability for sand dune formation.

The long-tailed pocket mouse was strongly associated with gravelly substrates and accompanying forbs. This was very clear in Figure 31C where this species was confined to the negative quadrant.

Merriam's kangaroo rat, although near the center in PC space (e.g., broad habitat selection) preferred sandier and sparser cover than did the pocket mice. Figure 31B clearly defines substrate preferences in the small mammal community. Figure 31C contrasts valleys (positive quadrant) with alluvials/high desert (negative quadrant).

Figure 32 was constructed to further define the relationships among habitat variables and study sites for each species. The relative relationships among the sites in principal components space are necessarily similar to Figure 21 in the habitat structure analysis. At the severely impacted site, the desert kangaroo rat was associated with forbs, while Merriam's kangaroo rat was associated with grass-sand substrates. The latter species is consistently oriented toward grass/sand substrates at each site (Figure 32A). The little pocket mouse is oriented toward coarse sand substrates (Figure 32B). Substrate-cover relationships are summarized in Figure 32C. Note how close together Merriam's kangaroo rats from VC, S, and M are to one another in principal components space, and note the strong orientation on the grass-sand axis, despite the vast environmental difference among these three sites. The long-tailed pocket mouse is restricted to sites in the negative quadrant.

ANOVA is another method for investigating partitioning of habitat variables among community members. This is not generally recommended because of the high probability of spurious associations when working with a large number of habitat variables, many of them highly correlated. However, in this case, there is a relatively small set of carefully selected and ecologically relevant variables, and the analysis can be used to complement the PCA.

A comparison of habitat variables between the two widespread rodents (Merriam's kangaroo rat and the little pocket mouse) was of interest. Since this was an *a priori* decision, orthogonal contrasts could be used. Table 14 summarizes the analysis with nine habitat variables. As expected, the results parallel PCA, adding statistical validity. The little pocket mouse preferred heavier shrub cover and more forb cover (*Amsinckia tesselata* and *Phacelia* spp. are strongly associated with creosote bush and burroweed), and coarse sand substrates (particle sizes 3 mm to $<$ 1 cm). Merriam's kangaroo rat was associated with sparser shrub cover and sandy substrates (particle sizes $<$ 3 mm).

Figure 33 summarizes ANOVA for the entire mammal community. In such an analysis, *a posteriori* range tests must be used, although their statistical power is low (see methods section). Note that the results closely parallel those of PCA.

CAD was used to discriminate the five study sites on the basis of rodent community structure. Figure 34 shows the group centroids and each mammal transect of the five study sites in discriminant space defined by mammal species abundance. Table 15 summarizes the analysis. The main pattern was due to the presence of unique species. CDF I separated the lightly impacted high desert site (on the basis of Merriam's kangaroo rat and long-tailed pocket mouse) and the valley control site (presence of grasshopper mouse) from the other sites. (CDF II separated impacted from lightly or unimpacted sites (on the basis of little pocket mouse, long-tailed pocket mouse, and grasshopper mouse). CDF III represents a gradient of habitat suitability for the two kangaroo rats, separating the severely impacted site from the alluvial sites. Nineteen out of 20 transects (95 percent) were correctly classified into their respective sites on the basis of their mammal species abundance patterns (Table 16).

Figure 35 and Tables 17 and 18 summarize the results of CAD if the groups analyzed consisted of pairs of adjacent transects. The main pattern was again attributed to the presence of "unique" species--desert kangaroo rat on the first two transects in the severely impacted site, long-tailed pocket mouse on the high desert transects, and the grasshopper mouse in the valley control (Figure 35A). The presence of the latter two species also affects the loci of the AC transects relative to one another. Most intrasite differences can be attributed to differences in the population densities of Merriam's kangaroo rat (the two control sites) and to the little pocket mouse (moderately impacted site) (Figure 35C).

The proximity of AC3-AC4 with S3-S4 along the first two axes of discriminant space examplifies a potential problem with CAD. The long-tailed pocket mouse and Merriam's kangaroo rat both have large positive contributions to the first two discriminant axes. The long-tailed pocket mouse possesses higher discriminant function coefficients but fewer numbers than Merriam's kangaroo rat. Because of this, the presence of the former species on site AC (but not on site S) contributes to comparable discriminant scores as higher populations of Merriam's kangaroo rat on site S. This was the problem encountered in the classification analysis (Tables 16 and 18).

5 ANALYSIS RESULTS

Habitat Disturbances

The extent of Army training conducted at Fort Irwin has had an appreciable impact on creosote bush and burroweed--the predominant woody vegetation. Decreases in the density (shrubs/ha), cover (m^2/ha), volume (m^3/ha), mean diameter, and mean height of these two species were quantitatively associated with the magnitude of Army training activities. Shrub volume was a particularly effective means for assessing habitat disturbance (Figure 11), since its measure included all of these parameters. The effects on subdominant shrub species require futher investigation. Several species were infrequently or never encountered at impacted sites. Cheesebush, a species associated with naturally disturbed areas (washes), increased in impacted areas. Alluvials and the high desert supported a greater cover of subdominant shrub species than valleys. Most shrubs in impacted sites were less than 1 m tall, while in lightly impacted or unimpacted sites, most were taller than 1 m (Figure 13).

Paralleling the loss of shrub cover or volume was a decrease in ground cover (Figure 15) and an increase in sandy substrates (Figure 14). The increase in sand is particularly interesting. The surface of most undisturbed desert soils consists of desert pavement, which is resistent to wind and water erosion (Refs. 117, 30). This is a gravelly, firm surface in which the particles appear neatly and closely arranged, and which is maintained at this equilibrium (Ref. 31). The sand and silt have been removed by the action of wind (Ref. 119) and water (Ref. 77). Soil shrinkage may also contribute to an upward movement of gravel (Ref. 117). Associated algae and lichens provide a "cement" that gives rigidity to the pavement surface and further inhibits erosion (Ref. 113). However, sand and silt deposits lie beneath this coarse, consolidated surface. Traffic, particularly by tracked vehicles, interrupts surface integrity, shuffles soil layers, destroys microbial components, and exposes soil fines to wind/water erosion. Heavy winds (60 to 100 km/hr) in heavily impacted training areas have produced severe dust/sand storms in which the visibility has been reduced to less than 5 m; however, similar winds at several undisturbed areas merely produced a haze.

Desert varnish, which is also characteristic of desert surfaces, is severely affected by vehicle traffic. Desert varnish is a thin black coating on rocks that consists of manganese and iron oxides. The mechanism of its origin has been debated for more than 100 years. The involvement of a variety of biological agents has been proposed: lichens (Ref. 76), blue-green algae (Ref. 104), and bacteria/micro-organisms (Refs. 56, 65, 8). Moore and Elvidge (Ref. 84) provide evidence that desert varnish is formed by the action of rainwater and windblown dust on rock surfaces. Scarred rocks in disturbed areas may take 10,000 years to revarnish (Ref. 84).

Coarse, gravelly soils are very susceptable to compaction, which decreases infiltration rate and increases runoff and erosion (Refs. 141, 133).

Forbs were commonly associated with gravelly substrates on alluvials and the high desert. Forb cover was substantially reduced on the impacted alluvial, presumably as the direct result of substrate disturbance. *Amsinckia tesselata* and *Phacelia* spp. were annual forbs strongly associated with burroweed and especially creosote bush. A reduction in these shrubs paralleled a reduction in forb cover.

A number of annual forb species responded favorably to the sandy, loose soils present at the severely impacted site. These are known as "weedy species," and their seeds generally germinate in disturbed soils. Weedy species are poor competitors, relying on high seed production and dispersal ability to colonize pioneer sites. Their high seed production makes them an important food resource in desert communities. Therefore, unimpacted sites at Fort Irwin had a large biomass of forbs dominated by fewer species, while impacted sites had a much lower biomass with many species, none of which was dominant.

Grasses were more strongly associated with sandy soils than with gravelly/rocky soils. Therefore, both the valley control and the disturbed sites (moderately impacted) had relatively good grass cover.

Grass and forb cover was unusually dense in the spring of 1983, because the previous winter (rainy season) was one of the wettest on record. The 1966-1984 mean for December to March rainfall was 2.9 in. (7.4 cm), but it was 7.2 in. (18.3 cm) for 1982-1983 (data from the Goldstone satellite tracking facility).

Biomass

Figure 36 and Table 19 show the biomass of birds (territorial, migrants, and transients) and small mammals (captures/trap-line) on each study site. The bird data represent actual biomass per unit area, calculated from population estimates. However, mammal biomass is *relative*, since it was calculated from trap-captures. The actual small mammal biomass present on 16 ha was probably one or two orders of magnitude greater than the values in Figure 36, since presumably less than 10 percent of the population was captured.

Habitat disturbance had a profound negative effect on bird biomass (orthogonal contrasts, $P < 0.003$). The lightly impacted high desert was similar to the controls. Interestingly, the loss of biomass was attributed to the total elimination of species specifically sensitive to the respective vegetation changes, not to population reductions in any species (Figure 22).

Small mammal biomass was statistically similar in impacted and control sites (orthogonal contrasts; M-AC, $P = 0.74$; S-VC, $P = 0.08$). However, community composition was quite different. Habitat disturbance appreciably decreased populations of the little pocket mouse, a small (7 g) but very abundant species at unimpacted sites. Correspondingly, the biomass of the much larger kangaroo rats increased in impacted sites compared to the controls (Figure 28). Alluvials had lower small mammal biomass than valleys (SNK, $P < 0.05$).

Impact Guilds

Fort Irwin birds and small mammals were grouped into categories, or guilds, according to their sensitivity (or insensitivity) to habitat disturbances. The guild is conceptually defined in terms of functional entities. The literature provides diverse background information (Refs. 98, 99, 142, 43, 18, 57, 127, 24, 55, 62, 71, 82, 58, 59, 60, 107, 85, 112, 70, 111, 79, 130).

Four impact guilds could be identified on the basis of functional response to habitat disturbance: species that (1) benefited, (2) were insensitive, (3) were moderately sensitive, and (4) were highly sensitive. Figure 37 shows the constructed impact guilds, and Table 20 gives the species compositions of the respective guilds. Two insensitive species (horned lark and Merriam's kangaroo rat) made up the predominant biomass in the Mojave Desert. Even unimpacted deserts have a harsh environment characterized by uncertainties in rainfall, temperature, wind, and productivity. Thus, it was not surprising that two dominant species were found over a broad range of habitat conditions. Some birds and small mammals have adapted to "dense" desert scrub, and they were, of course, sensitive to vegetation disturbance. This type of analysis conceptually clarified organism-habitat relationships.

Impact guild assessment in other ecosystems may not be as clear-cut. However, the analysis would be equally valid, and cluster analysis (Refs. 2, 114, 37, 53, 42, 36, 97) could be used to analytically "pigeon hole" species into appropriate guilds. There may be more than four guilds (e.g., slightly benefited or strongly benefited by habitat disturbance).

Species-Habitat Associations

Habitat relationships of the Mojave bird and small mammal communities and their responses to the environmental impacts reported in this study were consistent with species' specific natural histories. Except for horned larks, avian community structure was closely related to shrub cover (Figure 24A). Rotenberry and Wiens (Ref. 102) found sage and Brewer's sparrows to be abundant widespread species in the shrubsteppe ecosystem, being associated with patchy shrub cover (e.g., a mosaic of dense shrubs and bare ground). The unimpacted creosote desert has a similar habitat structure--widely spaced thickets of creosote bush clones. Western meadowlarks, not typically desert species, are strongly associated with dense grass cover (Ref. 140). Other surveys in creosote scrub have not listed this species (Table 21). Grass and forb cover was unusually high this spring because of the high rainfall the past winter (see Figure 15), particularly in unimpacted areas. This apparently attracted several territorial males. From field experience with four races of western white-crowned sparrows, Bent (Ref. 11) concluded that a combination of three elements made up their nesting habitat: shrubbery, grass and bare ground. This species overwinters in Mojave scrub (Ref. 73), but is more abundant in desert riparian woodland (Ref. 126).

Birds found at the moderately impacted site were species not associated with dense vegetation. LeConte's thrashers are uncommon and are often associated with sparse barren deserts, their main requirement being a cholla or spinescent thicket for a nest site (Refs. 47, 10). Black-throated sparrows are characteristic of the creosote scrub (Table 21); territorial pairs were observed in a wide range of undisturbed habitats, from valleys with dense creosote bush to rocky alluvials and boulder fields with scattered small shrubs. Chipping sparrows are found throughout the United States in open habitats with scattered perch sites. Horned larks are ground feeders and nesters, do not perch on shrubs, and are characteristic of sparse ground cover. Throughout their range, they avoid dense ground and shrub cover (Ref. 13, personal observation), so it was not surprising that their population sizes were unrelated to habitat disturbance.

Small mammal compositions reflected both vegetation and substrate characteristics (Figure 31). The little pocket mouse and the southern grasshopper mouse responded negatively to decreases in shrub cover. Thompson (Ref. 122) found that in the southern Mojave Desert, the little pocket mouse foraged primarily in shrub cover and avoided open areas. He also reported that both Merriam's and desert kangaroo rats preferred similar foraging sites, but that the foraging strategies differed among the three species (Figure 1 of Ref. 122). The quadrapedal pocket mouse restricts its foraging to a single shrub thicket near its nest. The kangaroo rats (bipedal) traverse open areas to forage at many shrub patches. The larger desert kangaroo rat, which is found in the sparsest cover, forages over larger areas, traveling longer distances between shrub patches than its smaller congener. Contrary to Thompson's findings, Kotler (Ref. 64) found in the Sonoran Desert that the desert kangaroo rat foraged extensively in the open. Interestingly, Braun (Ref. 16) reported that there was no relationship between body size and home range in several species of heteromyid rodents. The body sizes, morphologies, and feeding strategies of heteromyid rodents have evolved for predator avoidance when exploiting different habitat structures (Refs. 40, 138, 100, 64, 123).

This study showed that the two kangaroo rats were associated with open and sandy habitats, particularly the desert kangaroo rat. The latter species was confined to sand dunes with very sparse shrub cover, an uncommon and patchily distributed resource in the central Mojave Desert, but one that is created in severely disturbed training areas. Nader (Ref. 87) also reported that the desert kangaroo rat was highly specialized.

In the south-central Mojave Desert, Bury, et al. (Ref. 21), similarly reported a decrease in the little pocket mouse at ORV-impacted sites, but also reported decreases in Merriam's kangaroo rat. Vollmer, et al. (Ref. 132) reported equal population densities of small mammals on a control and on an ORV-impacted site; however, the test site consisted of a 9-ha area traversed 21 times over a single track, so impacts to soils and vegetation were very localized, and not comparable to the research reported here.

Mojave Desert Scrub Bird Surveys

Table 21 summarizes the scanty literature on Mojave breeding bird censuses. Bury, et al. (Ref. 21), reported a sharp decrease in birds with ORV impacts; however, their study plots were much too small at one site (4 ha at B), while few species and numbers were found at their other two sites. However, their census period was 22-30 May, well past the usual breeding peak in April. These problems and the fact that there were no measures of intrasite variability make interpretation tenuous.

The Audubon breeding bird surveys (1976-1979) and the Fort Irwin data from unimpacted sites were reasonably similar, considering differences in habitat localities (e.g., the Sierra alluvial), year to year population fluctuations, and observer differences (Ref. 95). All communities were similar in species compositions. The main discrepancy was greater densities of Brewer's sparrows but fewer sage sparrows at Fort Irwin. Another important source of data variability was small study plot sizes in the Audubon surveys. Bird density estimates are strongly distorted by small census plots (Refs. 25, 41, 61). This is particularly a problem in low-density communities such as the Mojave Desert. Small study plots not only present a statistical bias (Ref. 23), but contain fewer "habitat types."

Multivariate Analyses

Canonical analysis of discriminance was useful for selecting a smaller subset of habitat variables from a large initial data set. Principal components analysis effectively associated bird and small mammal species with relevant and critical habitat features.

Principal components ordination was more effective with mammals than with birds (see Figure 31), since the rodent species were individualistic in their habitat requirements, while most bird species selected dense shrub cover (see Figure 24). However, Mojave birds, because of their sensitivities to gradients of shrub cover, were better indicators of habitat disturbance (see Figure 27). Mammal community structure was also a good indicator of environmental impacts, but discriminant analysis was not as effective, because kangaroo rats benefitted by habitat disturbances (see Figure 34).

Multivariate analyses have extracted variables that not only quantitatively define environmental impact gradients and contrast alluvials with valleys, but also identify specific habitat variables that may be useful in managing nongame species in desert communities (Ref. 66). These procedures have been used effectively to evaluate the cause-effect relationships that Army training impacts have on the bird and small mammal fauna.

Army Training Effects on Nongame Species

Army training maneuvers at Fort Irwin decrease shrub and ground cover and increase the proportion of sand (particle sizes < 3 mm) present on the surface. Most desert bird species, including migrants and winter residents, are sensitive to decreases in shrub density/cover and may be eliminated. Two small mammals--the little pocket mouse and the southern grasshopper mouse--are similarly affected. The birds simply relocate, while the small mammals, having less cover and greater difficulty obtaining food, are eliminated by predators. (Coyotes, kit foxes, a wide variety of snakes, roadrunners, shrikes, hawks, and owls are chief predators.) Several bird species (black-throated sparrows, LeConte's thrashers, and some migrants) tolerate lower shrub densities, and may not be affected by up to 50 to 70 percent reductions in shrub cover. However, LeConte's thrashers require a large cholla or shrub thicket for their nest site, and these habitat components are usually severely impacted during training exercises.

Decreasing shrub cover, combined with increasing sandy substrates, enhances the habitat for Merriam's kangaroo rat, so this species will increase. Severely impacted training areas have little or no shrub cover and loose, sandy soils; bunch grasses and Russian thistle (tumbleweed) provide some stability for sand dune formation. This is the preferred habitat of a highly specialized mammal--the desert kangaroo rat; a patchily distributed species in the central Mojave Desert, that may be common in this type of habitat.

The horned lark, which is a ground nester and feeder, is a common desert species that tolerates very low shrub and ground cover. This species is very tolerant of habitat disturbance and does not require any shrub cover. However, it is not present when ground cover is totally eliminated, since it requires insects for food, at least small patches of grass for nest sites, and seeds during the non-nesting period.

Heavy vehicle traffic in gravelly soils generally causes compaction, which produces serious environmental problems. Decreased infiltration rates and increased runoff reduce water availability to plants and increase erosion and the magnitude of flash-floods. The compacted soil affects plant community structure, makes seed germination difficult, and makes it virtually impossible for fossorial animals (vertebrates and invertebrates) to dig burrows.

This study focused on the effects of habitat changes on bird and small mammal communities. The noise and vibration levels necessarily associated with extensive training exercises are another important environmental problem that warrants separate consideration.

Kangaroo rats, in particular, have evolved highly specialized auditory apparatuses: greatly enlarged auditory bullae (the volume of the middle ears in a Merriam's kangaroo rat is larger than its braincase), enlarged tympanic membrane, lengthened malleus, small stapes footplate, and greatly reduced ossicular ligaments (Refs. 135, 136, 137). These adaptations all interrelate to greatly amplify sound. These mammals are also unusually sensitive to low-frequency sounds (Ref. 131), which may be effective for detecting snake and owl predators. Brattstrom and Bondello (Ref. 15) reported that under laboratory-controlled conditions, dune buggy noise levels severely impaired the hearing of desert kangaroo rats to the point that they were unable to detect predators (rattlesnakes in their experiments). They also reported hearing losses in the fringe-toed lizard (*Uma scoparia*), a sand dune specialist. Bondello (Ref. 14) documented similar effects with desert iguanas (*Dipsosaurus dorsalis*).

Lizards and particularly snakes, are sensitive to ground vibrations--a highly adaptive feature under natural conditions. The effects of intense ground vibrations on their behavioral patterns, reproduction, and survival is unknown.

The effects of noise/vibration levels on desert birds is not well documented (Refs. 78, 12). Marler, et al. (Ref. 83) demonstrated that high noise levels produced permanent hearing damage in canaries. Allaire (Ref. 1) found that although ground nesting birds in an eastern deciduous forest were very sensitive to the dust and debris from blasting, the noise disturbance of strip-mining did not appear to affect any nesting species.

Since a prominent feature of a bird's environment is auditory (territorial song, communication between mates and between adults/offspring), excessive noise levels, including hearing damage, would appear to be highly deleterious. Common human experience that is analogous to the effects of noise on birds are gun shots, slammed car doors, noisy mufflers, etc.

There has been no research on the effects of dust and chemical obscurance/training smokes on natural wildlife populations. However, the U.S. Army Construction Engineering Research Laboratory has begun field and laboratory studies sponsored by the U.S. Army Medical Bioengineering Research and Development Laboratory to evaluate the genetic and environmental effects of these smokes on wildlife and vegetation, including a human risk assessment analysis.

Since desert communities recover from environmental damage very slowly (Ref. 134), and since reclamation efforts and success have been limited (Refs. 124, 90), the best approach for wildlife mitigation on training ranges may be to minimize or contain habitat damage during training exercises. Research is now being conducted to identify critical habitat components and macrohabitat units and their importance to ecosystem integrity or function.

6 SUMMARY AND CONCLUSIONS

1. This study has quantitatively assessed the ecological effects of large-scale Army training maneuvers and war game scenarios on the Mojave Desert ecosystem at Fort Irwin. Specific habitat (environmental) variables were identified that contributed substantially to evaluating ecosystem degradation.

Creosote bush usually provided more than 60 percent of shrub cover, and was by far the dominant three-dimensional structural habitat component at Fort Irwin. This species represented the best and most direct way to monitor ecosystem degradation. Three measurable parameters of its presence were highly correlated (density, diameter, height), and any one of these could be used as an indicator of habitat disturbance. Shrub cover (incorporating density and diameter) was used to measure shrub dominance, since there was ambiguity in defining individual shrubs. Shrub volume was a very sensitive measure for assessing habitat disturbance, since its measure incorporated all three parameters (see Figure 11).

Two Mojave Desert breeding bird species and two small mammals were identified as sensitive indicators of habitat damage resulting from Army training activities: Brewer's and sage sparrows, little pocket mouse, and southern grasshopper mouse. The little pocket mouse appears to be an excellent indicator species because of its widespread distribution, high abundance, and strong dependence on shrub cover. Two additional breeding birds (black-throated sparrow, LeConte's thrasher) and most migratory species tolerated moderate disturbance, but were absent or very rare in heavily impacted areas. Their absence would indicate severely degraded habitats. The black-throated sparrow, another widespread and abundant creosote scrub species, would be an excellent indicator species for higher impact levels. Also, the presence of desert kangaroo rats is an indicator of very low shrub and ground cover and loose sandy substrates, both of which are characteristics of heavily trained areas using tracked vehicles. Avian biomass was a useful indicator of relative habitat degradation in this desert ecosystem, but small mammal biomass was not (see Figure 36).

2. Rigorous analytical approaches were developed to describe and statistically evaluate environmental impacts.

A priori orthogonal contrasts experimental designs were examined in detail and are recommended as the most valid approach for assessing environmental impacts. *A posteriori* range tests (multiple comparisons) are shown to be both analytically and graphically useful for examining within and between habitat heterogeneity (see Figures 4, 5, 6, 8, 9, 10, 16, 17, 18, and 19).

Canonical analysis of discriminance was useful for selecting linearly independent subsets of habitat variables from the original data set. Matrices constructed of these subsets were therefore assured of being nonsingular (possessing a determinant)--a necessary prerequisite for any canonical analysis.

Principal components analysis--a dimension reduction ordination technique--was effective for extracting weighted linear combinations of habitat variables that best characterized environmental impact gradients. In this way, the analysis identified the relative importance of each habitat variable along each dimension of the ordination (see Figure 21).

3. Species-habitat associations were described in a quantitative multivariate framework for the bird and small mammal communities. In the first step, principal components analyses were used to ordinate sampling units (transects) in principal components space of habitat variables. Bird and small mammal ordinations were then derived from sampling unit principal components scores weighted by species-abundance estimates for each respective sampling unit. This hybrid ordination totally corrects for unequal species sample sizes and closely associates species-abundance patterns with specific habitat features in an n-dimensional space of habitat variables (see Figures 24, 25, 31, and 32).

4. Both impacted sites and unimpacted control sites have been quantitatively described in a multivariate framework on the basis of their bird or small mammal community structure.

Canonical analyses of discriminance were used to classify the five study sites (three levels of environmental disturbance and two unimpacted controls) in a three-dimensional space defined by species-abundance patterns. Such a classification would be useful for guiding future environmental impact assessments or monitoring, through surveys of species-abundance characteristics at study sites. The Mojave bird community structure was an excellent indicator for classifying study sites on the basis of environmental impacts. This was attributed to the sensitivity of most bird species to gradients of shrub cover. Although the structure of small mammal communities was also a good indicator of environmental degradation, discriminant analysis was not as effective, since kangaroo rats benefitted from several aspects of habitat disturbance (see Figures 27 and 34).

Table 14

Statistical Comparison of Merriam's Kangaroo Rat and Little Pocket Mouse on the Basis of Habitat Variable Associations

Habitat Variable	Species Contrast (Mean) Merriam's Kangaroo Rat	Little Pocket Mouse	Bartlett's* Test	Variance** Estimate	Student's t	Degrees of Freedom	Orthogonal*** Contrast Probability
CCB (m^2/ha)	742	1199	<0.001	P	-7.28	388	<0.001
				S	-6.45	122	<0.001
CBW (m^2/ha)	269	487	<0.001	P	-6.25	388	<0.001
				S	-5.45	118	<0.001
Crest (m^2/ha)	66.1	69.3	0.017 NS	P	0.87	388	0.38 NS
				S	1.01	185	0.32 NS
SHCOV (m^2/ha)	1077	1755	<0.001	P	-7.36	388	<0.001
				S	-6.48	121	<0.001
GRASS (%)	18.6	19.4	<0.001	P	-0.69	388	0.49 NS
				S	-0.67	139	0.50 NS
FORB (%)	12.3	16.1	<0.001	P	-4.14	388	<0.001
				S	-3.59	118	<0.001
GRAV (%)	34.7	30.3	<0.001	P	2.20	388	0.028 NS
				S	2.43	175	0.016 NS
CSAND (%)	28.0	43.8	<0.001	P	-5.93	388	<0.001
				S	-6.82	191	<0.001
SAND (%)	34.9	24.7	<0.001	P	3.29	388	0.001
				S	2.78	115	0.006

*Test for homogeneity of sample variances. Ho probability (homogeneous sample variances), $P \leq 0.01$.

**P = pooled, S = separate. The pooled variance estimate is usually more reliable, particularly if Bartlett's test shows that sample variances are homogeneous (not significant).

***Not significant, $P > 0.01$.

Table 13

Partitioning of Principal Components Into the Percent Variance Accounted for in Each Habitat Variable (Table 12)

Contribution to PC	Habitat Variable	Percent of Variance Accounted for in Each Habitat Variable			
		PC I	PC II	PC III	PC IV
Positive	CCB	71			
	CBW	85			
	SHCOV	82			
	CSAND	32		62	
	GRASS		82		
	SAND		30		
	CREST		90		90
	FORB	24			
Negative	SAND	48			
	FORB		64		
	GRAV		23	59	

Table 12

Principal Components Analysis of Mammal Species Based on Habitat Variables

Principal Component (PC)	Eigenvalue	Percent of Variance	Cumulative Percent
I	4.55	50.5	50.5
II	2.54	28.3	78.8
III	0.998	11.1	89.9
IV	0.466	5.2	95.1

Habitat Variable	Varimax Rotated Factor Matrix			
	PC I	PC II	PC III	PC IV
CCB	.845	-.263	.107	.400
CBW	.926	.156	.058	-.016
CREST	.229	-.016	-.174	.947
SHCOV	.905	-.124	.084	.383
GRASS	.236	.906	.167	.018
FORB	.489	-.803	-.208	.068
GRAV	.251	-.480	-.769	.304
CSAND	.568	.139	.789	-.032
SAND	-.691	.552	.318	-.295

Table 11

Statistical Evaluation of Merriam's Kangaroo Rat and Little Pocket Mouse at Impacted Sites

Species	Site Contrast (Mean relative numbers/transect)	Bartlett's* Test	Variance** Estimate	Student's t	Degrees of Freedom	Orthogonal*** Contrast Probability
Merriam's Kangaroo rat Overall ANOVA (all sites) P = 0.28	S(24.9) VC(26.0)	0.001	P	-1.23	15.0	0.24 NS
			S	-0.93	3.8	0.41 NS
	M(27.0) AC(13.8)	0.001	P	1.41	15.0	0.18 NS
			S	1.66	3.1	0.20 NS
	S1S2- S3S4 (0) (49.7) VC1VC2- VC3VC4 (39.7) (12.2)	0.067 NS	P	-1.83	10.0	0.097 NS
			S	-4.30	1.2	0.15 NS
Overall ANOVA (all sites) P = 0.023	M1M2- M3M4 (24.2) (29.8) AC1AC2 AC3AC4 (9.2) (18.3)	0.067 NS	P	2.08	10.0	0.064 NS
			S	1.38	1.1	0.40 NS
Little Pocket Mouse	S(28.0) VC(221.1)	0.023 NS	P	-3.78	15.0	0.002
			S	-6.09	4.7	0.002
	M(15.0) AC(71.7)	0.023 NS	P	-3.71	15.0	0.002
			S	-2.61	3.3	0.080 NS
	S1S2 S3S4 (17.1) (38.8) VC1VC2- VC3VC4 (164.6) (277.5)	0.63 NS	P	-5.17	10.0	<0.001
			S	-8.25	2.6	0.004
	M1M2- M3M4 (3.5) (26.4) AC1AC2- AC3AC4 (64.1) (79.3)	0.63 NS	P	-5.08	10.0	<0.001
			S	-3.69	1.4	0.17 NS

*Test for homogeneity of sample variances. Ho probability (homogeneous sample variances), $P \leq 0.01$.

*P = pooled, S = separate. The pooled variance estimate is usually more reliable, particularly if Bartlett's test shows that sample variances are homogeneous (not significant).

***Not significant, $P > 0.05$.

Table 10

Classification of Study Sites on the Basis of Avian Community Structure

Number of Transects	Actual Site	Predicted Site VC	AC	S	L	M
4	VC	4				
3	AC		3			
6	S			6		
4	L				4	
6	M					6

Percentage of grouped cases correctly classified: $\frac{23}{23}$, or 100 percent.

Table 9

Canonical Analysis of Discriminance of Study Sites Based on Avian Community Structure

Canonical Discriminant Function (CDF)	Eigenvalue	Percent Variance	Cumulative Percent	Canonical Correlation	Wilks Lambda	Degrees of Freedom	Significance
					.000105*	32*	
I	40.23	57.4	57.4	.988	.00432	21	< 0.0001
II	25.75	36.7	94.1	.981	.116	12	0.0008
III	2.93	4.2	98.3	.864	.455	5	0.032

Standardized Canonical Discriminant Function Coefficients

Bird Species	CDF I	CDF II	CDF III
Horned lark (HL)	-.209	1.354	.713
Black-throated sparrow (BTS)	1.158	-1.497	.179
Brewer's sparrow (BS)	2.069	0.032	-.766
Sage sparrow (SAS)	-.460	2.234	1.005
Western meadowlark (WML)	-.985	-1.155	.466
LeConte's thrasher (LCT)	-.949	1.496	.959
White-crowned sparrow (WCS)	-.618	.493	.646
Chipping sparrow (CS)	.556	.130	.224

*Initial

Table 8

Classification of Bird Species Based on Their Associations With Habitat Variables

Number of Individuals	Actual Species	Percent Correctly Classified	Predicted Species: HL	BTS	BS	SAS	WML	LCT	WCS	CS
214	HL	29.9	64	30	36	28	16	8	0	32
106	BTS	20.8	10	22	14	14	14	6	0	26
80	BS	35.0	0	2	28	24	8	0	0	18
9	SAS	55.6	0	1	1	5	1	0	0	1
13	WML	23.1	0	0	0	6	3	0	0	4
7	LCT	0	0	1	2	2	0	0	0	2
23	WCS	0	0	0	3	7	0	2	0	11
4	CS	50.0	0	1	1	0	0	0	0	2

Percent of grouped cases correctly classified = 27.2%.

Table 7

Canonical Analysis of Discriminance of Bird Species Based on Principal Components' Scores Representing Linear Combinations of Original Habitat Variables

Canonical Discriminant Function (CDF)	Eigenvalue	Percent Variance	Cumulative Percent	Canonical Correlation	Wilks Lambda	Degrees of Freedom	Significance
					.743*	28*	
I	.231	71.7	71.7	.433	.915	18	0.002
II	.058	18.0	89.7	.234	.968	10	0.14
III	.026	8.2	97.9	.160	.993	4	0.55

Standardized Canonical Discriminant Function Coefficients

Principal Component	CDF I	CDF II	CDF III
I	.946	.286	-.275
II	.212	.577	.192
III	.242	.497	.734

*Initial

Table 6

Statistical Evaluation of Horned Larks and Black-Throated Sparrows at Impacted Sites

Species	Site Contrast (Mean individ-duals/transect)	Bartlett's* Test	Variance** Estimate	Student's t	Degrees of Freedom	Orthogonal*** Contrast Probability
Horned Lark Overall ANOVA (all sites, P = 0.03)	S(9.0) VC(10.5)	0.47 NS	P	0.94	18.0	0.36 NS
			S	0.86	5.3	0.43 NS
	M(7.7) AC(7.3)	0.47 NS	P	-.19	18.0	0.85 NS
			S	-.17	4.4	0.87 NS
Black-throated sparrow	S(0.3) VC(5.0)	0.51 NS	P	6.63	18.0	<0.001
			S	7.76	7.9	<0.001
	M(7.7) AC(6.7)	0.51 NS	P	-0.72	18.0	0.48 NS
			S	-1.08	5.1	0.33 NS

*Test for homogeneity of sample variances. Ho probability (homogeneous sample variances), $P \leq 0.01$.
**P = pooled, S = separate. The pooled variance estimate is usually more reliable, particularly if Bartlett's test shows that sample variances are homogeneous (not significant).
***Not significant, $P > 0.05$.

Table 5

Partitioning of Principal Components into the Percent Variance Accounted for in Each Habitat Variable (Table 4)

Contribution to PC	Habitat Variable	Habitat Variable			
		PC I	PC II	PC III	PC IV
Positive	CCB	73	15		
	CBW	71			
	CREST		66	18	
	FORB	54		17	
	GRASS		24		
	LIT	21			32
	GRAV			71	
	CSAND	45			
	ROCK			48	
	CVDBW			72	
	CVHBW			49	
	CVNBW				68
	L2			20	
	L4J	53	18		
	L8		20	29	
	L10	72			
	L12J	71	18		
	CL4	36	48		
Negative	GRASS			32	24
	CSAND			27	
	SAND	64		25	
	CVDCB	78			
	CVDR		77		
	CVHCB	85			
	CVHR		77		
	CVNCB				24
	CVNR		78		
	L2				45
	L4J				16

Table 4

Principal Components Analysis of Study Sites (and Bird Species) Based on Habitat Variables

Principal Component (PC)	Eigenvalue	Percent of Variance	Cumulative Percent
I	10.12	40.5	40.5
II	3.96	15.9	56.3
III	3.46	13.8	70.2
IV	2.00	8.0	78.2

Habitat Variable	Varimax Rotated Factor Matrix PC I	PC II	PC III	PC IV
CCB	.857	.387	.064	.273
CBW	.842	.226	.045	-.271
CREST	.170	.814	.423	-.041
GRASS	-.103	.487	-.567	-.492
FORB	.736	-.206	.408	.290
LIT	.460	.122	.167	.568
GRAV	.362	.125	.845	-.040
CSAND	.671	.199	-.520	.104
SAND	-.802	-.195	-.504	-.101
ROCK	.104	.219	.693	-.010
CVDCB	-.886	-.160	.034	-.076
CVDBW	-.108	.094	.851	.141
CVDR	-.304	-.877	-.137	.045
CVHCB	-.924	-.158	.077	-.027
CVHBW	-.254	.250	.700	.277
CVHR	-.200	-.876	-.252	.003
CVNCB	-.187	-.034	-.072	-.485
CVNBW	.012	-.096	.151	.826
CVNR	-.081	-.884	-.016	.073
L2	.260	.070	.450	-.667
L4J	.726	.418	-.031	-.404
L8	.363	.448	.536	-.068
L10	.849	-.038	.172	.165
L12J	.842	.433	.092	.109
CL4	.602	.696	.014	.280

Table 3

Canonical Analysis of Discriminance of Study Sites Based on Habitat Variables

Canonical Discriminant Function (CDF)	Eigenvalue	Percent Variance	Cumulative Percent	Canonical Correlation	Wilks Lambda	Degrees of Freedom	Significance
					.0000001*	72*	
I	624.03	78.5	78.5	.999	.0000797	51	0.0001
II	147.80	18.6	97.1	.997	.0119	32	0.046
III	19.60	2.5	99.6	.975	.244	15	0.47

Standardized Canonical Discriminant Function Coefficients

Habitat Variables	CDF I	CDF II	CDF III
CCB	7.998	1.202	-.710
CBW	5.734	2.678	-1.491
CREST	2.030	-2.542	-.232
GRASS	.683	1.595	.468
FORB	-.276	.119	-.172
LIT	-4.523	-1.488	2.347
GRAV	-.341	-2.643	3.764
CSAND	-3.610	-.493	4.026
SAND	-2.176	-.243	3.121
ROCK	-.760	.299	1.189
CVDCB	-2.132	1.130	-.879
CVDBW	-3.961	-2.475	.042
CVDR	2.479	-.357	-1.642
CVHCB	2.739	.534	-.431
CVHBW	.540	.461	1.021
CVHR	1.730	.908	1.347
CVNCB	-1.459	.773	.904
CL4	-1.593	1.617	.171

*Initial

Table 2

Statistical Evaluation of Ground Cover and Substrate Sizes

Habitat Variable	Site Contrast (Mean-Percent)		Bartlett's* Test	Variance** Estimate	Student's t	Degrees of Freedom	Orthogonal*** Contrast Probability
Grass	S(18.3)	VC(27.1)	0.054 NS	P	2.78	87.0	0.007
				S	2.63	35.6	0.012
	M(20.3)	AC(15.0)	0.054 NS	P	-1.50	87.0	0.14 NS
				S	-2.18	24.8	0.038 NS
Forb	S(5.5)	VC(11.9)	0.088 NS	P	2.72	87.0	0.008
				S	2.62	24.9	0.015 NS
	M(4.5)	AC(28.0)	0.088 NS	P	7.89	87.0	<0.001
				S	6.26	14.4	<0.001
Litter	S(0.6)	VC(3.8)	0.016 NS	P	2.97	87.0	0.004
				S	2.39	14.2	0.027 NS
	M(1.3)	AC(2.0)	0.016 NS	P	1.22	87.0	0.23 NS
				S	1.35	22.1	0.19 NS
Sand (< 3 mm)	S(82.2)	VC(28.7)	0.39 NS	P	-15.20	87.0	<0.001
				S	-13.41	27.5	<0.001
	M(47.4)	AC(3.2)	0.39 NS	P	-13.11	87.0	<0.001
				S	-15.04	29.7	<0.001
Coarse Sand (3 mm to < 1 cm)	S(13.4)	VC(62.6)	<0.001	P	10.76	87.0	<0.001
				S	7.37	19.0	<0.001
	M(24.2)	AC(18.9)	<0.001	P	-2.41	87.0	0.018 NS
				S	-3.10	18.9	0.006
Gravel (1 to 8 cm)	S(4.4)	VC(8.6)	<0.001	P	-0.20	87.0	0.84 NS
				S	-0.15	18.3	0.89 NS
	M(24.1)	AC(75.7)	<0.001	P	11.43	87.0	<0.001
				S	11.10	17.4	<0.001
Rock (> 8 cm)	S(<0.2)	VC(0.2)	0.26 NS	P	0.29	87.0	0.78 NS
				S	1.00	15.0	0.33 NS
	M(4.3)	AC(2.2)	0.26 NS	P	-2.06	87.0	0.042 NS
				S	-1.70	28.8	0.099 NS
Bare Ground	S(75.7)	VC(57.3)	0.049 NS	P	-4.85	87.0	<0.001
				S	-5.54	35.3	<0.001
	M(73.9)	AC(55.0)	0.049 NS	P	-4.41	87.0	<0.001
				S	-4.63	16.8	<0.001

*Test for homogeneity of sample variances. Ho probability (homogeneous sample variances), P ≤ 0.01.
**P = pooled, S = separate. The pooled variance estimate is usually more reliable, particularly if Bartlett's test shows that sample variances are homogeneous (not significant).
***Not significant, P > 0.01.

Table 1

Statistical Evaluation and Shrub Parameters

Habitat Variable	Site Contrast (Mean)		Bartlett's* Test	Variance** Estimate	Student's t	Degrees of Freedom	Orthogonal*** Contrast Probability
Creosote Bush Density (shrubs/ha)	S(9.0)	VC(22.4)	0.009	P	6.34	87.0	<0.001
				S	4.79	20.1	<0.001
	M(8.5)	AC(27.5)	0.009	P	8.29	87.0	<0.001
				S	9.11	19.3	<0.001
Burroweed Density (Shrubs/ha)	S(6.9)	VC(63.8)	0.39 NS	P	8.65	87.0	<0.001
				S	8.52	19.4	<0.001
	M(33.1)	AC(64.7)	0.39 NS	P	3.37	87.0	0.001
				S	2.85	17.7	0.011
Subdominant Shrubs (12 spp.) Density (Shrubs/ha)	S(6.4)	VC(4.1)	0.030 NS	P	0.044	87.0	0.97 NS
				S	0.051	37.9	0.96 NS
	M(8.2)	AC(15.8)	0.030 NS	P	0.90	87.0	0.37 NS
				S	0.72	14.2	0.48 NS
Creosote Bush Diameter (cm)	S(86.0)	VC(162.2)	<0.001	P	14.22	992	<0.001
				S	14.69	362	<0.001
	M(127.0)	AC(142.4)	<0.001	P	3.43	995	0.001
				S	3.51	358	<0.001
Burroweed Diameter (cm)	S(41.4)	VC(67.0)	<0.001	P	13.68	2076	<0.001
				S	16.10	384	<0.001
	M(45.6)	AC(55.2)	<0.001	P	7.62	2076	<0.001
				S	7.54	676	<0.001
Subdominant Shrubs (12 spp.) Diameter (cm)	S(47.8)	VC(57.0)	0.15 NS	P	1.71	612	0.087 NS
				S	1.47	39.8	0.15 NS
	M(65.3)	AC(55.6)	0.15 NS	P	-3.49	612	0.001
				S	-3.42	188	0.001
Creosote Bush Height (cm)	S(58.6)	VC(127.2)	<0.001	P	19.42	995	<0.001
				S	20.12	305	<0.001
	M(93.3)	AC(106.7)	<0.001	P	4.92	995	<0.001
				S	5.21	306	<0.001
Burroweed Height (cm)	S(27.8)	VC(41.2)	0.037 NS	P	14.36	2076	<0.001
				S	14.98	284	<0.001
	M(29.9)	AC(33.0)	0.037 NS	P	5.28	2076	<0.001
				S	5.30	756	<0.001
Subdominant Shrubs (12 spp.) Height (cm)	S(37.8)	VC(48.5)	0.012	P	3.98	612	<0.001
				S	4.31	44.7	<0.001
	M(49.5)	AC(43.9)	0.012	P	-3.05	612	0.002
				S	-3.05	1.79	0.003

*Test for homogeneity of sample variances. Ho probability (homogeneous sample variances), $P \leq 0.01$.
**P = pooled, S = separate. The pooled variance estimate is usually more reliable, particularly if Bartlett's test shows that sample variances are homogeneous (not significant).
***Not significant, $P > 0.01$.

Table 15

Canonical Analysis of Discriminance of Study Sites Based on Small Mammal Community Structure

Canonical Discriminant Function (CDF)	Eigenvalue	Percent Variance	Cumulative Percent	Canonical Correlation	Wilks Lambda	Degrees of Freedom	Significance
					.00177*	20*	
I	29.04	81.8	81.8	.983	.0532	12	< 0.0001
II	4.80	13.5	95.4	.910	.308	6	0.011
III	1.11	3.1	98.5	.725	.650	2	0.049

Standardized Canonical Discriminant Function Coefficients

Mammal Species	CDF I	CDF II	CDF III
Desert kangaroo rat (DES)	1.520	-.078	1.496
Merriam's kangaroo rat (MER)	1.921	-.079	.896
Little pocket mouse (LON)	.029	.695	.360
Long-tailed pocket mouse (FOR)	1.489	.435	-.053
Grasshopper mouse (TOR)	-1.163	.415	-.011

*Initial

Table 16

Classification of Study Sites on the Basis of Small Mammal Community Structure

Number of Transects	Actual Group	Predicted Group Membership				
		S	M	L	VC	AC
4	S	4				
4	.M		4			
4	L			4		
4	VC				4	
4	AC	1				3

Percent of grouped cases correctly classified: 19/20, 95 percent.

N	Actual Group	Predicted Group	2nd Highest Probability for Group Membership				
			S	M	L	VC	AC
4	S	S		4			
4	M	M	4				
4	L	L	4				
4	VC	VC					4
3	AC	AC		2		1	
1	AC	S					1

Table 17

Canonical Analysis of Discriminance of Study Sites With Groups Defined by Pairing Adjacent Trap-Lines

Canonical Discriminant Function (CDF)	Eigenvalue	Percent Variance	Cumulative Percent	Canonical Correlation	Wilks Lambda	Degrees of Freedom	Significance
					0.0000009*	45*	
I	291.87	72.8	72.8	.998	0.000252	32	< 0.0001
II	97.91	24.4	97.2	.995	0.0249	21	0.0037
II	9.26	2.3	99.5	.950	0.255	12	0.20

Standardized Canonical Discriminant Function Coefficients

Mammal Species	CDF I	CDF II	CDF III
Desert kangaroo rat (DES)	-0.913	0.524	0.075
Merriam's kangaroo rat (MER)	1.430	1.734	-0.137
Little pocket mouse (LON)	0.638	0.178	0.923
Long-tailed pocket mouse (FOR)	1.840	2.240	0.291
Grasshopper mouse (TOR)	-1.478	-1.850	0.010

*Initial

Table 18

Classification of Study Sites With Mammal Groups Defined by Pairing Adjacent Trap-Lines

		Predicted Group Membership									
Number of Transects	Actual Group	S1 S2	S3 S4	M1 M2	M3 M4	L1 L2	L3 L4	VC1 VC2	VC3 VC4	AC1 AC2	AC3 AC4
2	S1 S2	2									
2	S3 S4		2								
2	M1 M2			2							
2	M3 M4				2						
2	L1 L2					1	1				
2	L3 L4					1	1				
2	VC1 VC2							2			
2	VC3 VC4								2		
2	AC1 AC2									2	
2	AC3 AC4		1								1

Percent of grouped cases correctly classified: $\frac{17}{20}$, 85 percent.

			2nd Highest Probability for Group Membership									
N	Actual Group	Predicted Group	S1 S2	S3 S4	M1 M2	M3 M4	L1 L2	L3 L4	VC1 VC2	VC3 VC4	AC1 AC2	AC3 AC4
2	S1 S2	S1 S2			2							
2	S3 S4	S3 S4				2						
2	M1 M2	M1 M2				2						
2	M3 M4	M3 M4		2								
1	L1	L3 L4					1					
1	L2	L1 L2						1				
1	L3	L3 L4					1					
1	L4	L1 L2						1				
2	VC1 VC2	VC1 VC2								2		
2	VC3 VC4	VC3 VC4							2			
2	AC1 AC2	AC1 AC2				2						
1	AC3	AC3 AC4		1								
1	AC4	S3 S4										1

Table 19

Statistical Evaluation of Bird and Small Mammal Biomass at Impacted Sites

Biomass	Site Contrast (Mean - Grams)		Bartlett's* Test	Variance** Estimate	Student's t	Degrees of Freedom	Orthogonal*** Contrast Probability
Birds	S(289)	VC(743)	0.087 NS	P	7.61	18.0	<0.001
				S	6.35	7.5	<0.001
Birds	M(398)	AC(642)	0.087 NS	P	3.40	18.0	0.003
				S	4.20	2.2	0.052
Mammals	S(294)	VC(461)	0.10 NS	P	-1.88	15.0	0.079 NS
ANOVA (all sites, P = 0.002)				S	-2.34	5.6	0.058 NS
	M(184)	AC(191)	0.10 NS	P	0.34	15.0	0.74 NS
				S	0.25	3.8	0.81 NS

*Test for homogeneity of sample variances. Ho probability (homogeneous sample variances), P ≤ 0.01.
**P = pooled, S = separate. The pooled variance estimate is usually more reliable, particularly if Bartlett's test shows that sample variances are homogeneous (not significant).
***Not significant, P > 0.05.

Mann-Whitney U Test

Biomass	Site Contrast (Mean - Grams)		Two-Tailed Probability* Exact	Two-Tailed Probability* Corrected for Ties
Birds	S(289)	VC(743)	0.0095	0.010
	M(398)	AC(642)	0.024	0.020
	S(289)	M(398)	0.026	0.024
Mammals	S(294)	VC(461)	0.057 NS	0.043
	M(184)	AC(191)	0.89 NS	0.77 NS
	S(294)	M(184)	0.11 NS	0.083 NS

*Not significant, P > 0.05.

Table 20

Species Compositions of Impact Guilds

BIOMASS (g)-Actual for Birds, Relative for Mammals

Impact Guild	Species in Guild	S	VC	M	AC	L
Benefited	Desert Kangaroo Rat	108.6	0	0	0	0
	Sum	108.6	0	0	0	0
Insensitive	Merriam's Kangaroo Rat	153.2	159.8	166.4	84.6	225.6
	Horned Lark	284.4	331.8	242.3	231.7	395.0
	Sum	437.6	491.6	408.7	316.3	620.6
Moderately Sensitive	Black-throated Sparrow	4.5	67.5	103.5	90.0	60.8
	White-crowned Sparrow	.0	45.5	17.3	78.0	19.5
	Chipping Sparrow	.0	.0	4.2	4.2	3.2
	Sum	4.5	113.0	125.0	168.0	83.5
Highly Sensitive	Little Pocket Mouse	32.5	257.4	17.2	83.4	97.6
	Grasshopper Mouse	.0	43.4	.0	7.2	.0
	Brewer's Sparrow	.0	71.5	.0	44.0	115.5
	Sage Sparrow	.0	27.0	.0	6.0	9.0
	Western Meadowlark	.0	169.5	.0	188.3	56.5
	LeConte's Thrasher	.0	30.5	30.5	.0	30.5
	Sum	32.5	599.3	47.7	328.9	309.1
Habitat Specialist*	Long-tailed Pocket Mouse	0	0	0	15.8	105.0
	Sum	0	0	0	15.8	105.0

*May be highly sensitive or insensitive-depending on specific damage to essential habitat components.

Table 21

Survey of Mojave Desert Shrub Breeding Bird Censuses

Habitat	Topography*	County**	Impact***	Census Year	Study Plot Size (ha)	Number of territorial males 100 ha: HL	BTS	BS	SAS	WML	LCT	Total males 100 ha	Reference
Creosote scrub	V	SB	N	83	64	33	16	20	5	5	0	79	Krzysik
"	A	SB	N	83	48	23	21	13	1	5	0	63	(this study)
"	HD	SB	L	83	64	39	14	33	2	2	2	92	
"	A	SB	M	83	96	24	24	0	0	0	0	48	
"	V	SB	S	83	96	28	1	0	0	0	0	29	
Creosote scrub	V-B	SB	N	74	4	0	19	25	50	0	25	119	(Ref. 21)
"	V-B	SB	M	74	4	0	13	0	0	0	0	19	
"	V-B	SB	S	74	4	0	0	0	0	0	0	0	
"	V-A	SB	N	74	40	8	3	0	0	0	2	16	
"	V-A	SB	M	74	40	8	3	0	0	0	0	10	
"	V-J	SB	N	74	40	5	19	0	0	0	0	24	
"	V-J	SB	M	74	40	9	0	0	0	0	0	9	
Creosote scrub	V	SB	N	76	18	0	17	0	0	0	0	17	(Ref. 69)
"	V	K	N	77	36	36	0	0	8	0	+	44	(Ref. 72)
Creosote scrub	A	I	N	79	26	12	47	3	20	0	0	90	(Ref. 48)
"	A-S	I	N	79	26	0	47	2	94	0	0	157	
Mixed scrub	A	I	N	79	26	35	39	12	1	0	0	94	(Ref. 49)
Atriplex scrub	V	I	N	79	26	55	12	3	35	0	0	114	(Ref. 50)
"	P	SB	N	78	36	25	0	2	22	0	+	53	(Ref. 74)

* V = valley; A = alluvial; HD = high desert; P = edge of playa; S = Sierra Mountains slope; B, A, J = specific sites.
**SB = San Bernardino; K = Kern; I = Inyo.
***Impacts as judged by authors: N = none; L = light; M = moderate; S = severe.
+Present

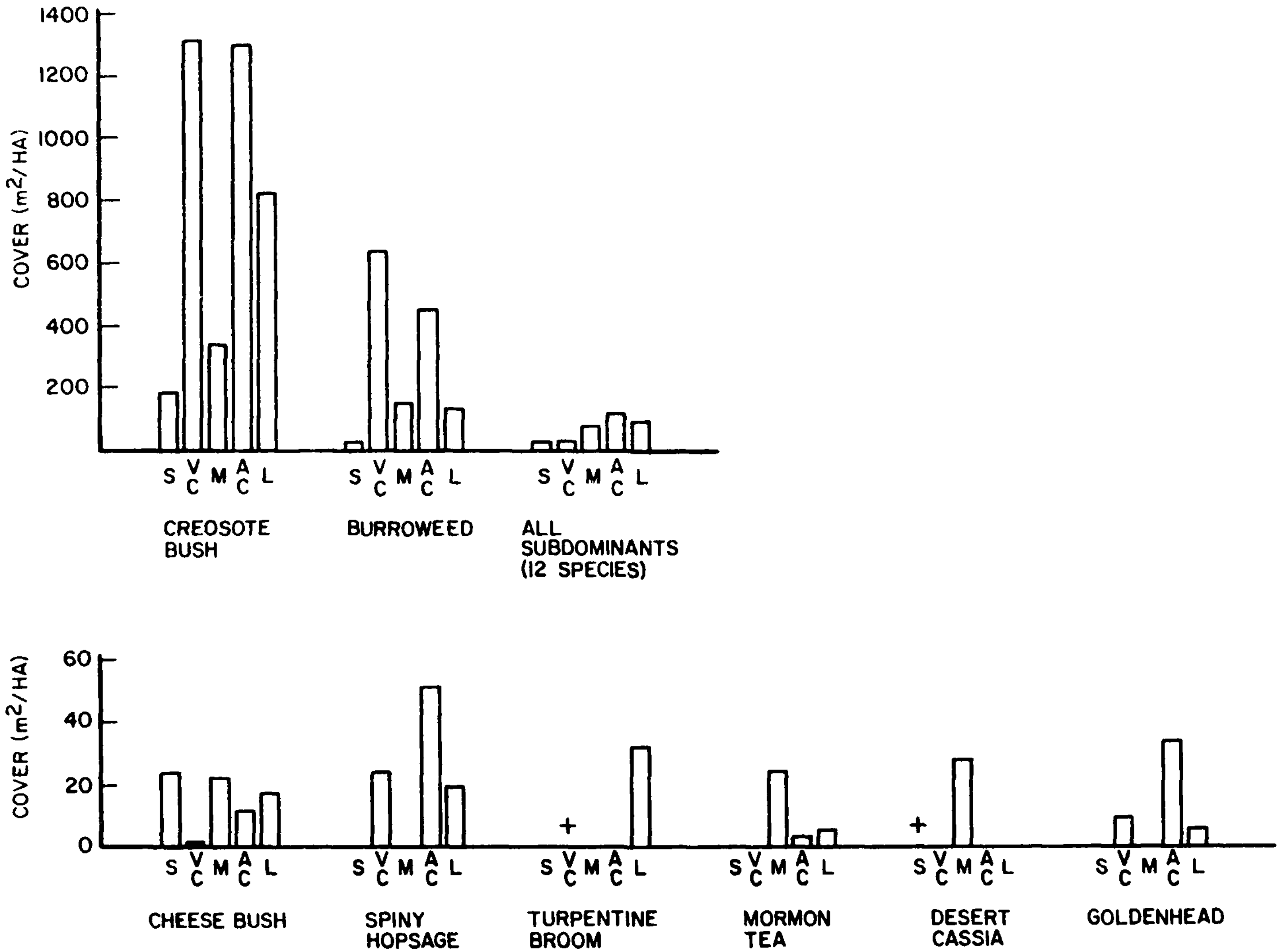


Figure 1. Shrub cover of the eight most abundant woody species.

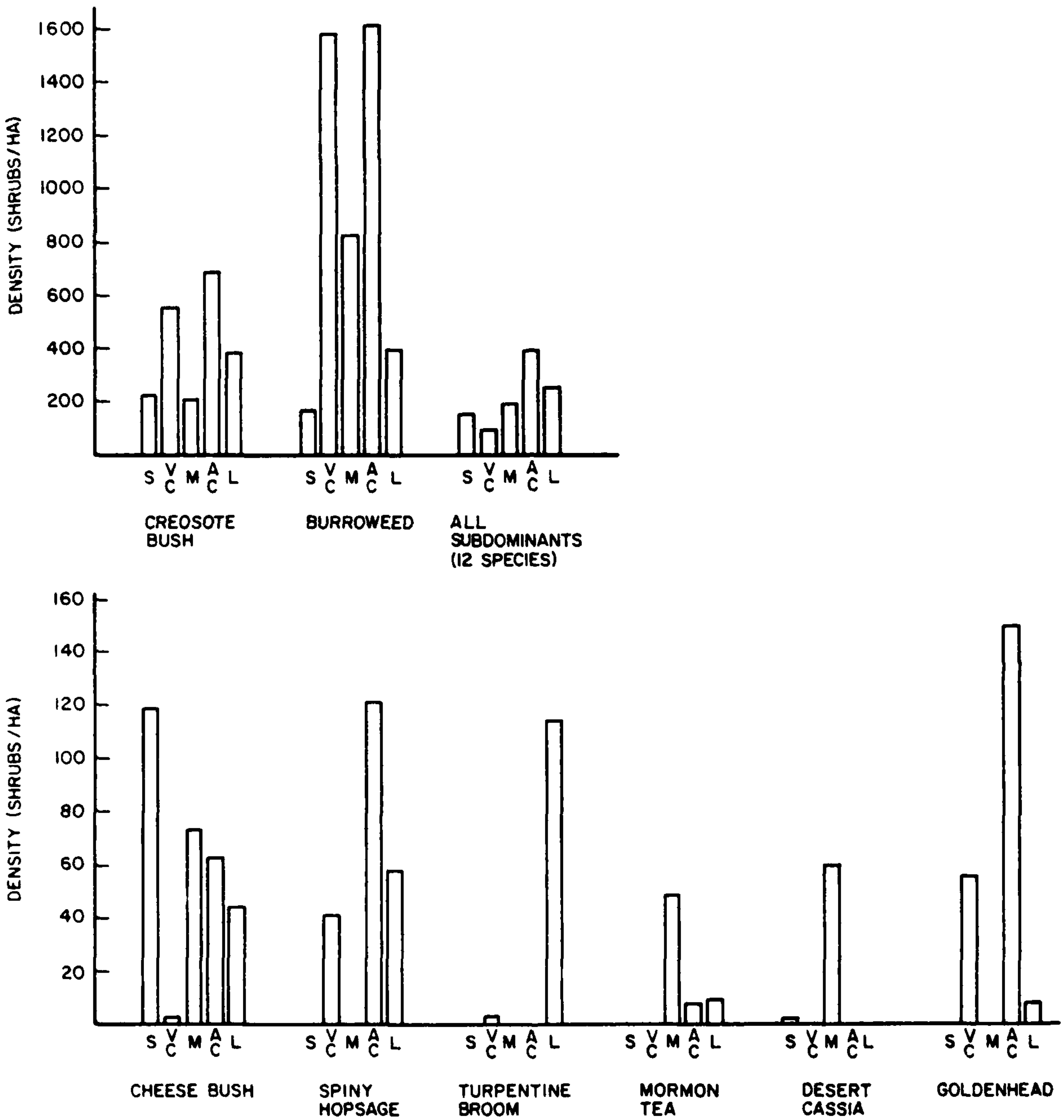


Figure 2. Shrub density of the eight most abundant woody species.

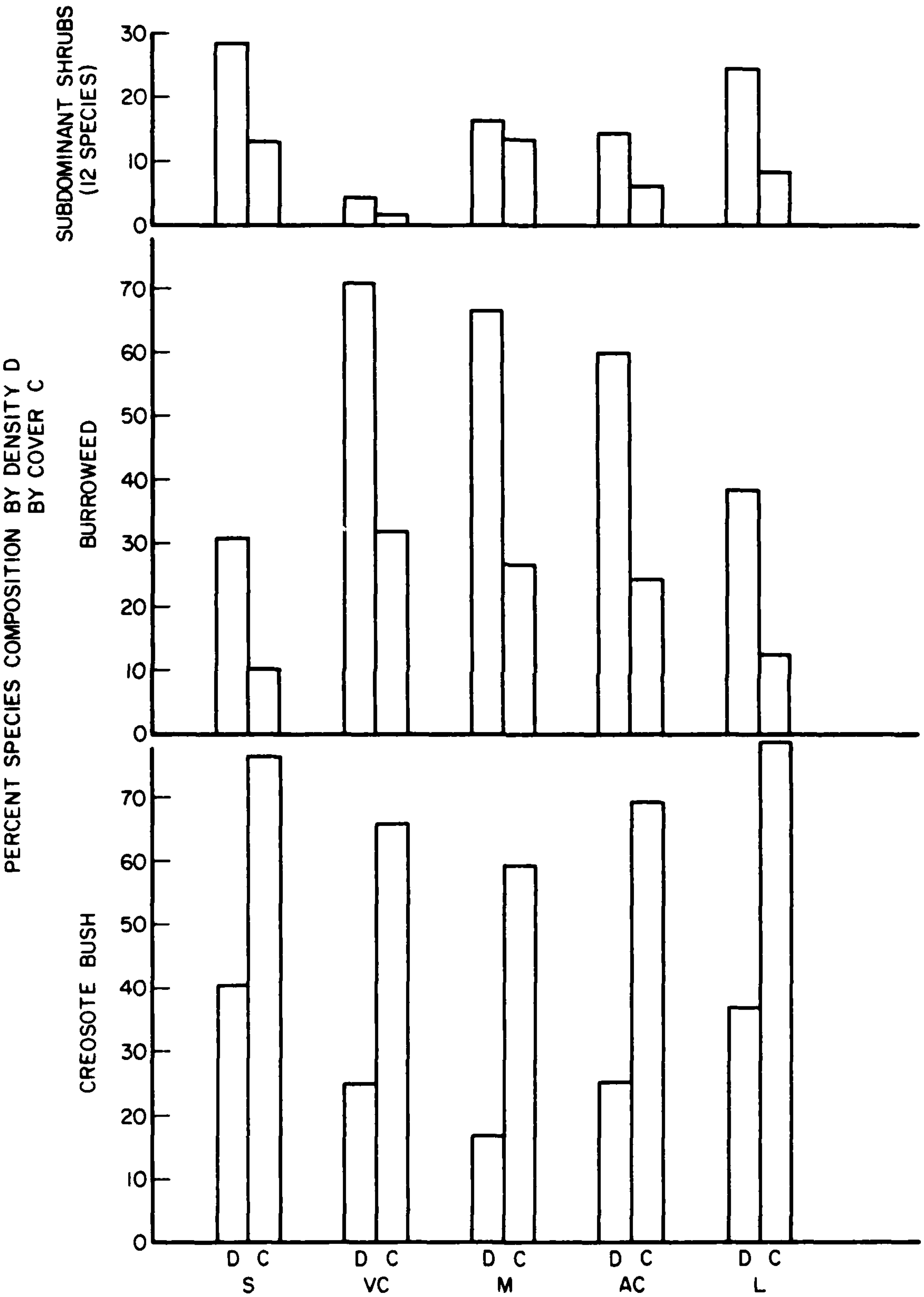


Figure 3. Percent species composition of woody vegetation (shrubs).

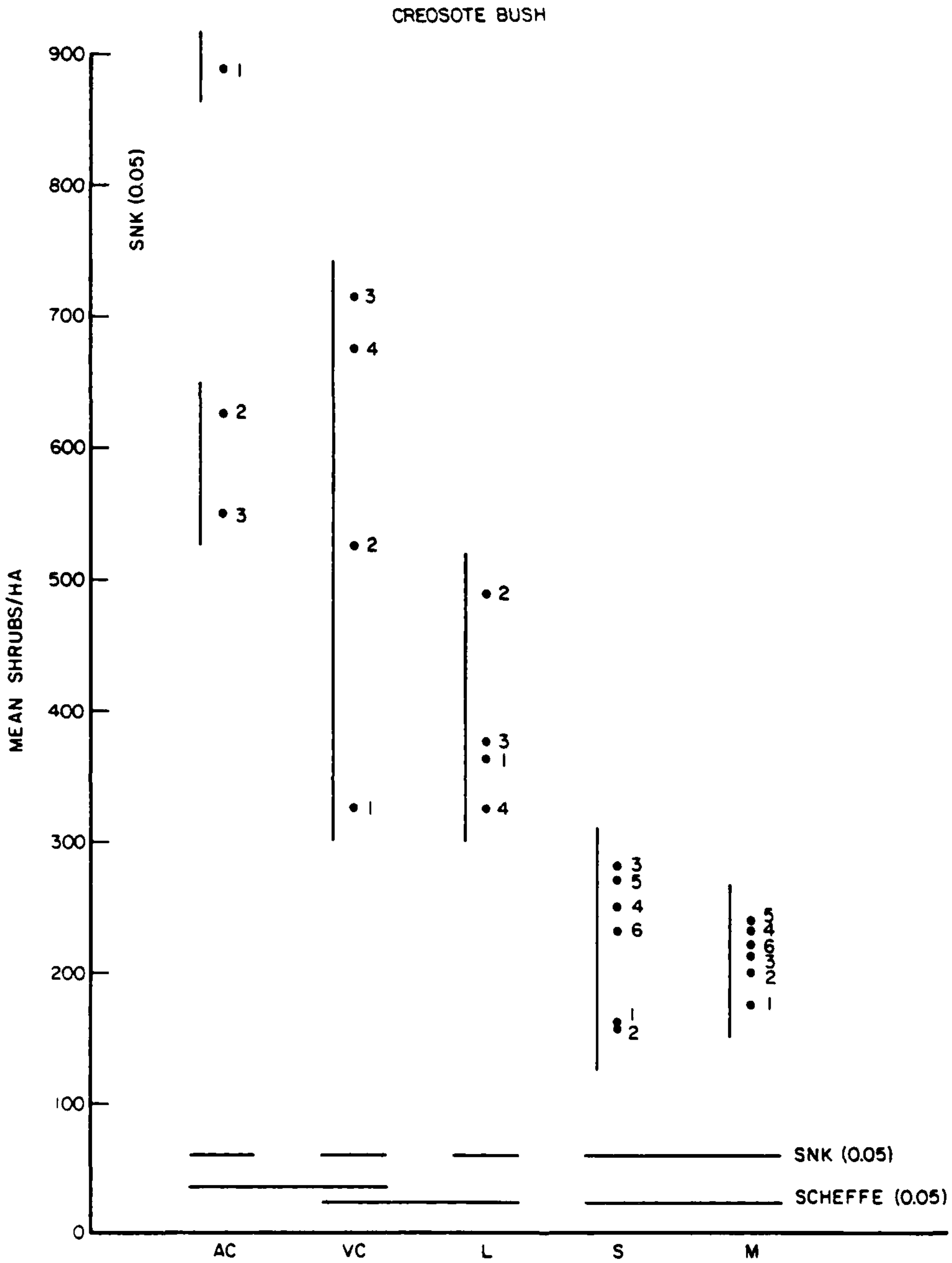


Figure 4. Intra- and intersite comparisons of creosote bush density.

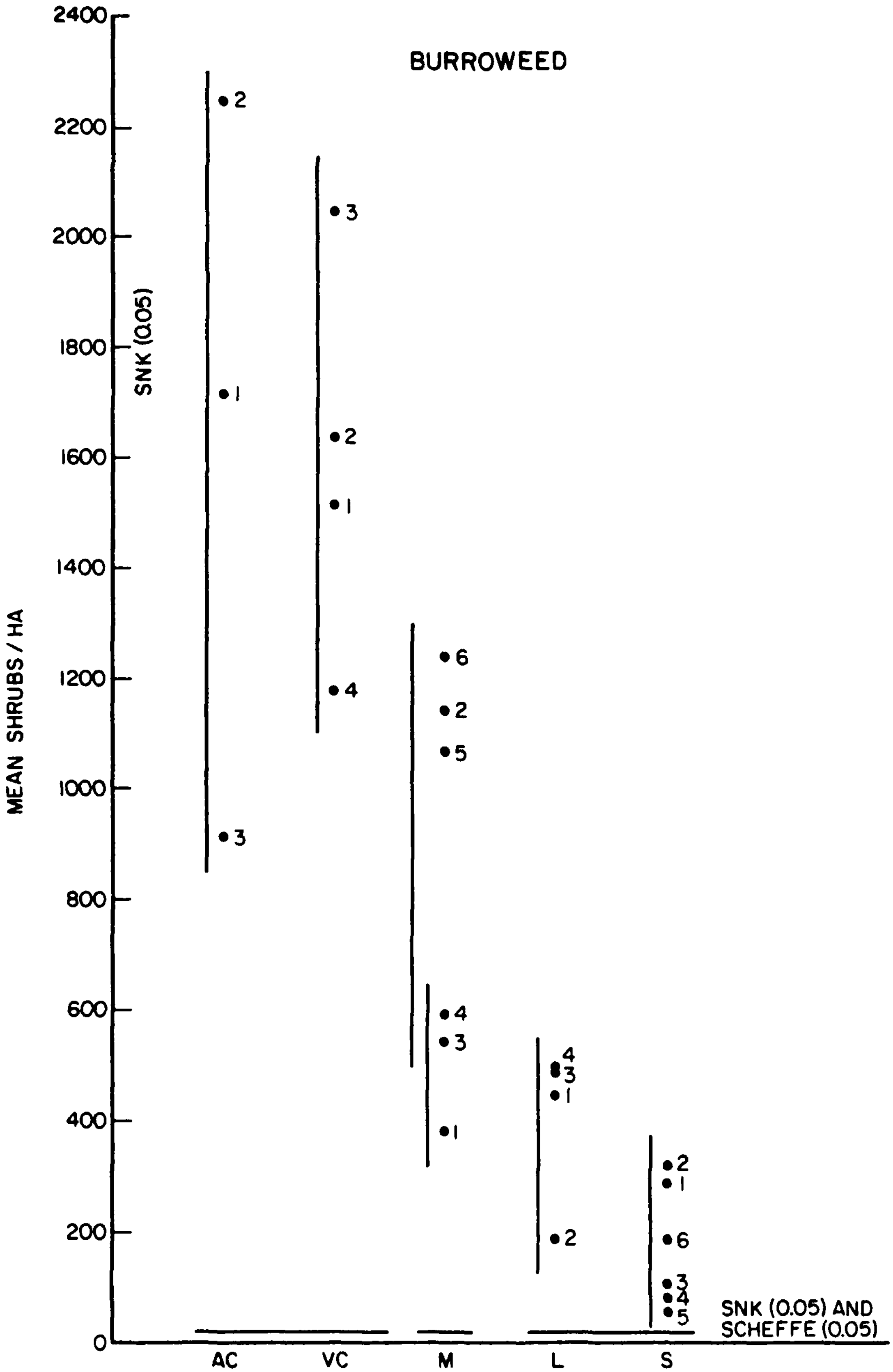


Figure 5. Intra- and intersite comparisons of burroweed density.

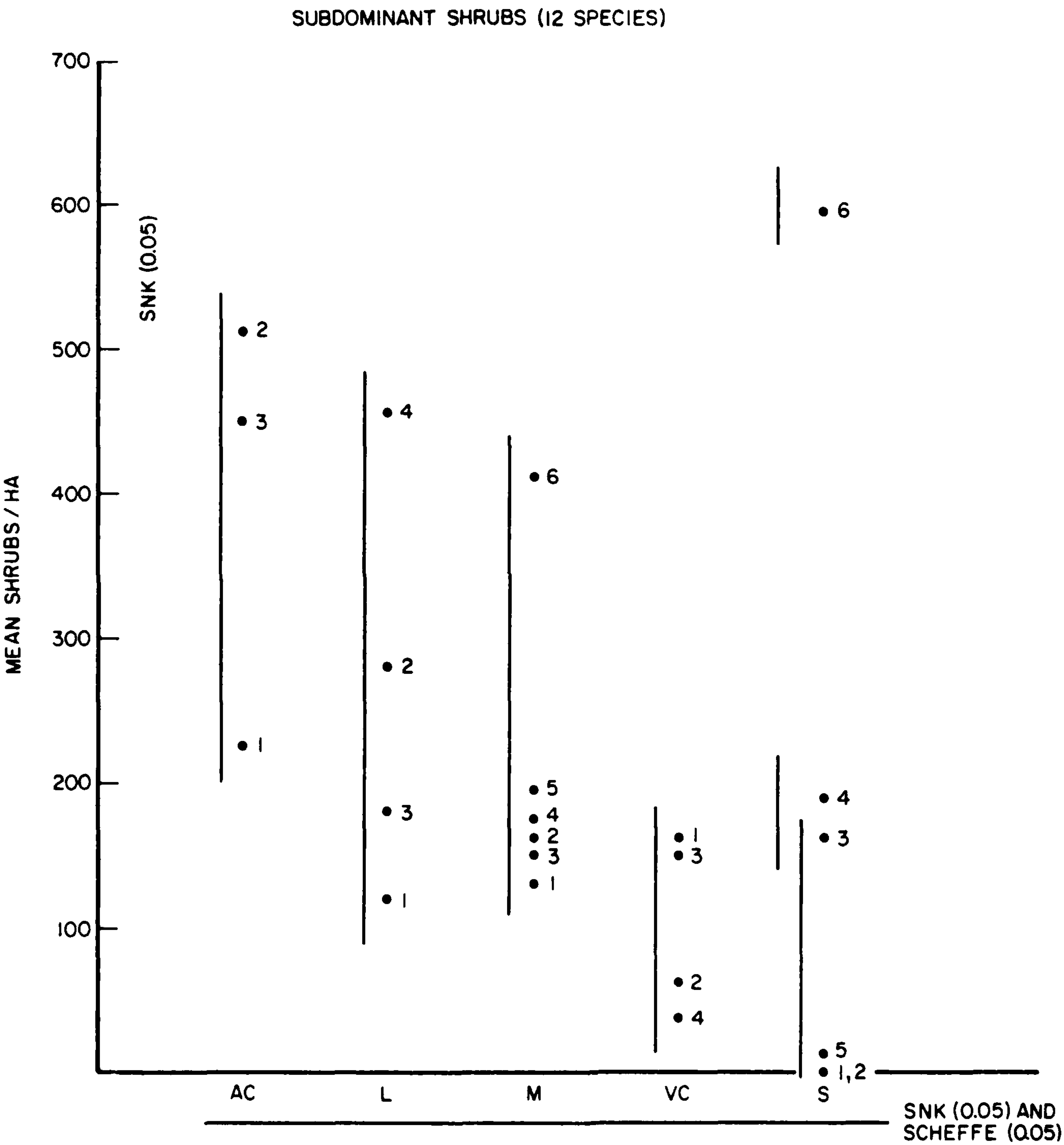


Figure 6. Intra- and intersite comparisons of subdominant shrub species density.

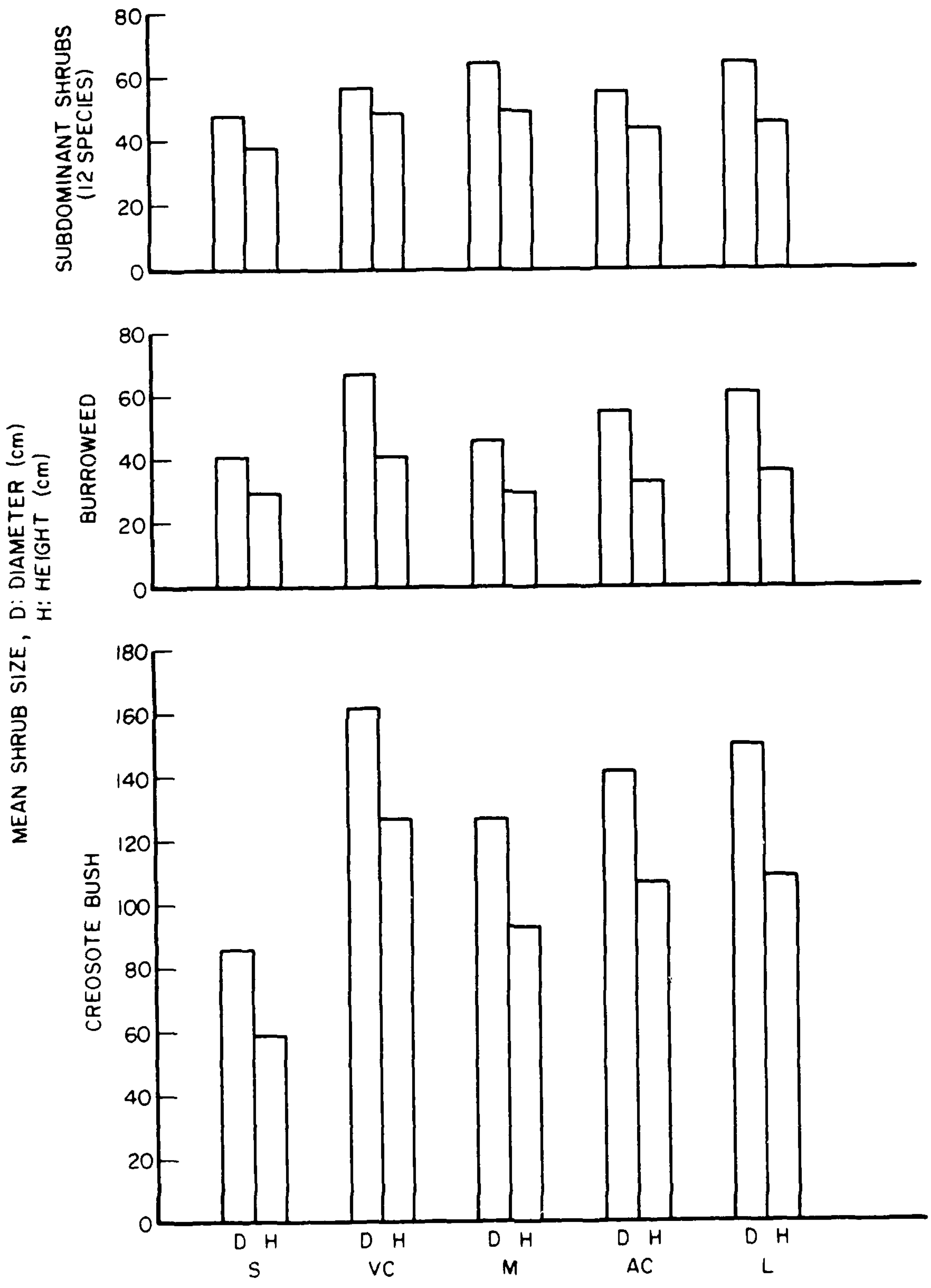


Figure 7. Mean shrub size at each study site.

(B)

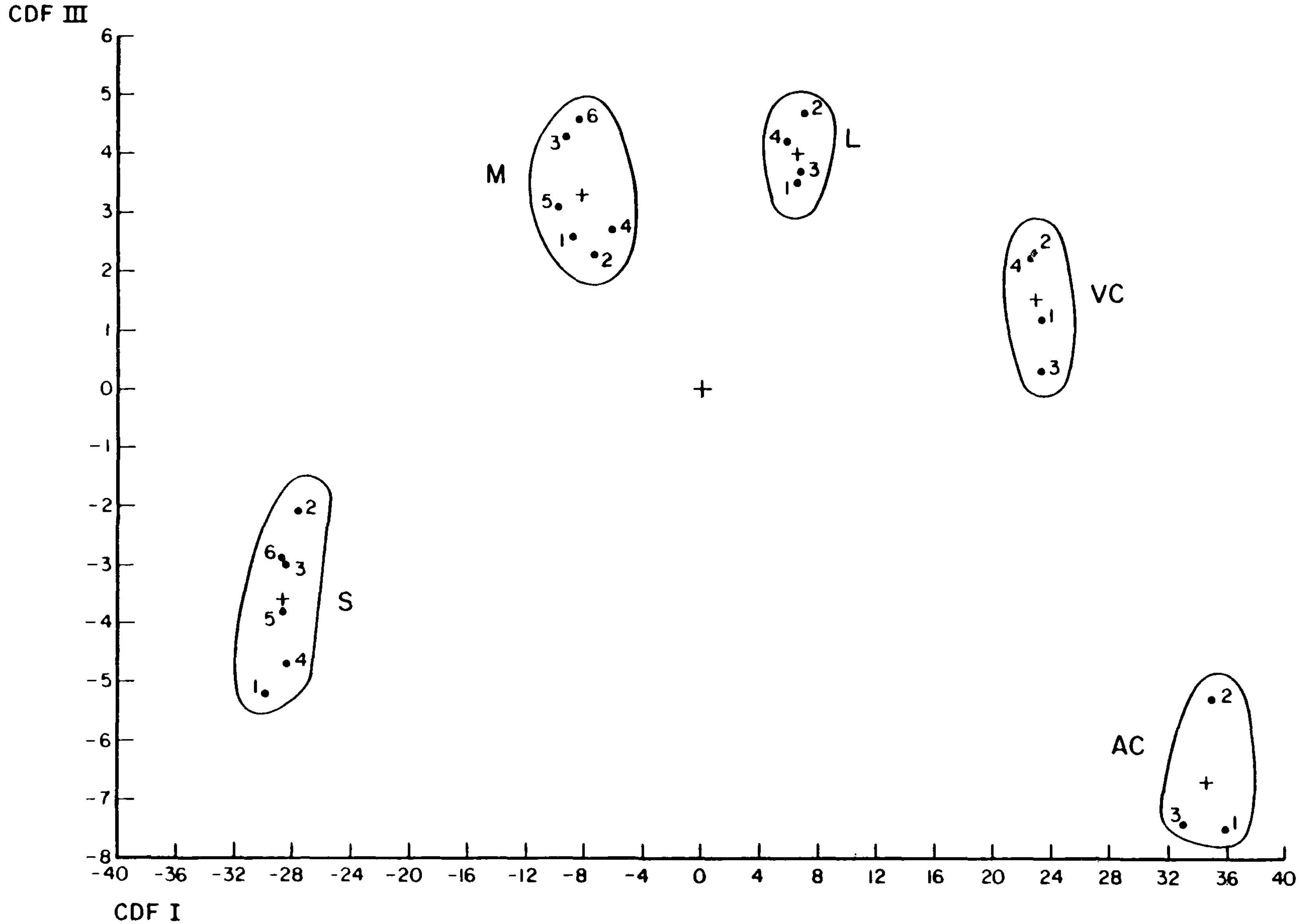


Figure 20. (Cont'd).

(A)

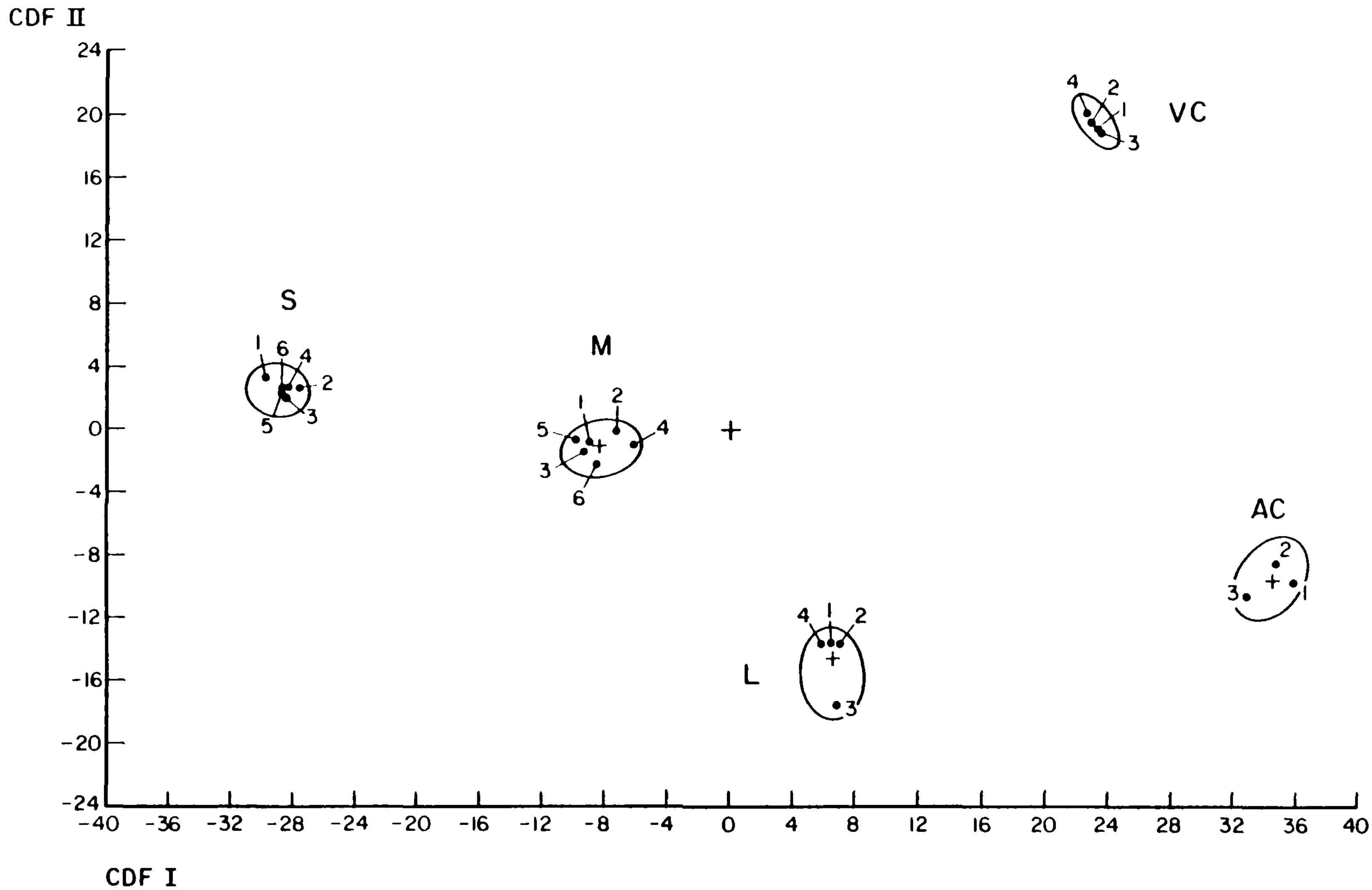


Figure 20. Canonical analysis of discriminance of the five study sites based on habitat variables.

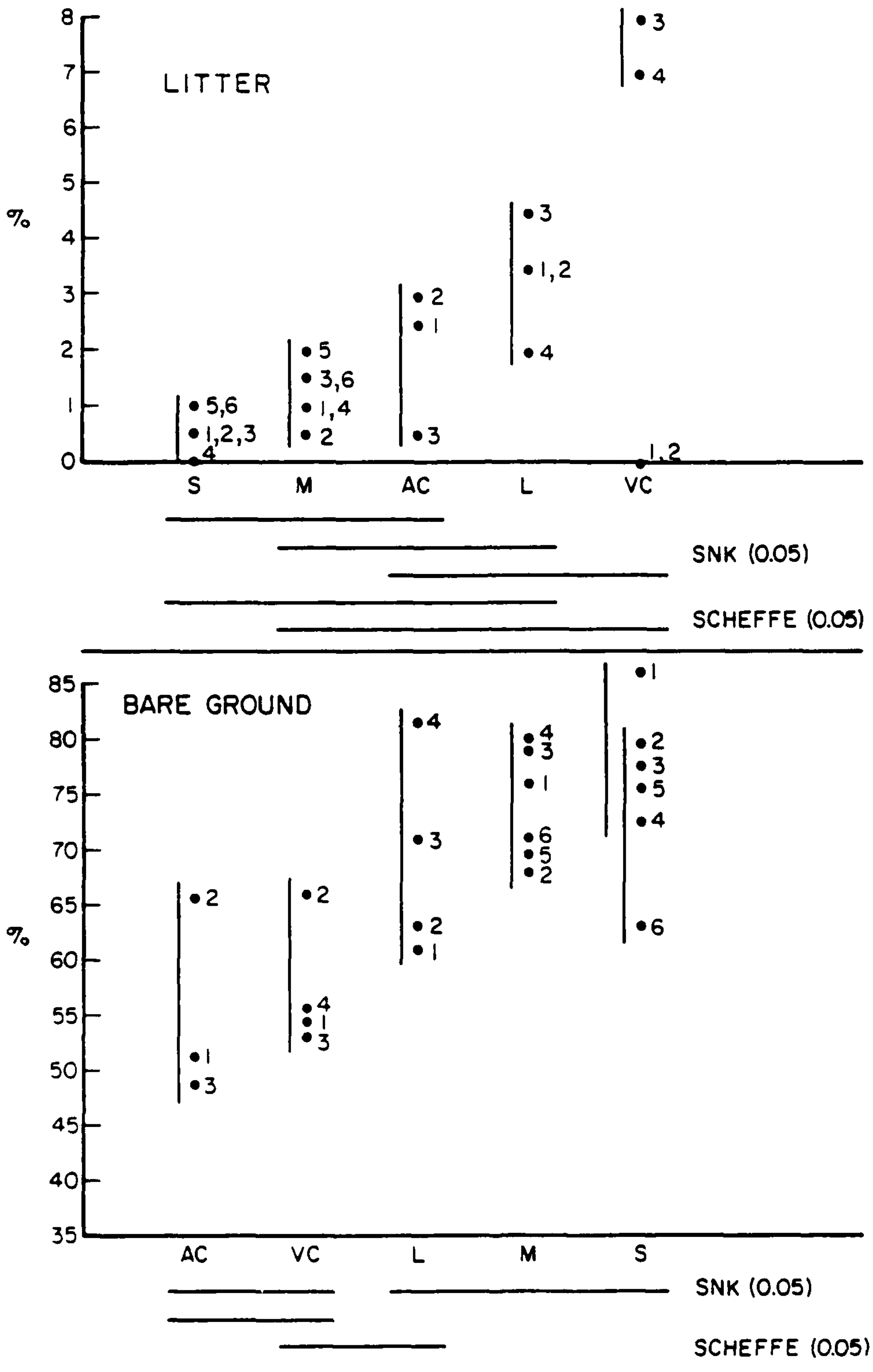


Figure 19. Intra- and intersite comparisons of bare ground and litter.

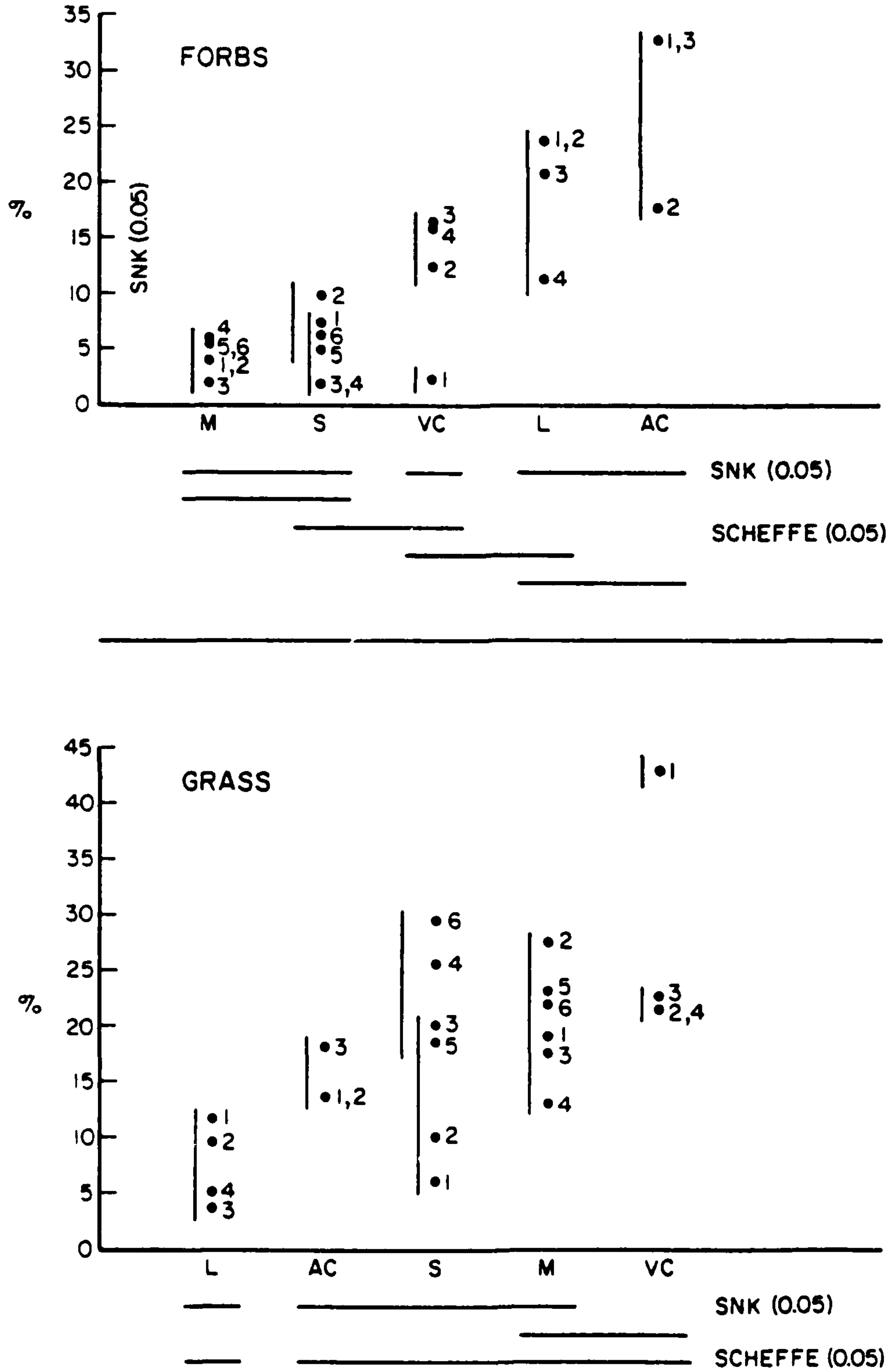


Figure 18. Intra- and intersite comparisons of grass and forbs.

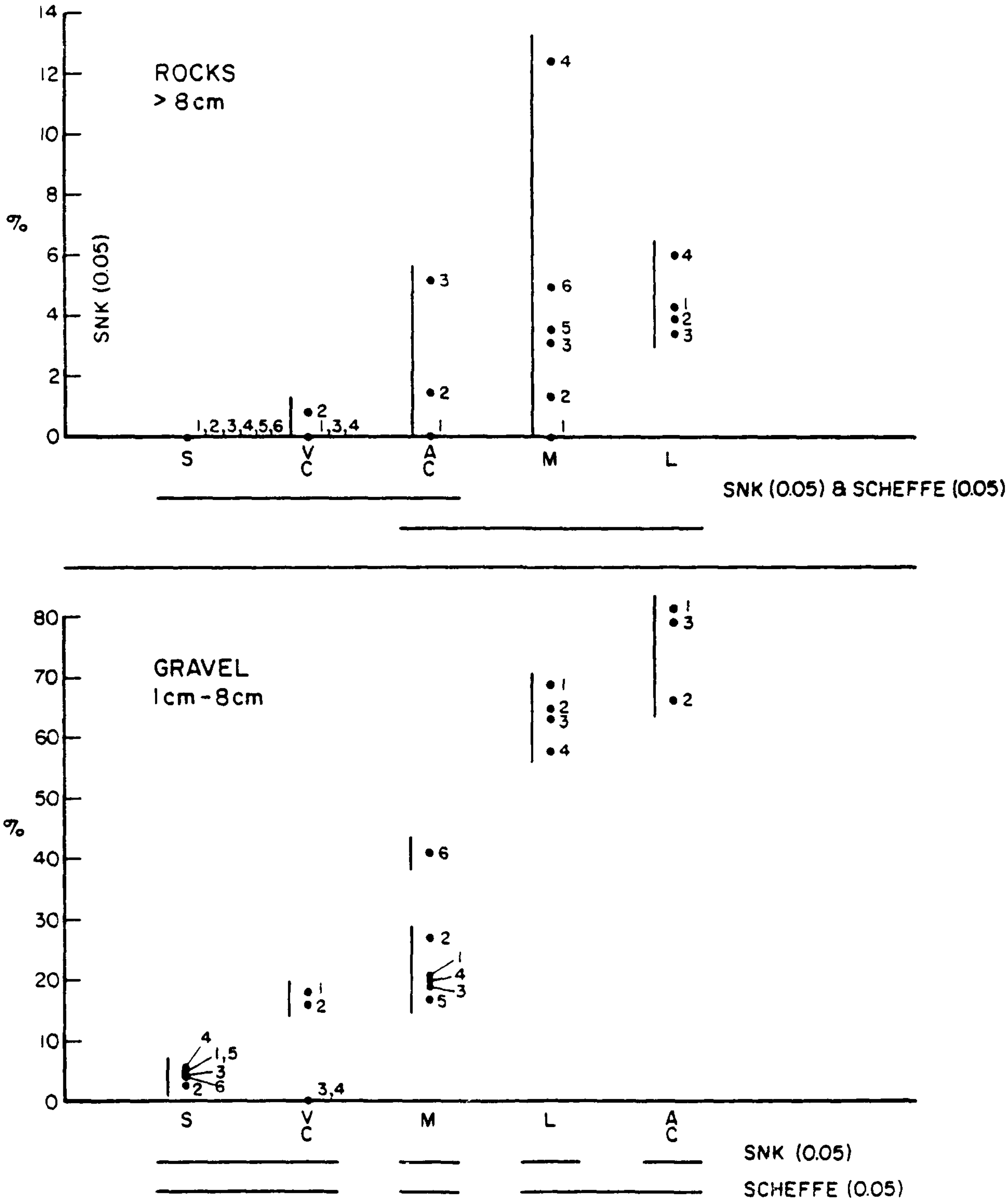


Figure 17. Intra- and intersite comparisons of gravel and rock substrates.

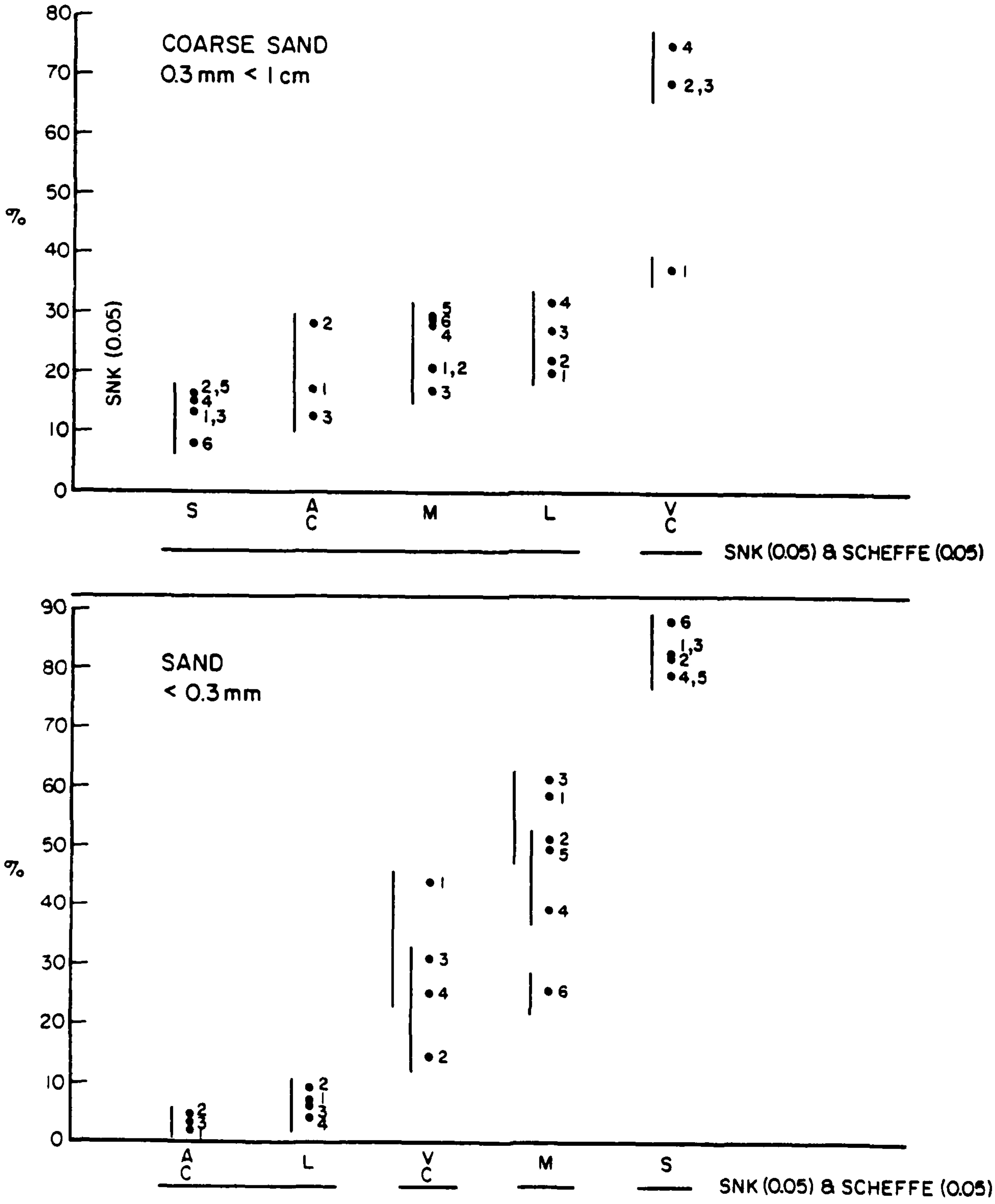


Figure 16. Intra- and intersite comparisons of sand and course sand substrates.

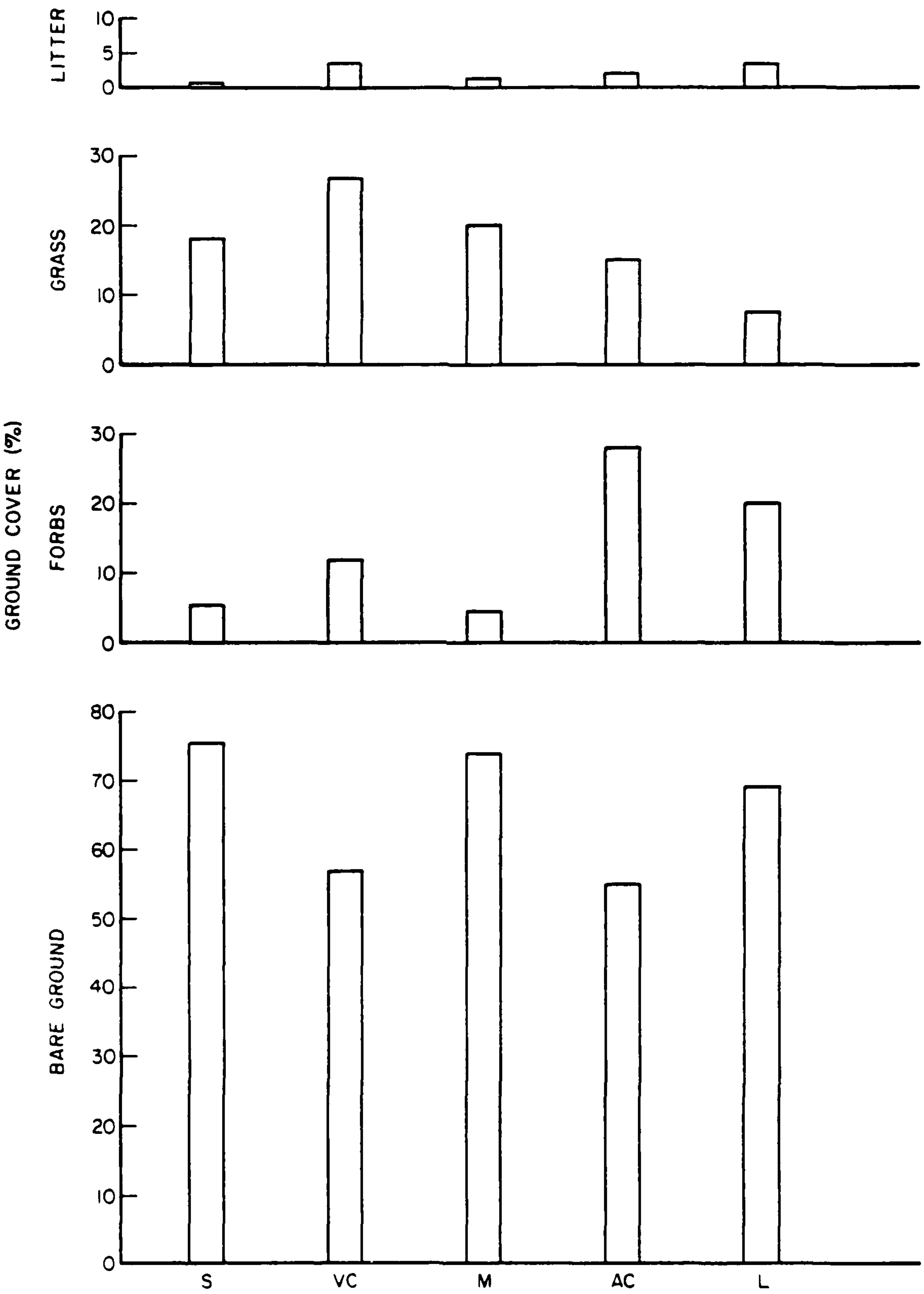


Figure 15. Ground cover at the study sites.

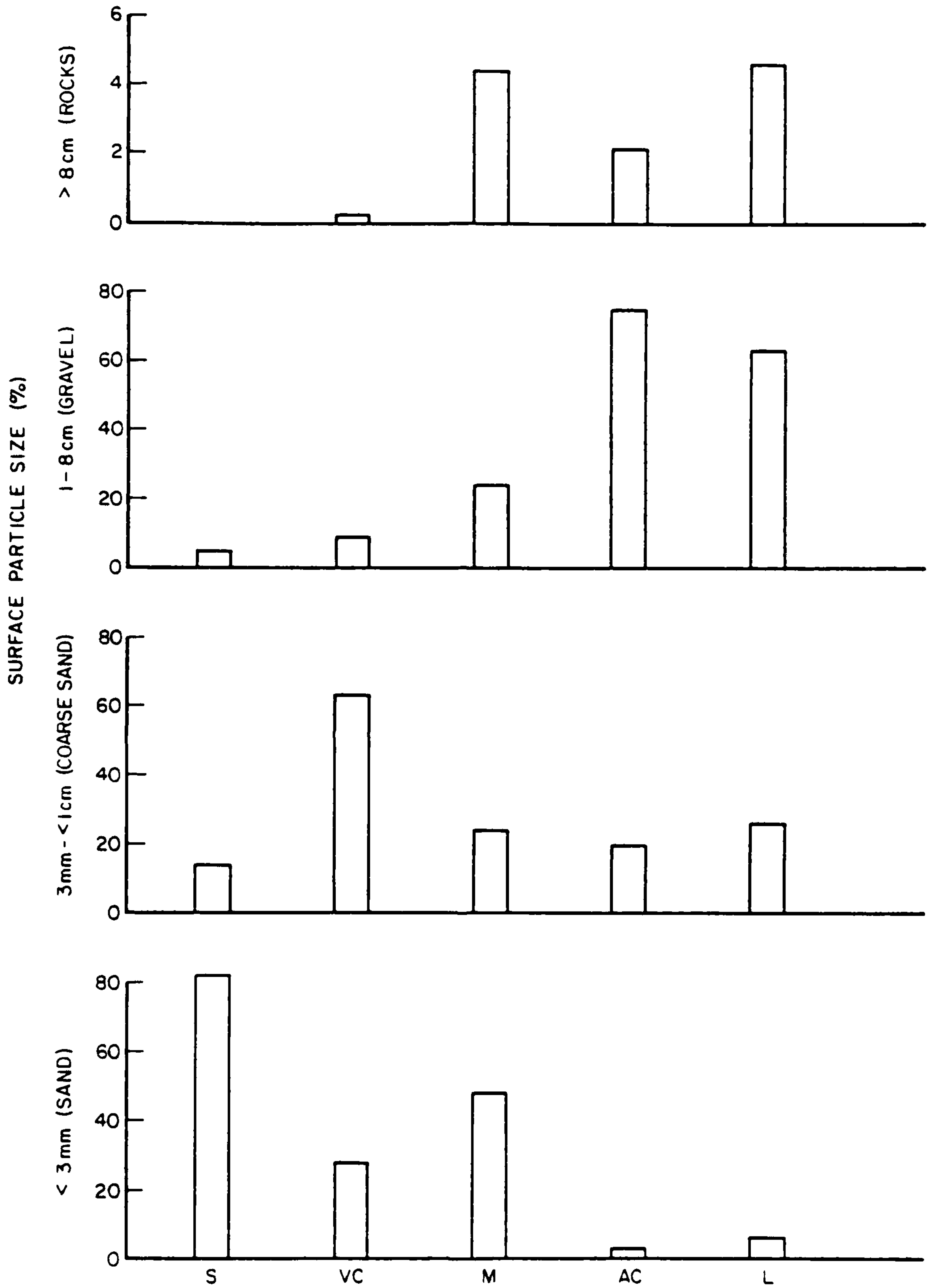


Figure 14. Substrate particle size distribution at the study sites.

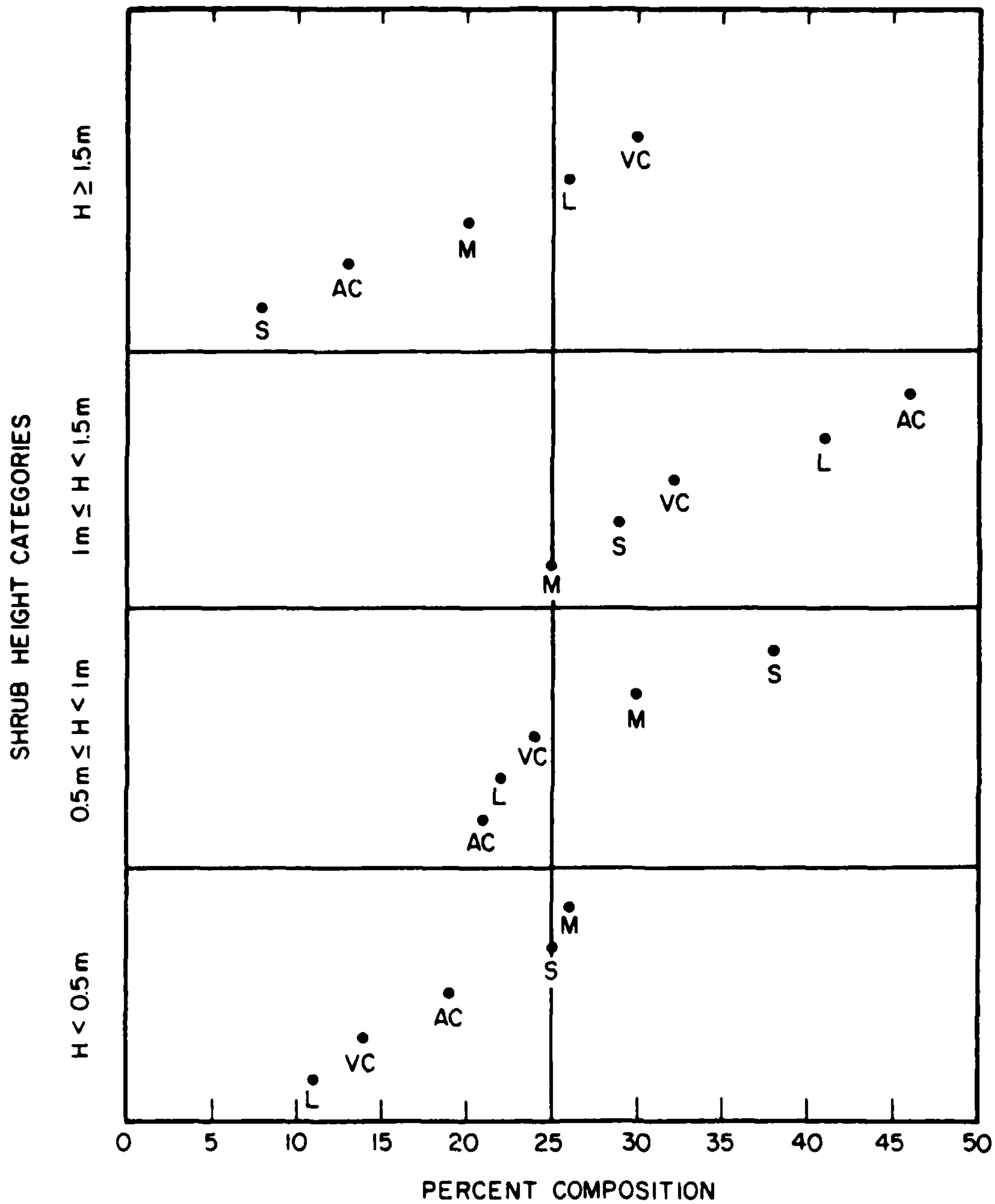


Figure 13. Percent composition of shrub height categories present at each study site.

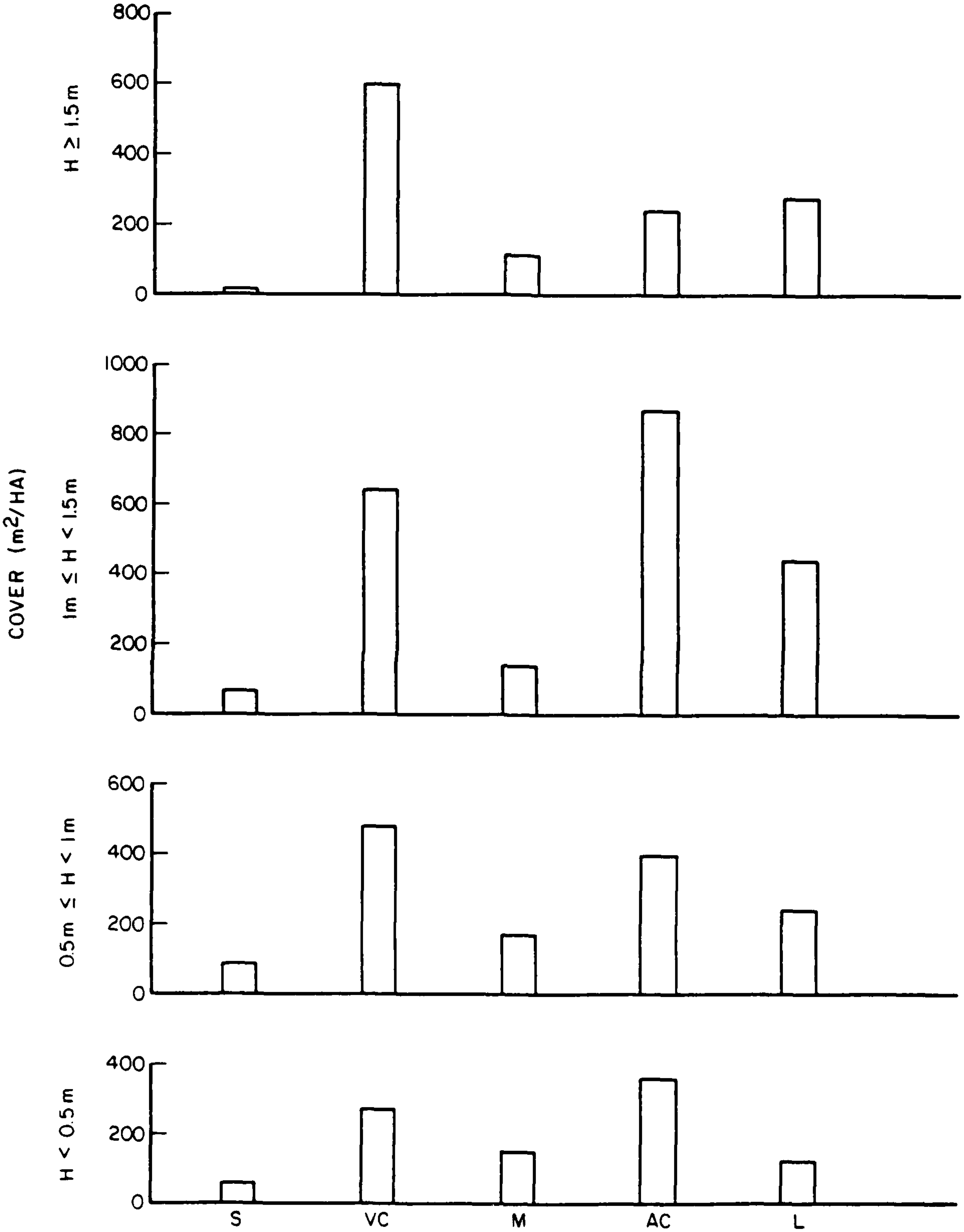


Figure 12. Shrub cover present in each of four height categories at each study site.

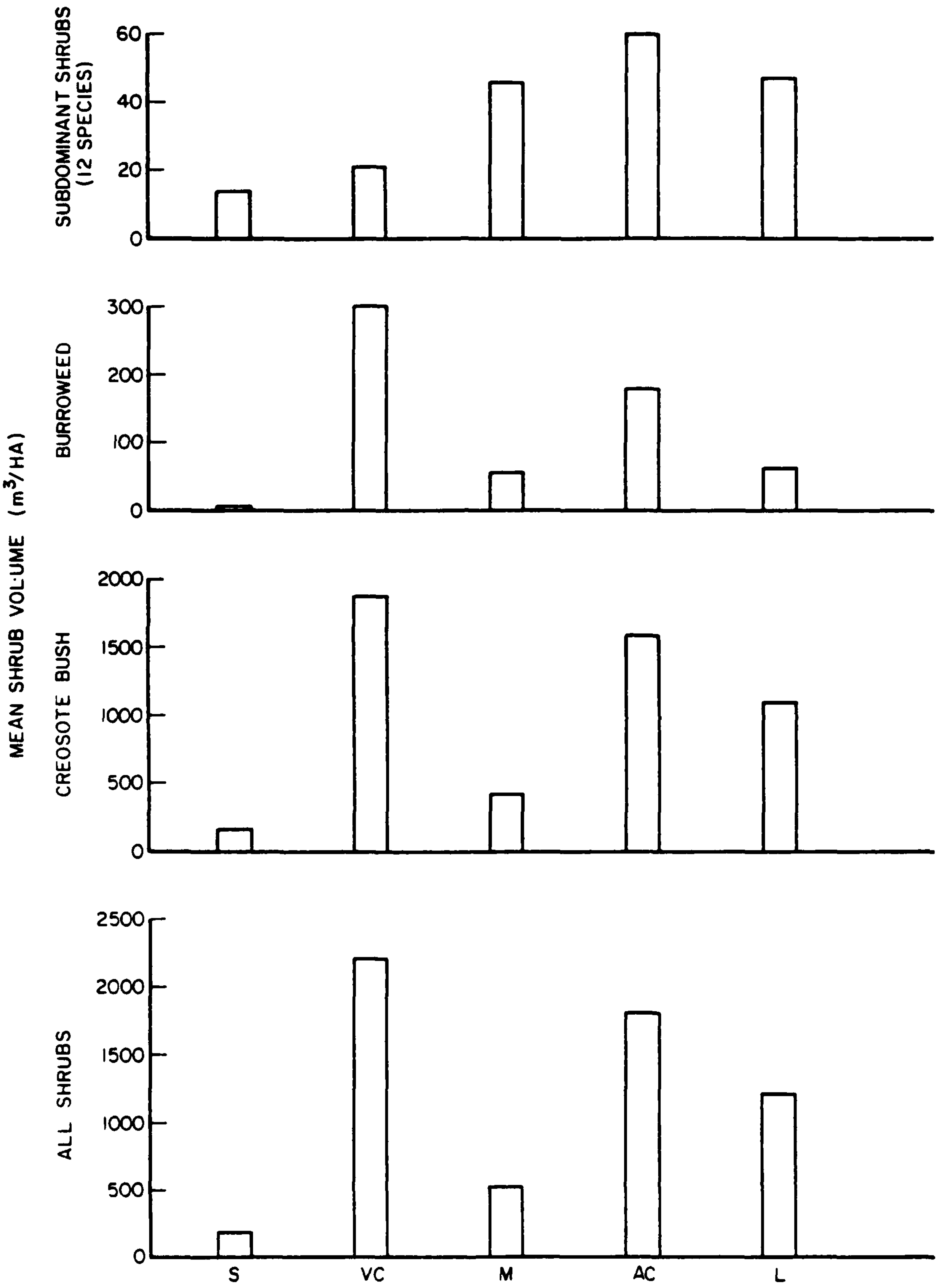


Figure 11. Mean shrub volume at each study site.

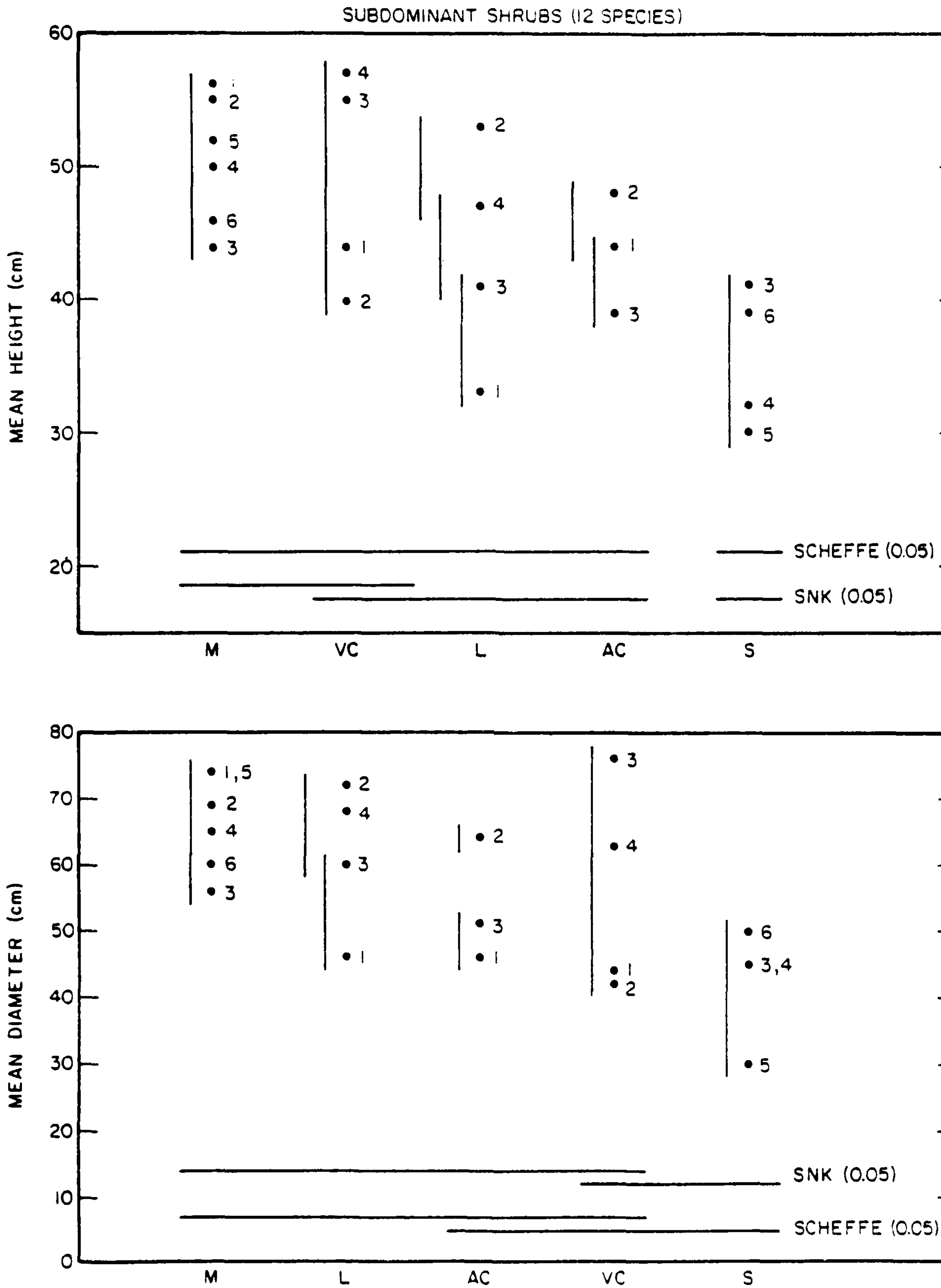


Figure 10. Intra- and intersite comparisons of subdominant shrub species mean heights and diameters.

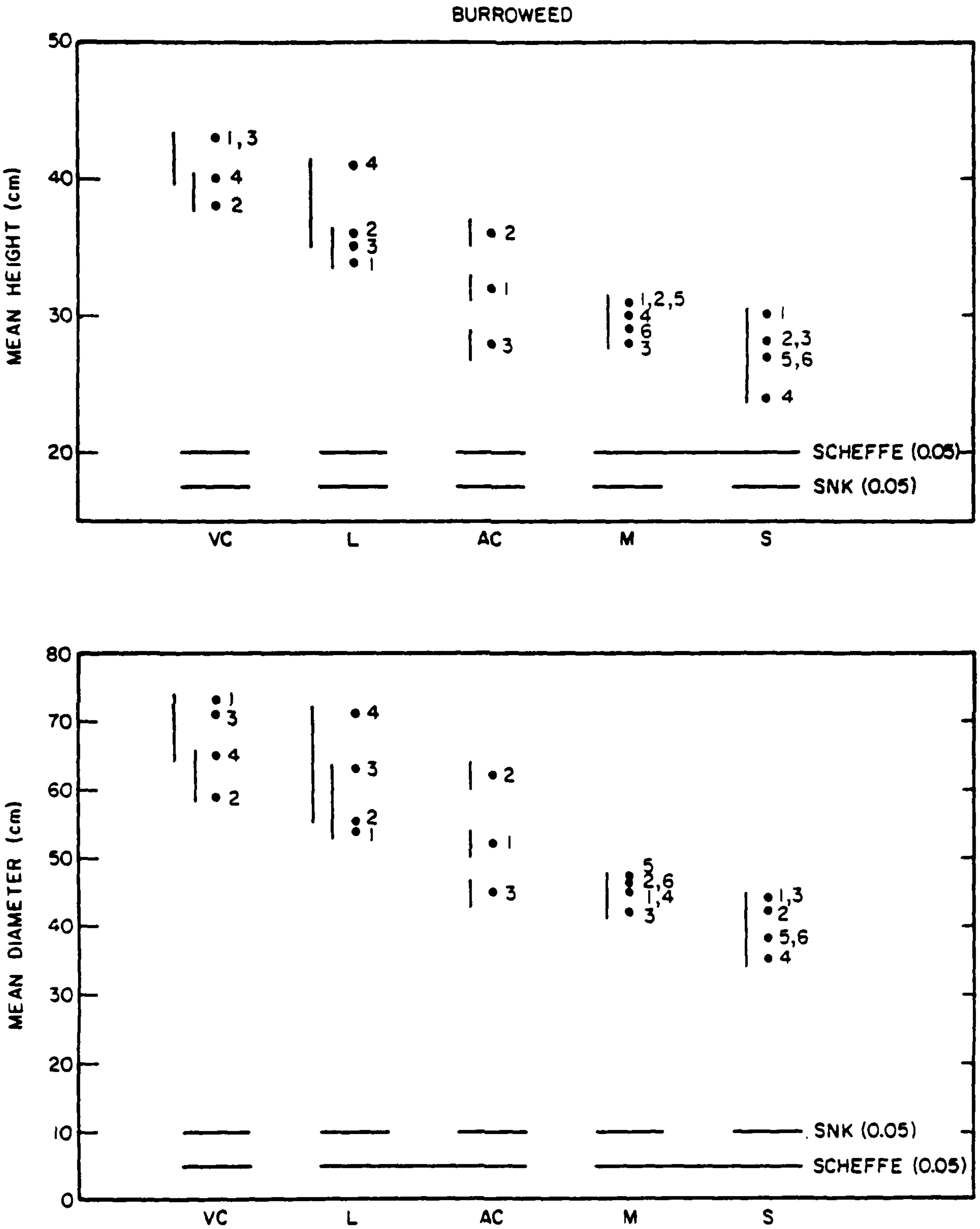


Figure 9. Intra- and intersite comparisons of burroweed mean heights and diameters.

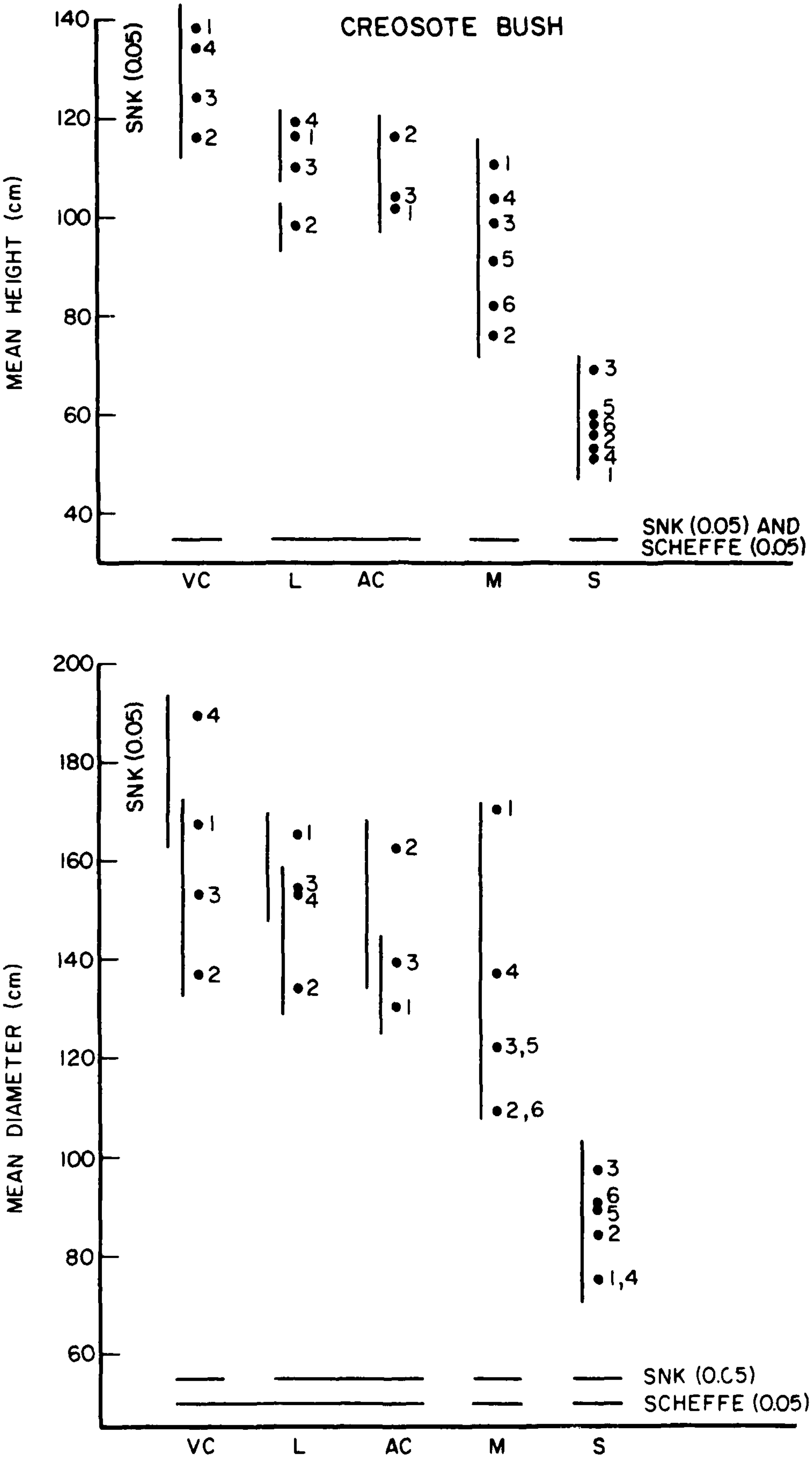
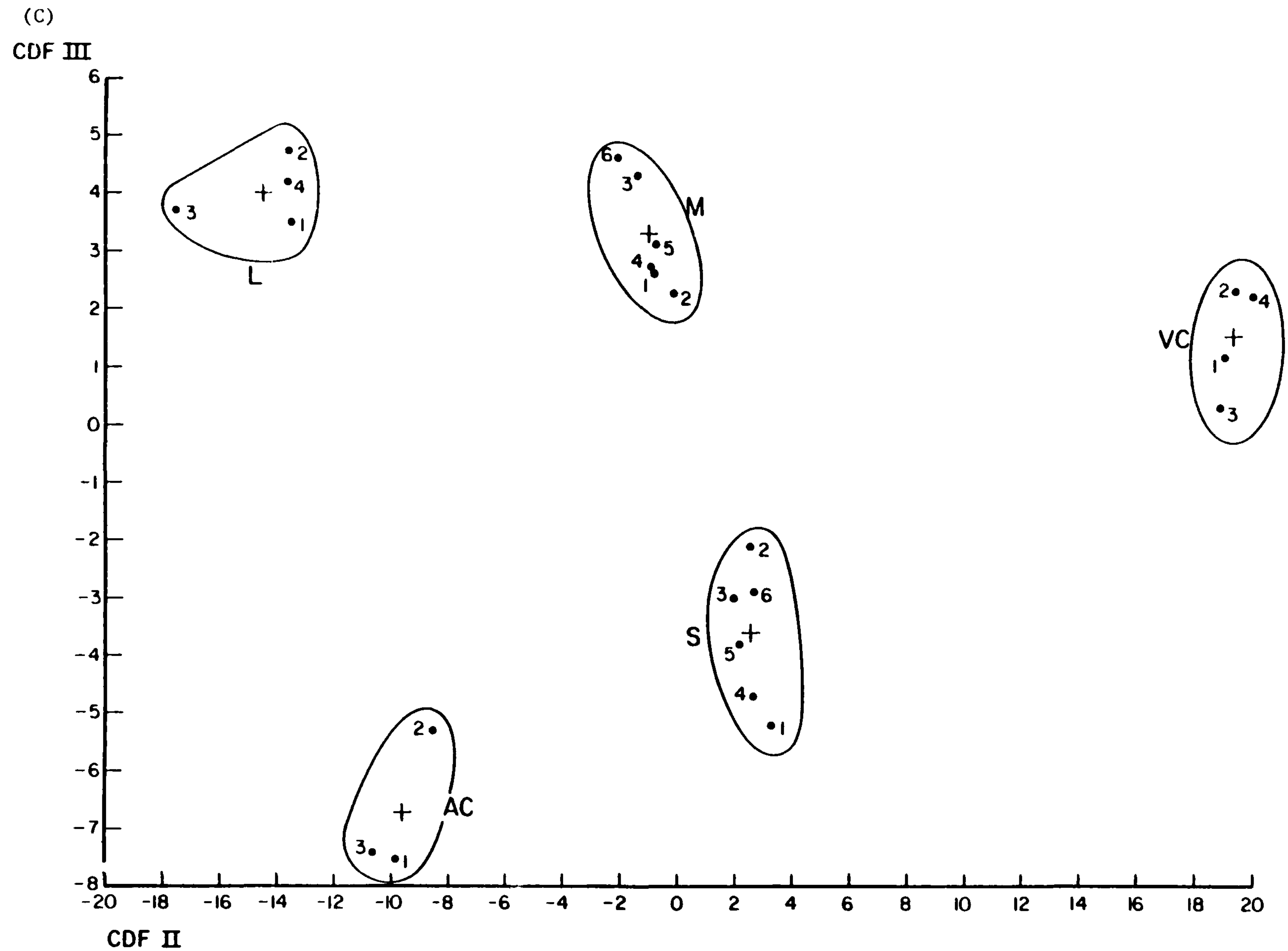


Figure 8. Intra- and intersite comparisons of creosote bush mean heights and diameters.



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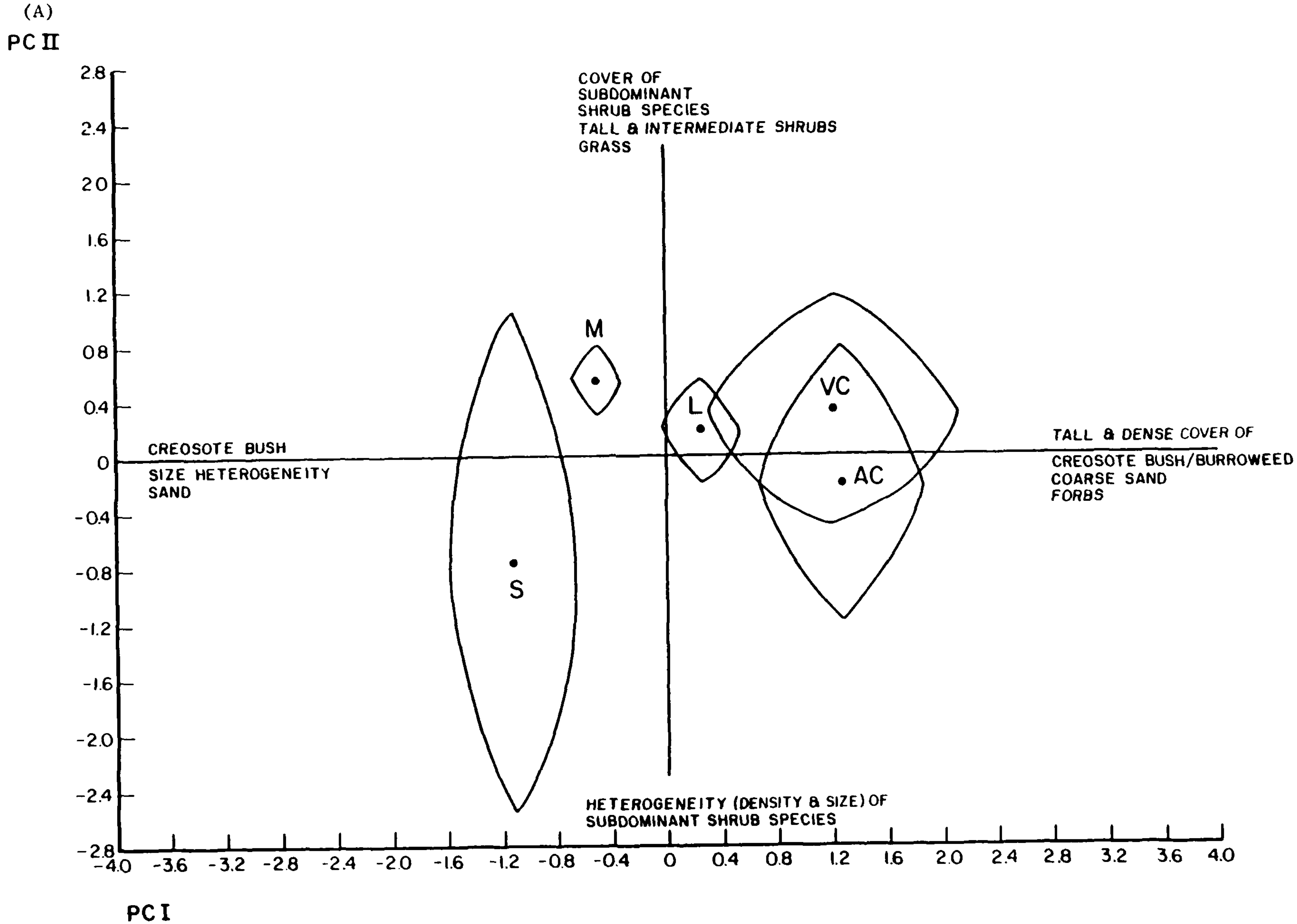
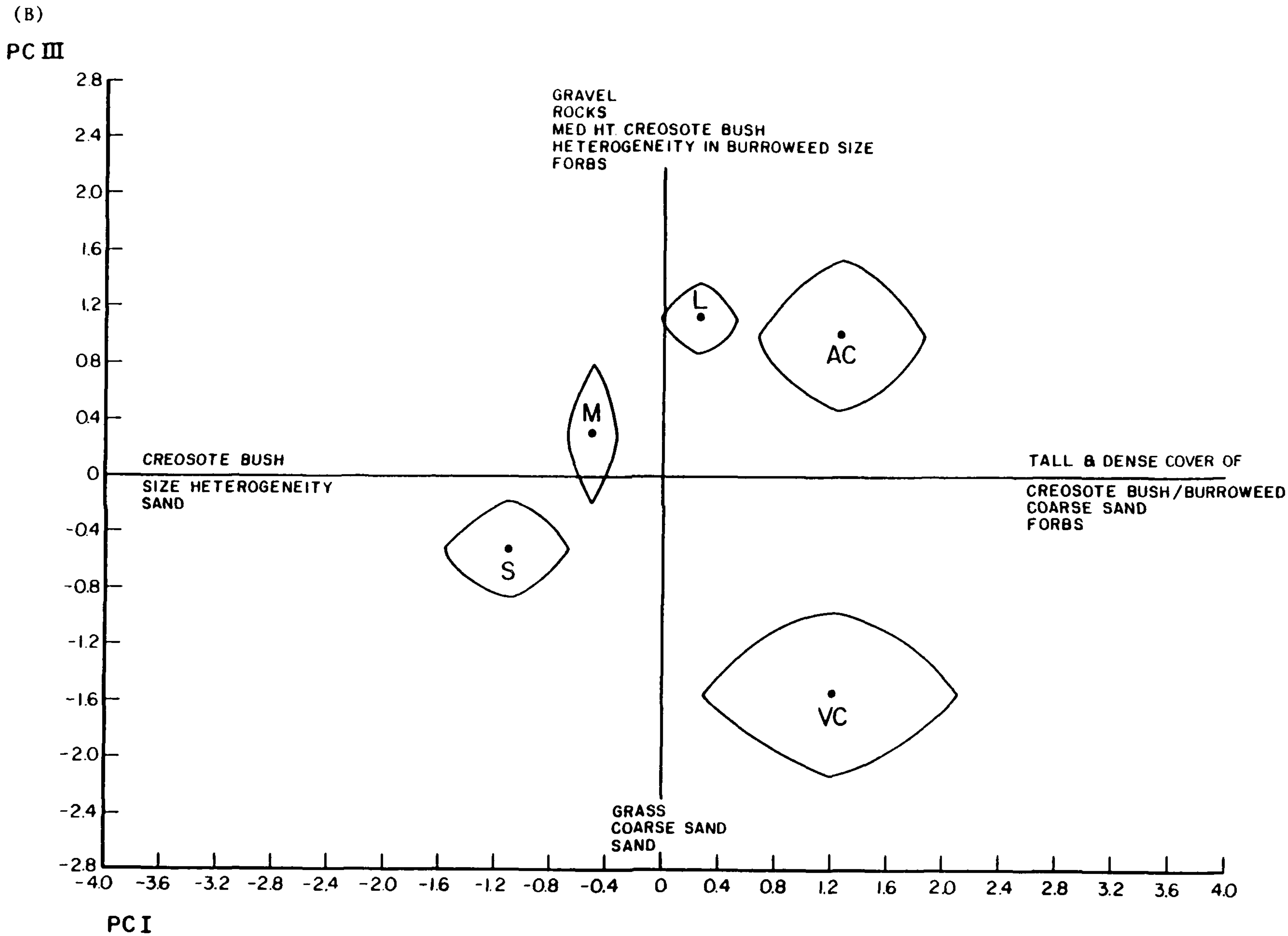


Figure 21. Ordination of study sites in principal components space of habitat variables.



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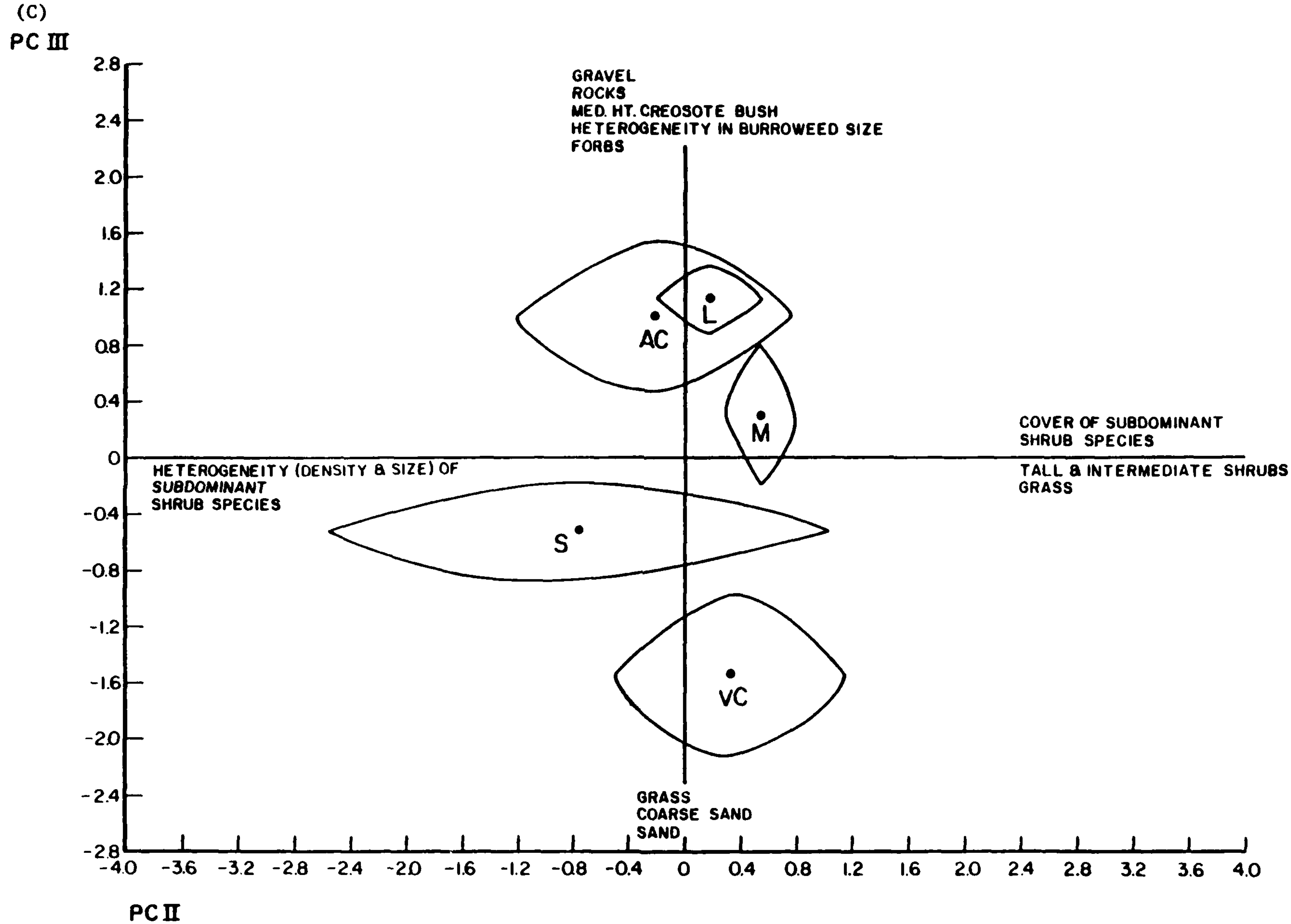

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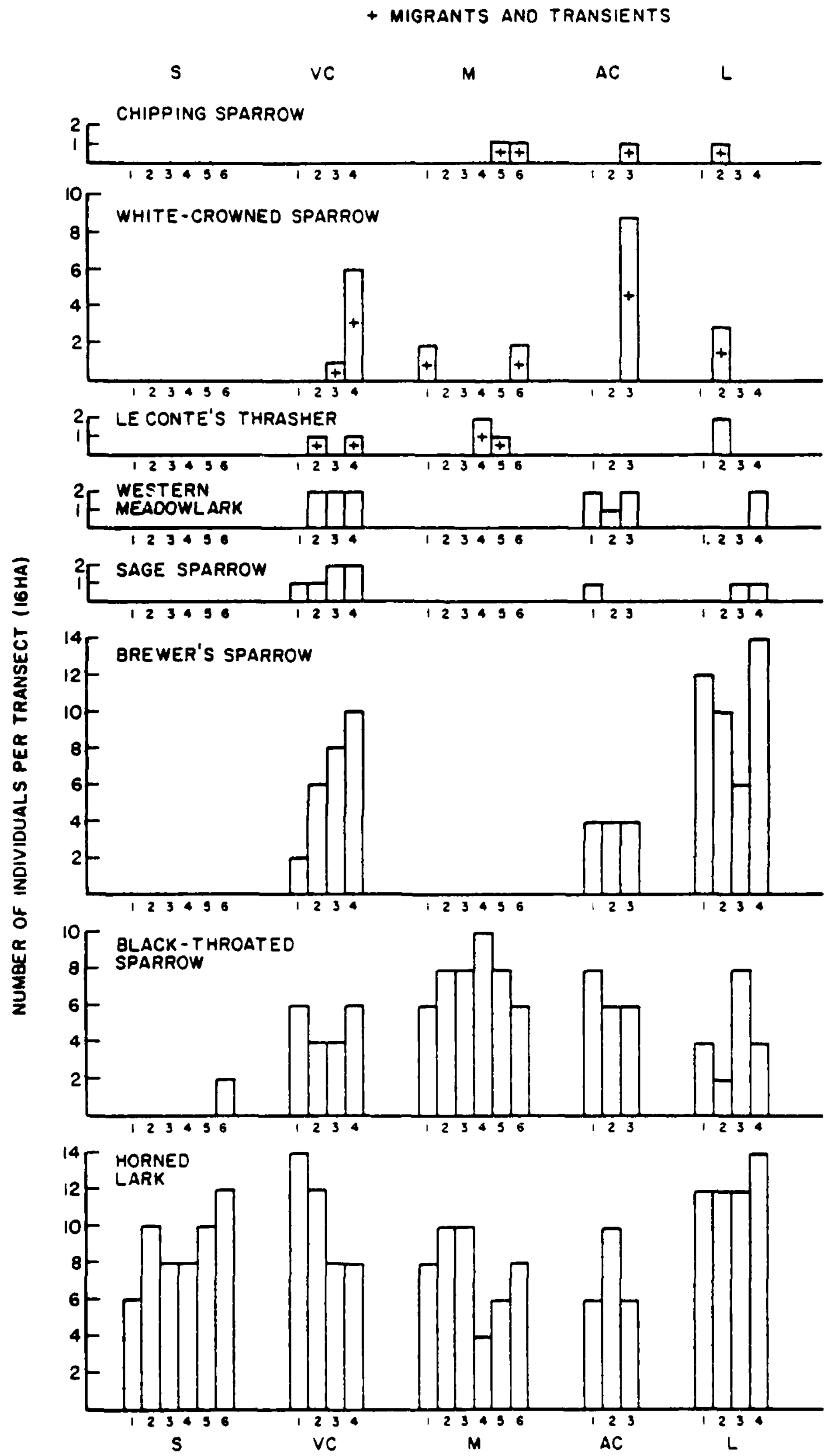


Figure 22. Number of bird individuals of each species on each transect (16 ha) at the study sites.

(A)

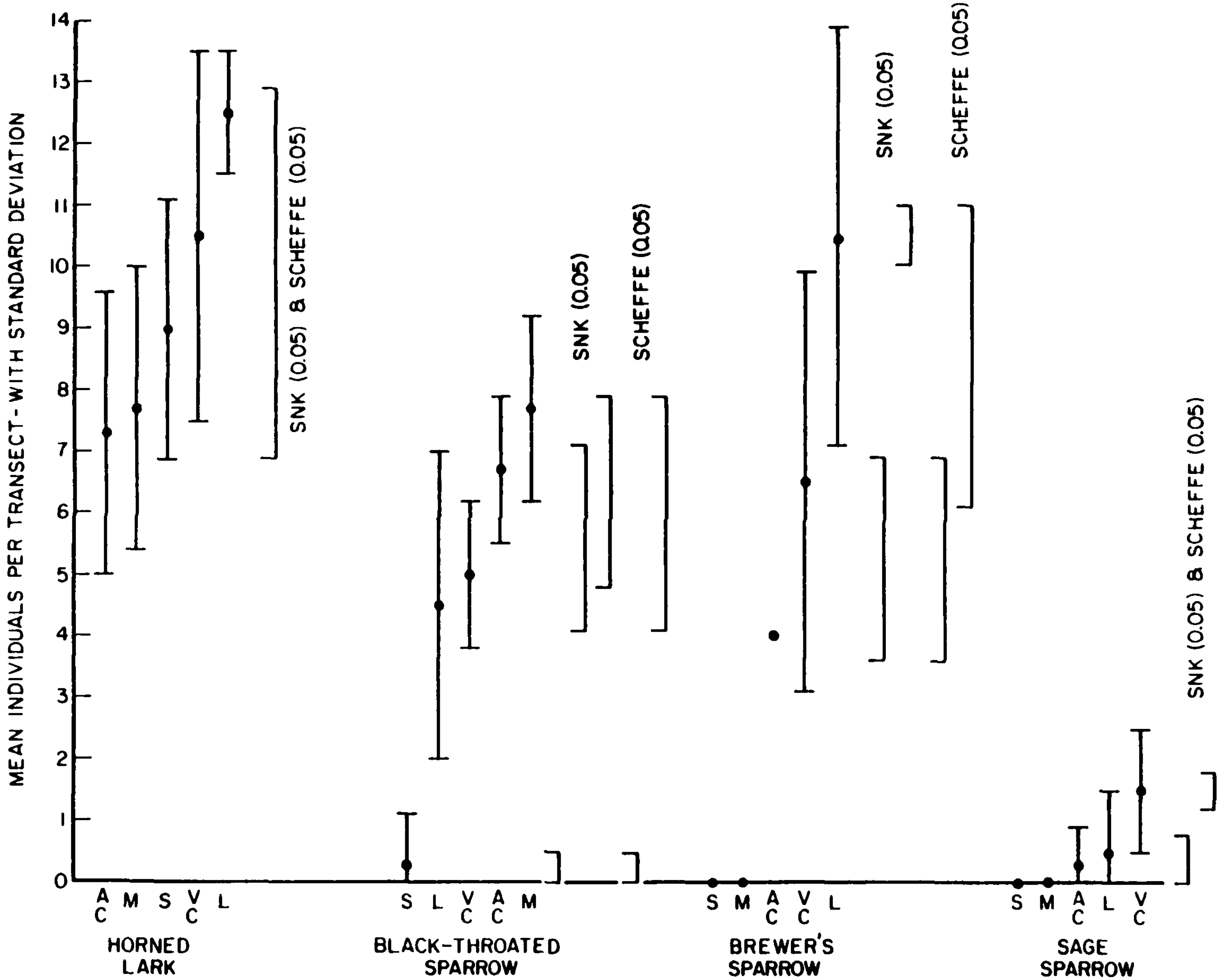
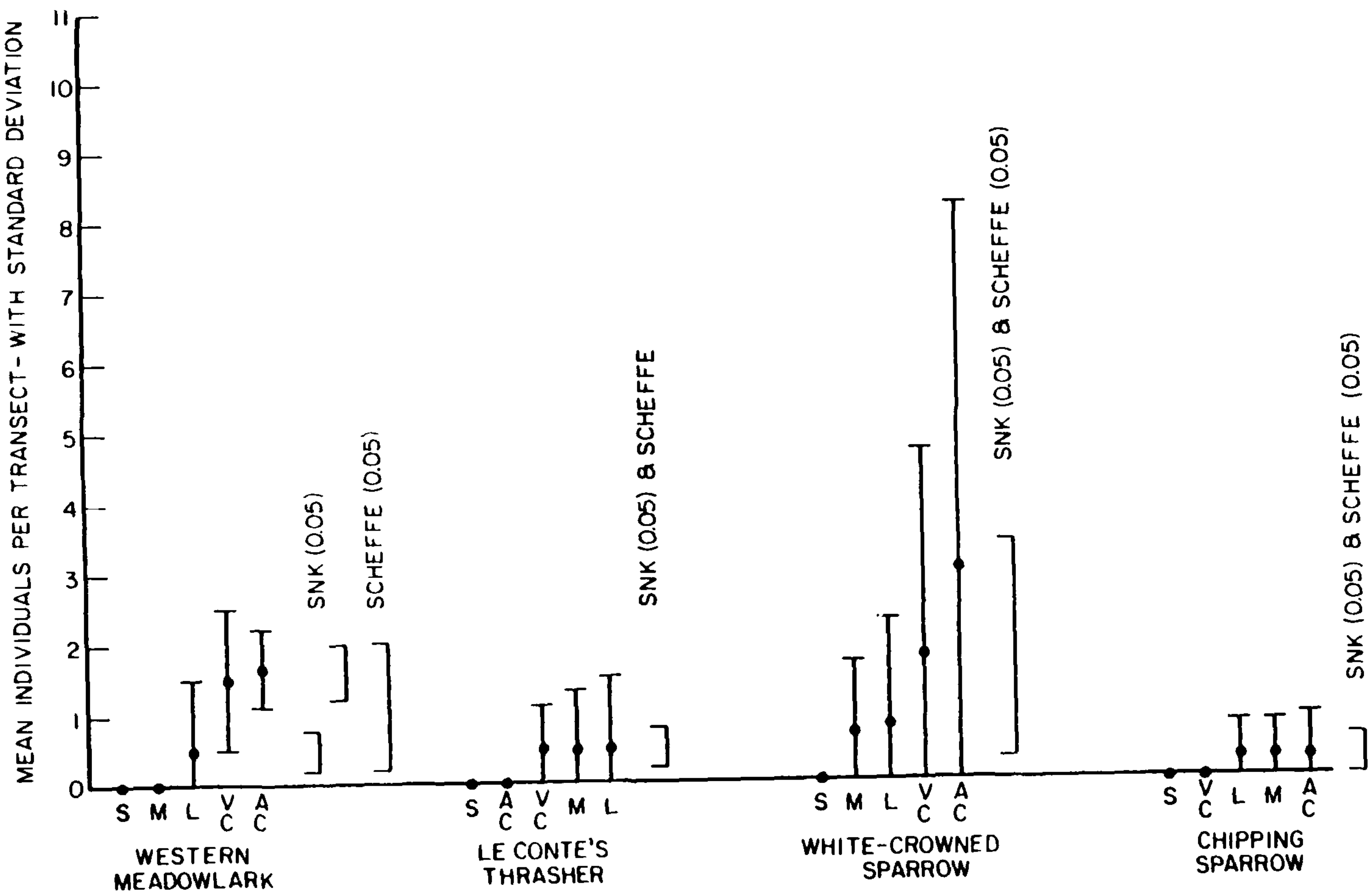


Figure 23. Intersite comparisons of the Avian Community.

(B)



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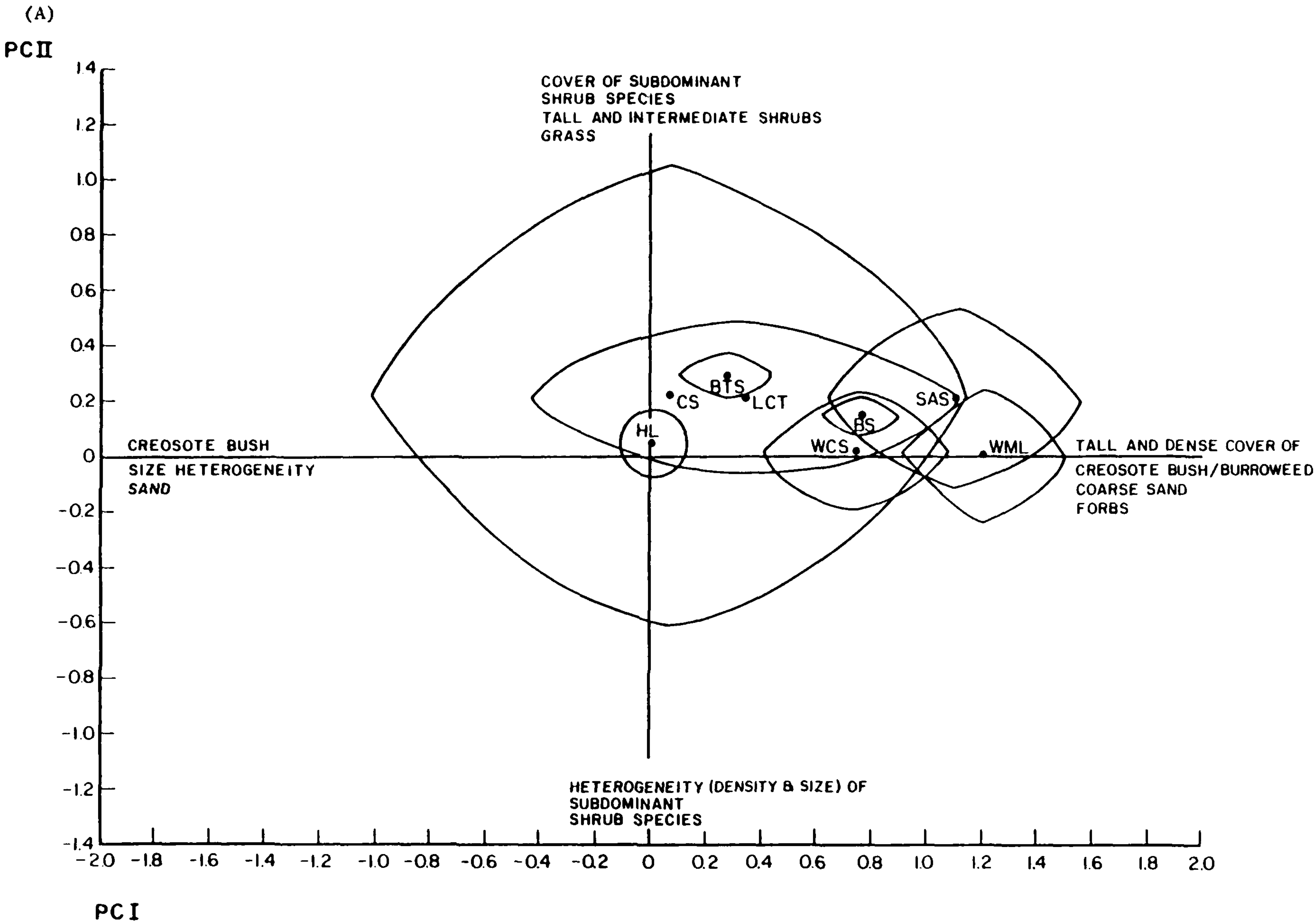


Figure 24. Ordination of bird species in principal components space of habitat variables.

(B)

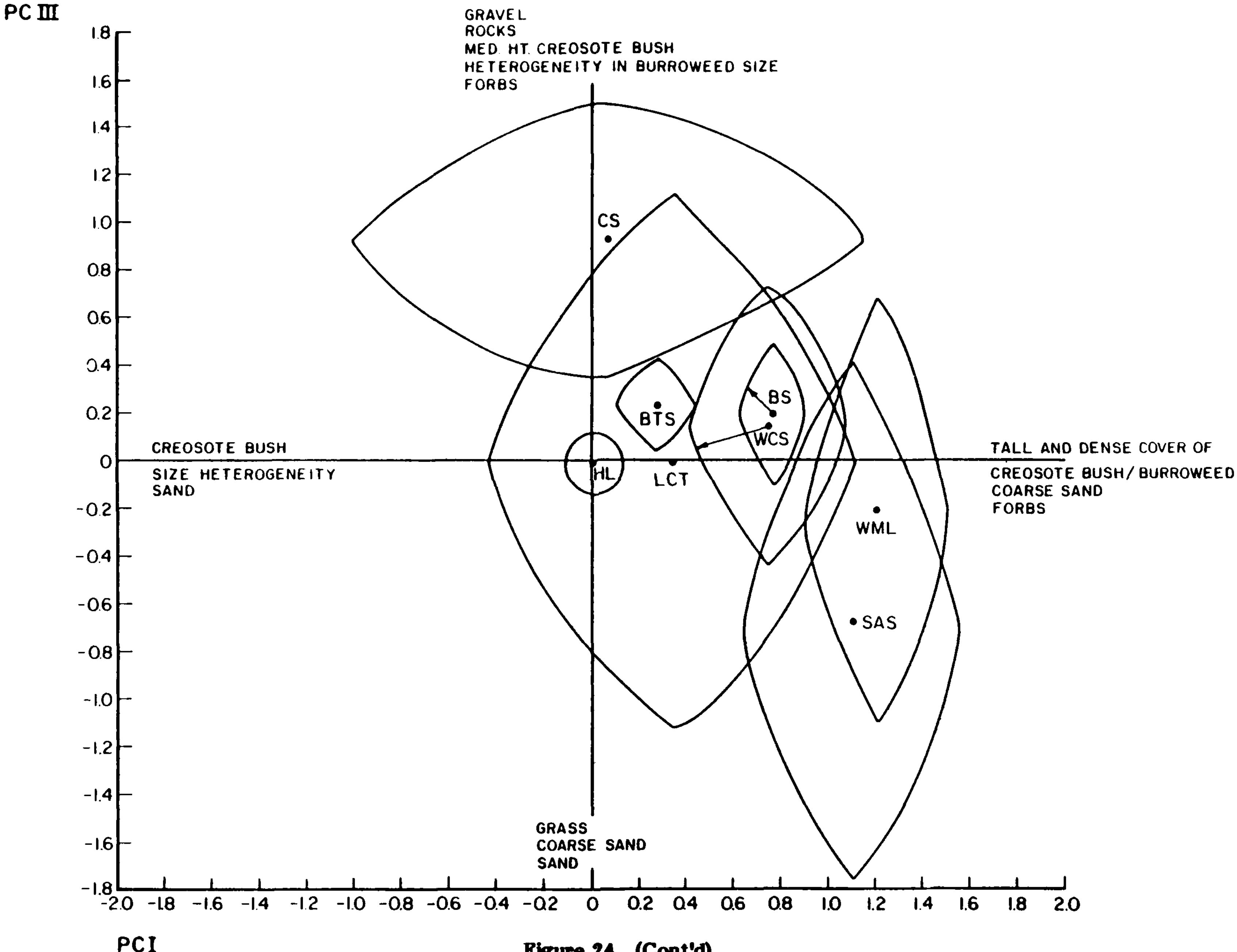


Figure 24. (Cont'd).

(C)

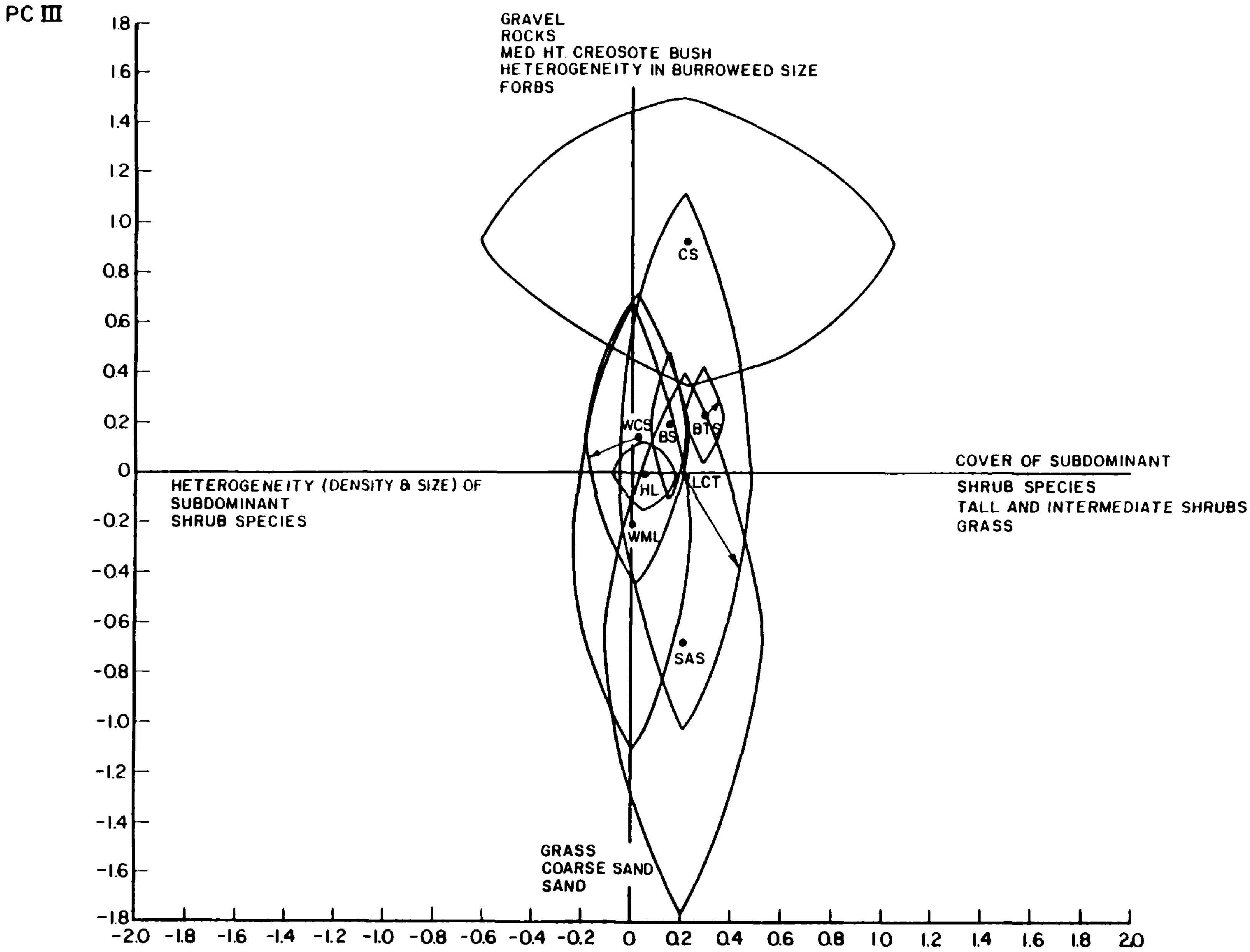


Figure 24. (Cont'd).

(A)

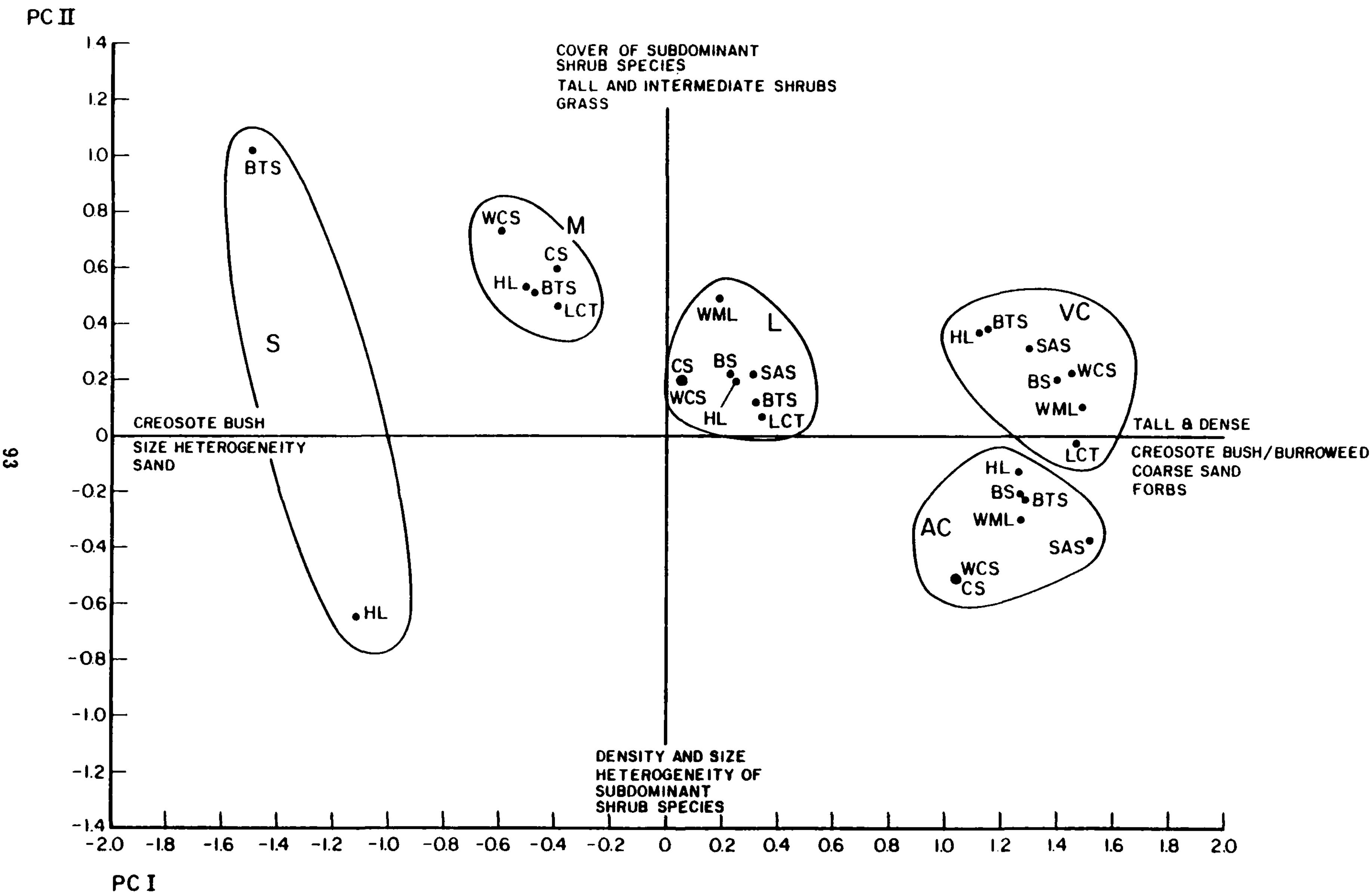
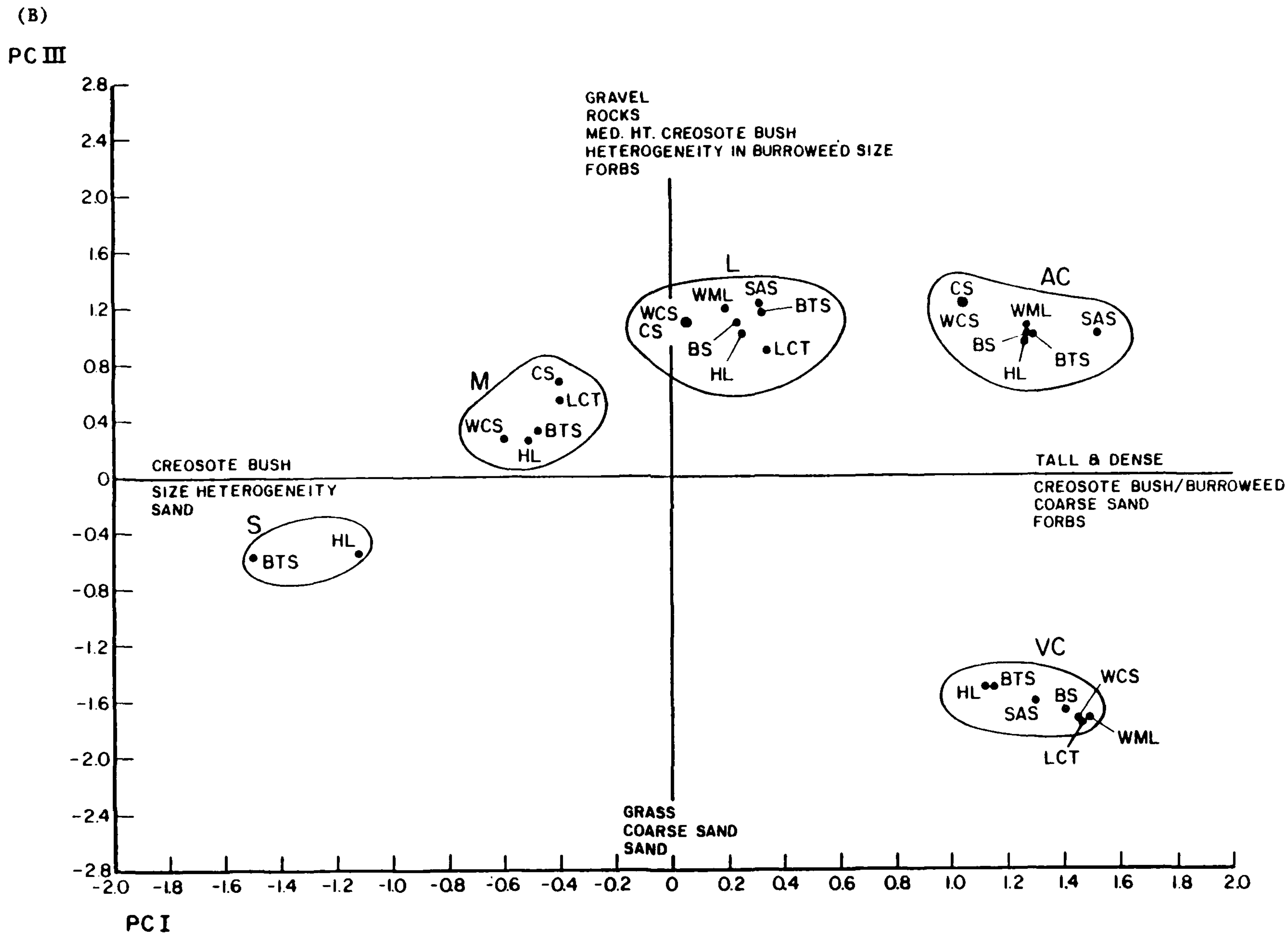


Figure 25. Ordination of individual bird species within each study site.



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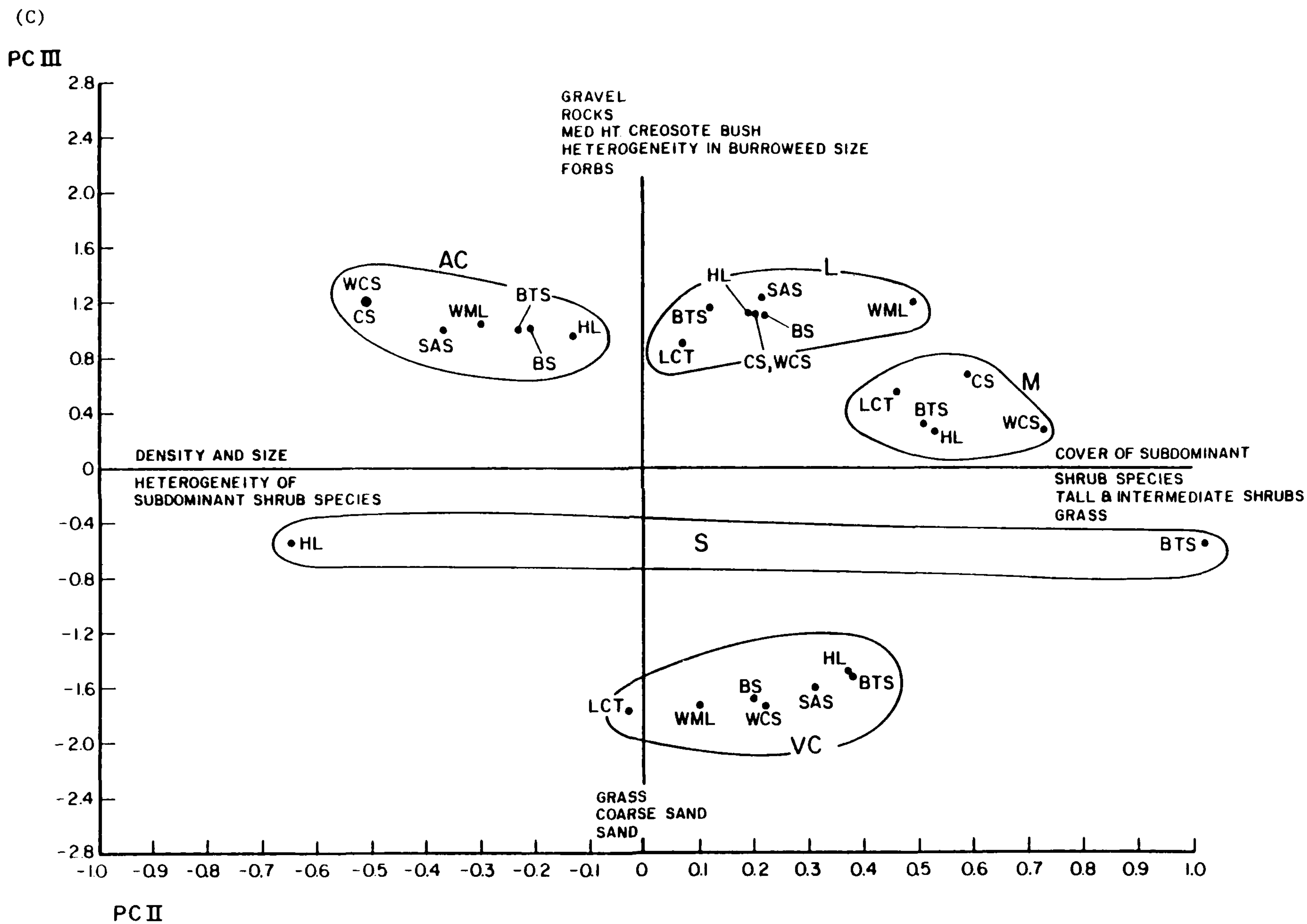

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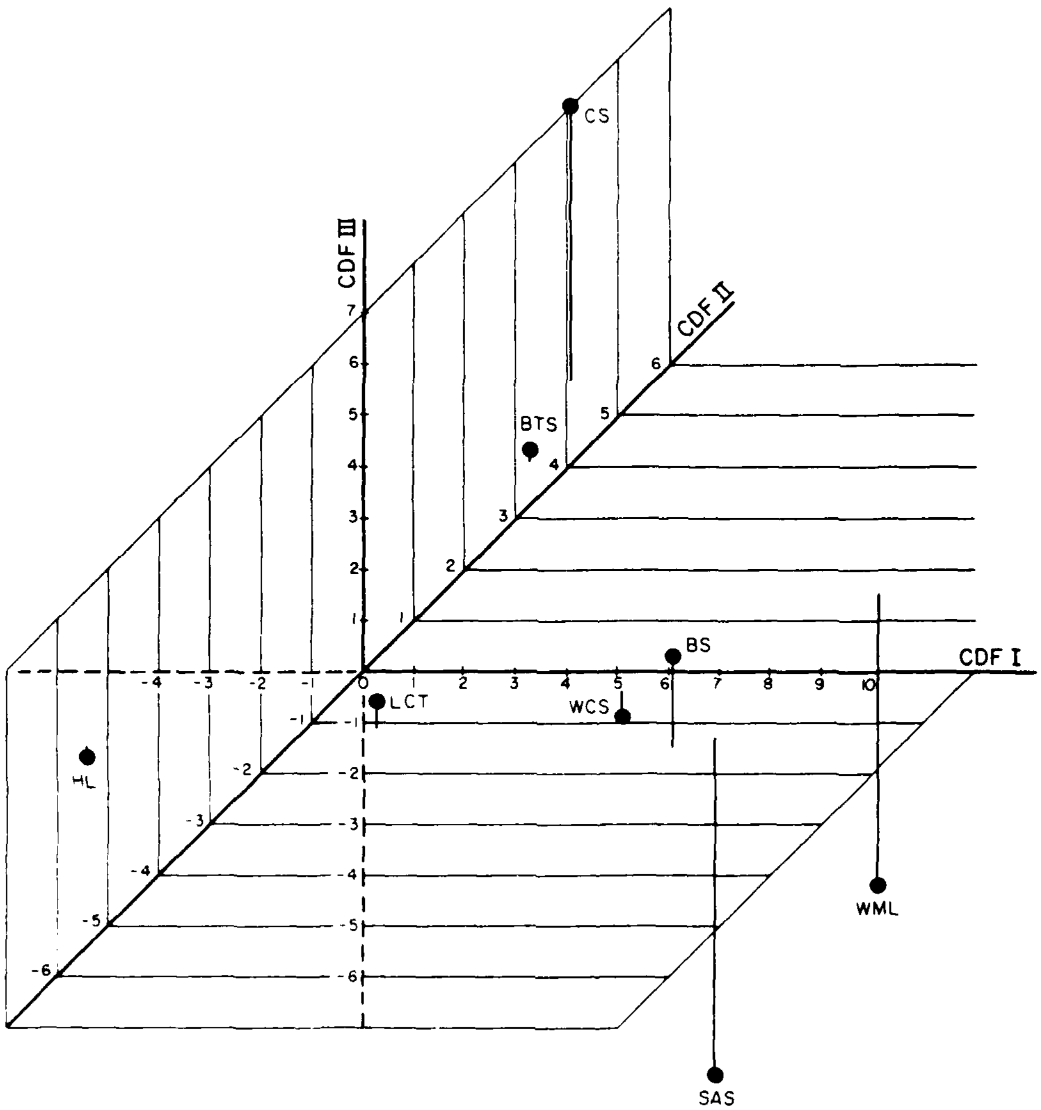


Figure 26. Canonical analysis of discriminance of bird species based on habitat variables.

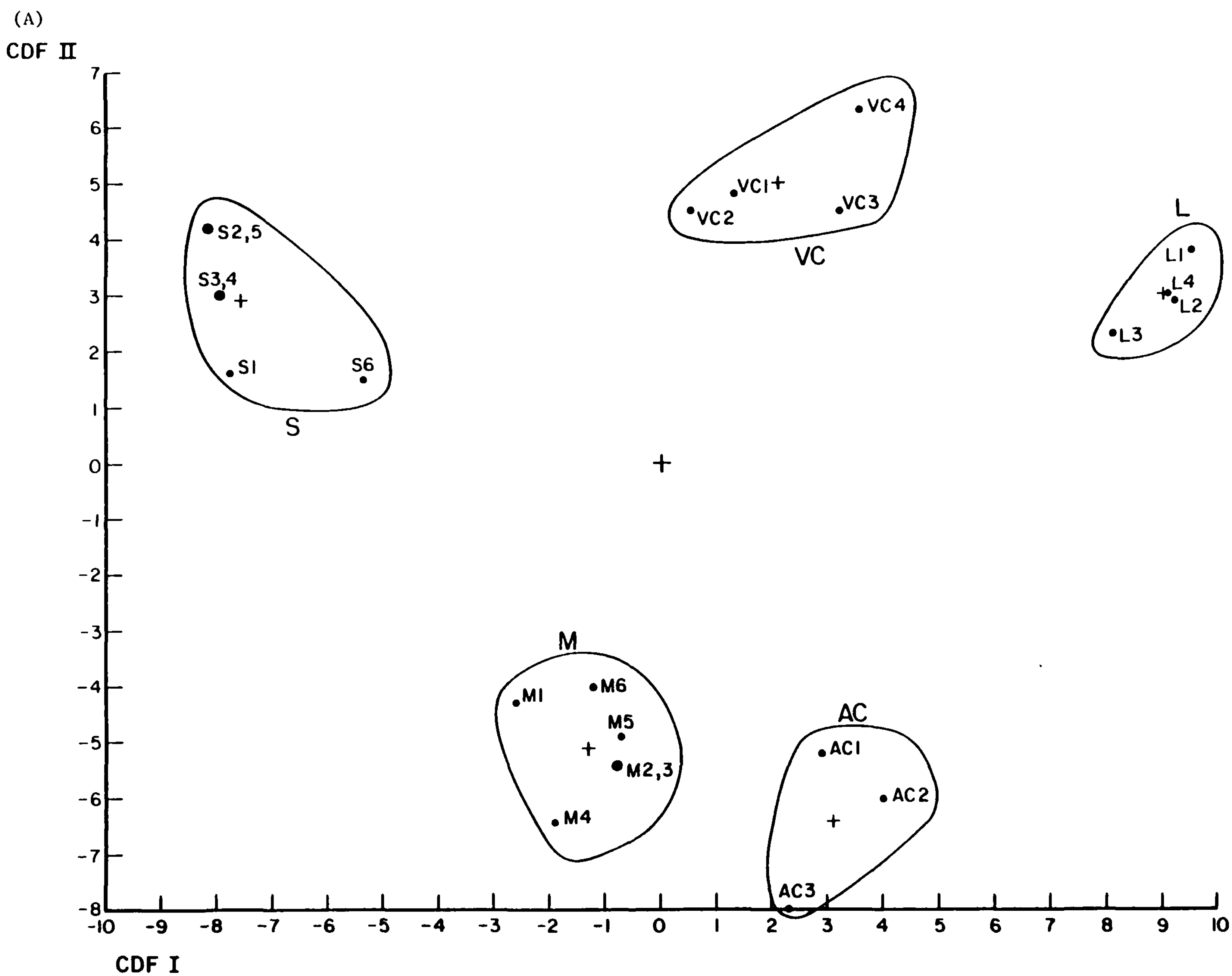
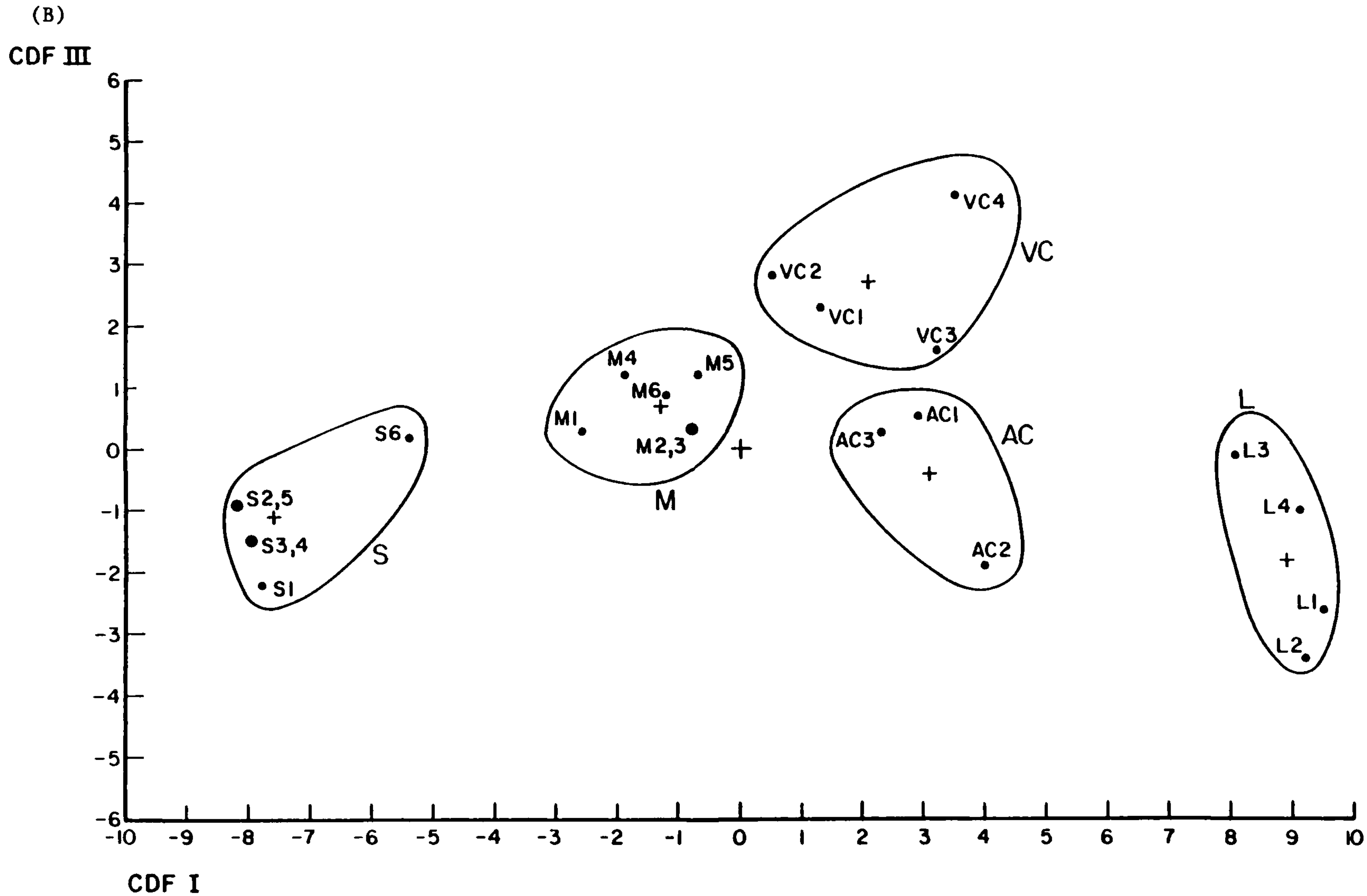


Figure 27. Canonical analysis of discriminance of the five study sites based on Avian Community structure.



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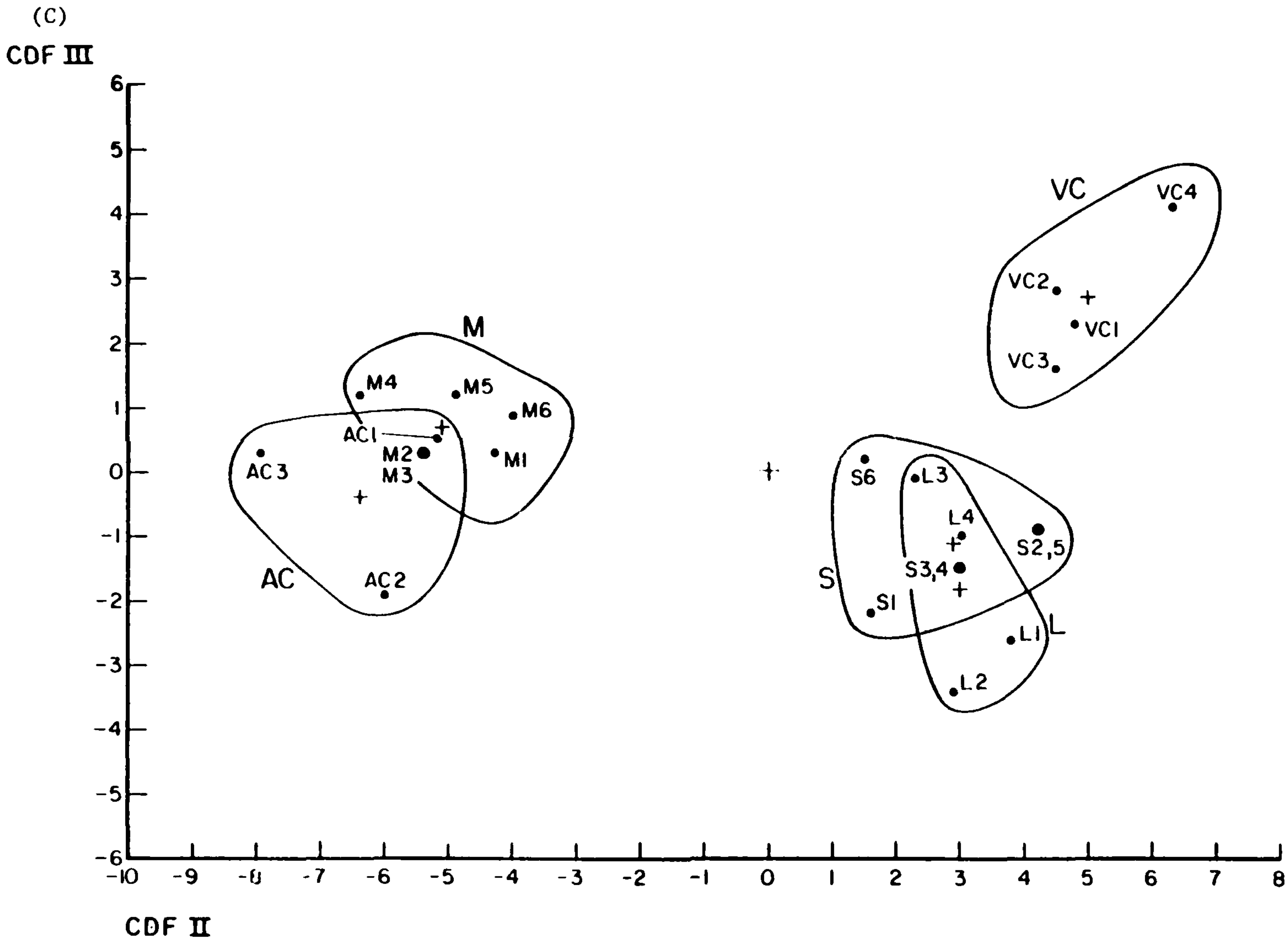

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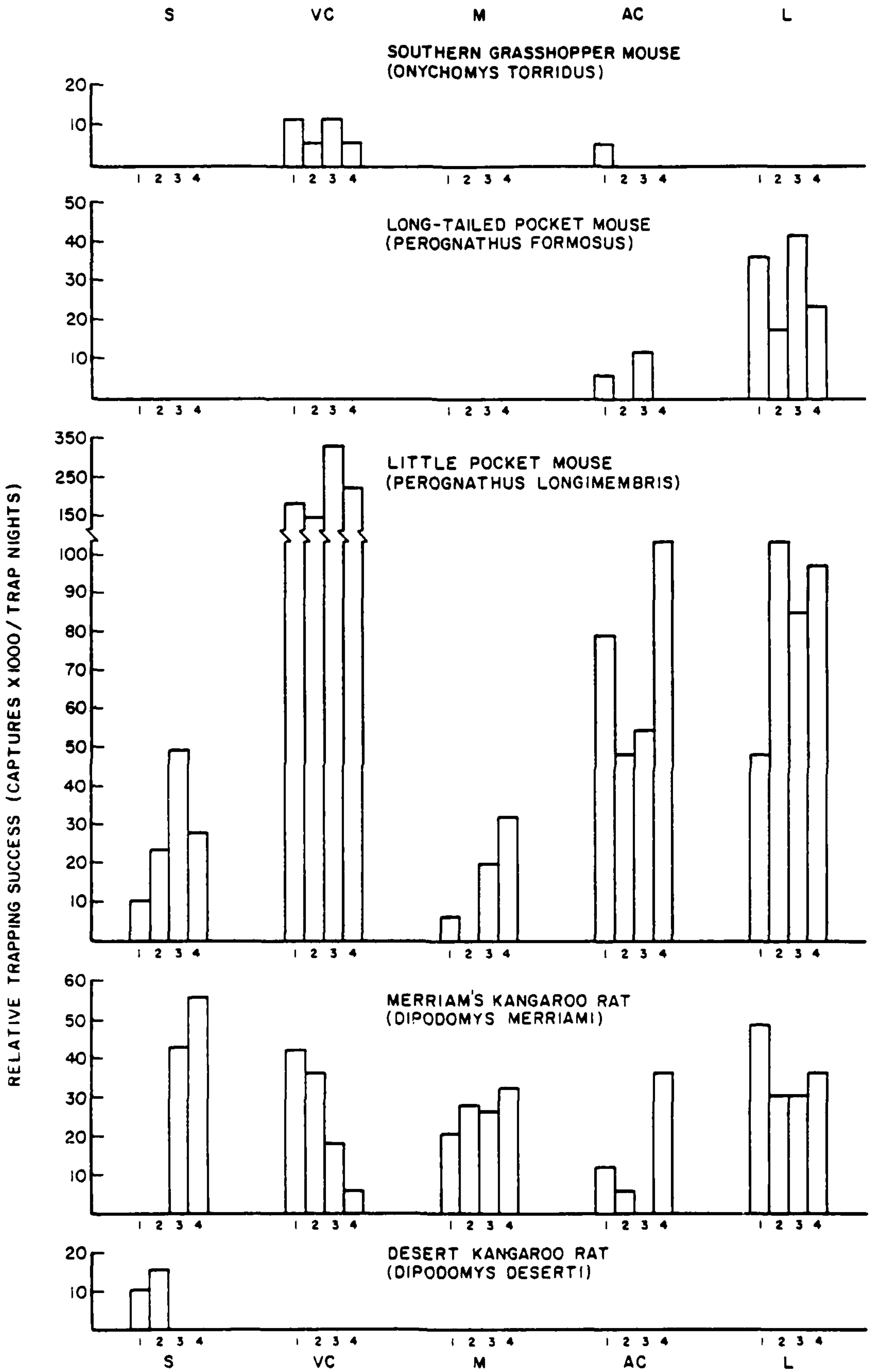

Figure 28. Small mammal relative trapping success in each trap-line at the study sites.

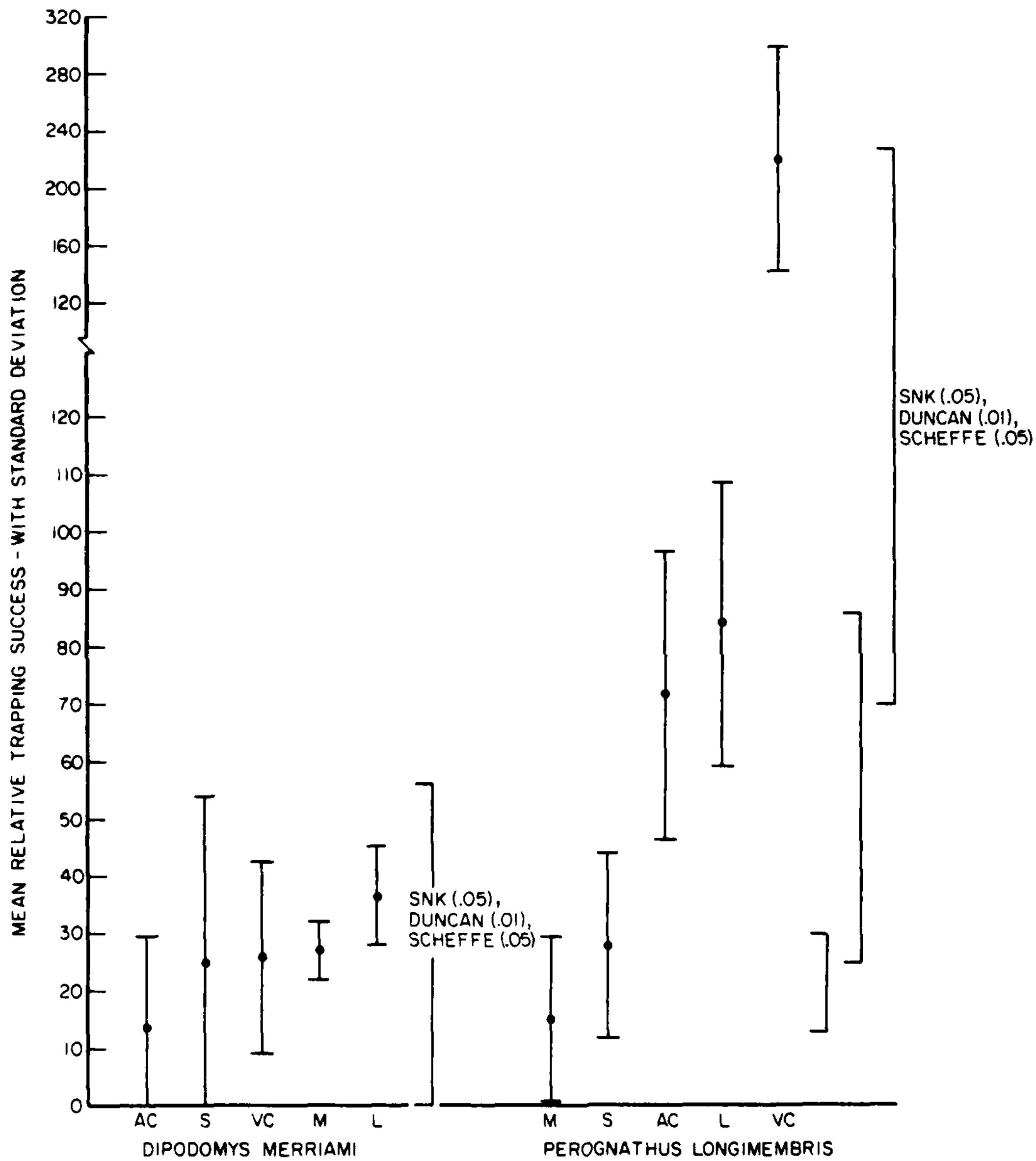

Figure 29. **Intersite trapping comparisons of Merriam's kangaroo rat and little pocket mouse.**

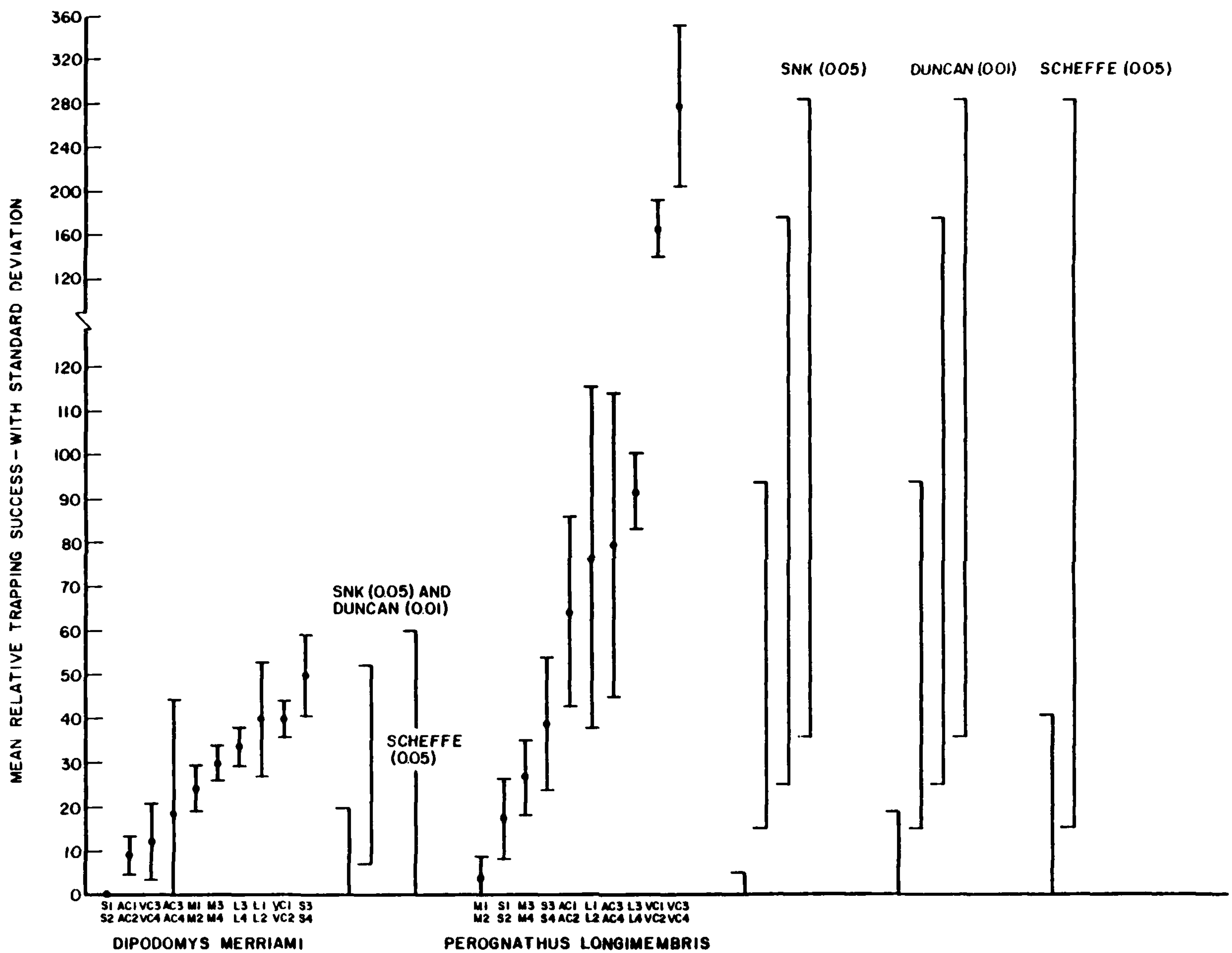

Figure 30. Paired adjacent trap-line comparisons of Merriam's kangaroo rat and little pocket mouse.

(A)

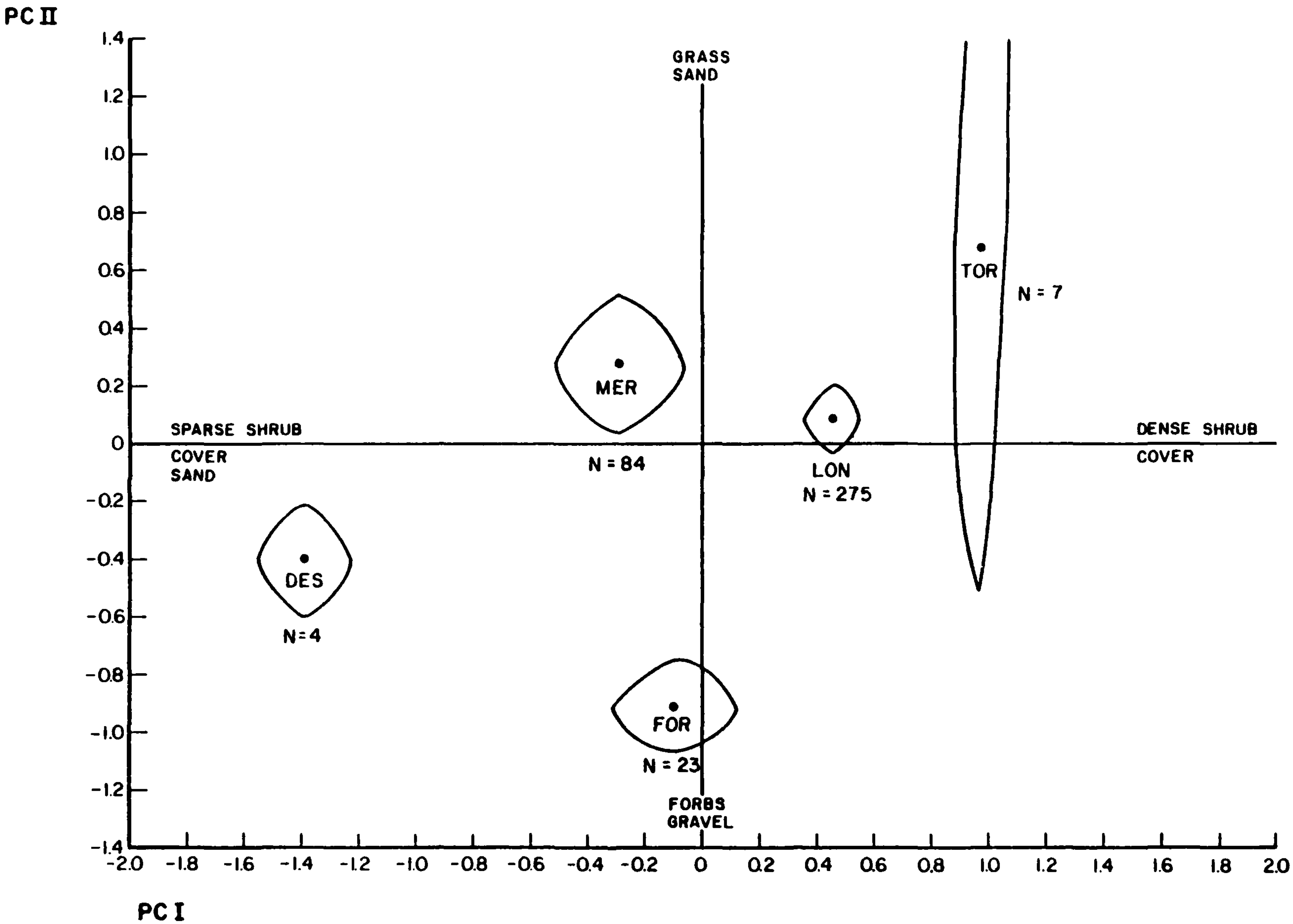

Figure 31. Ordination of mammal species in principal components space of habitat variables.

(B)

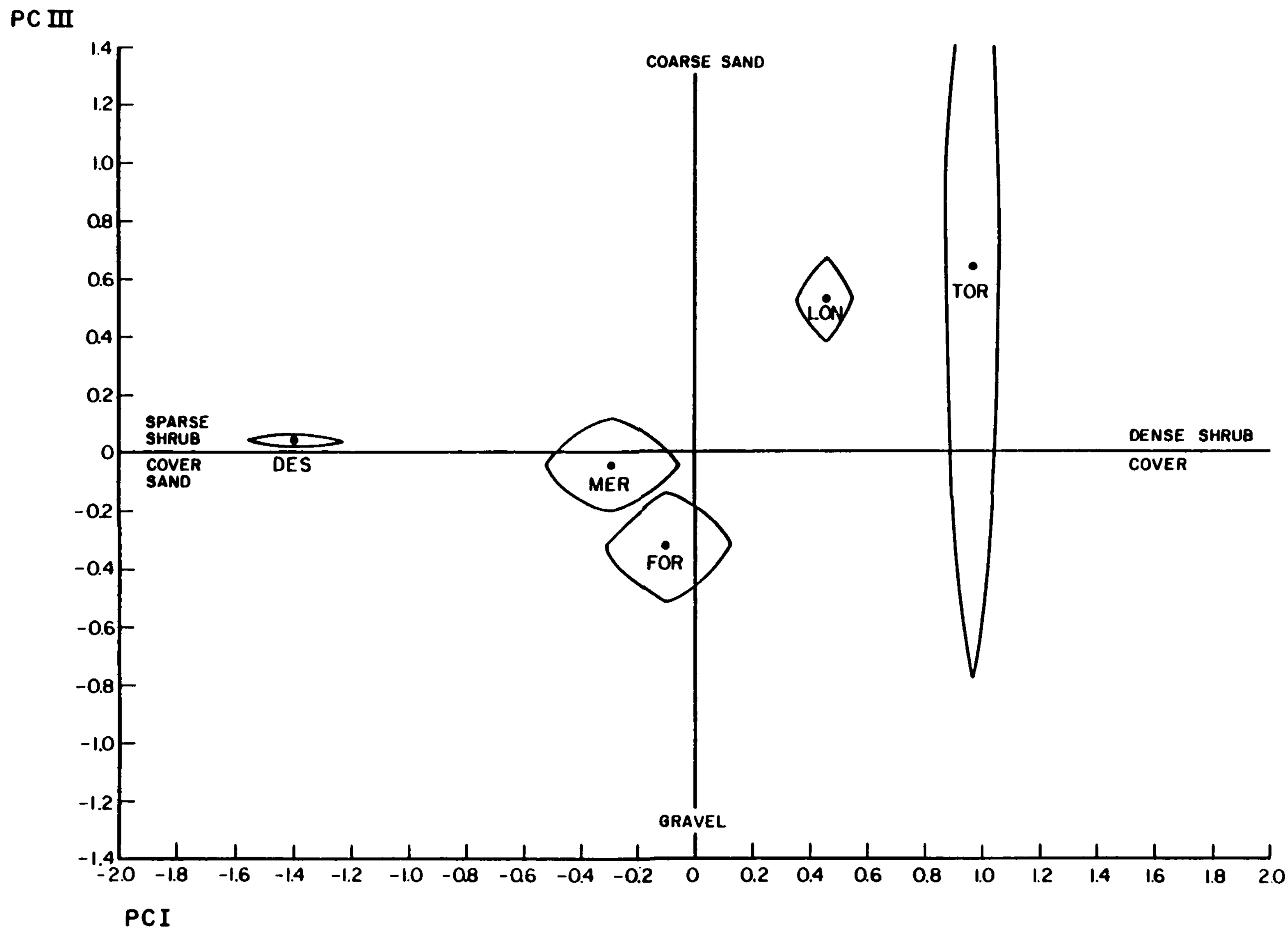

Figure 31. (Cont'd).

(C)

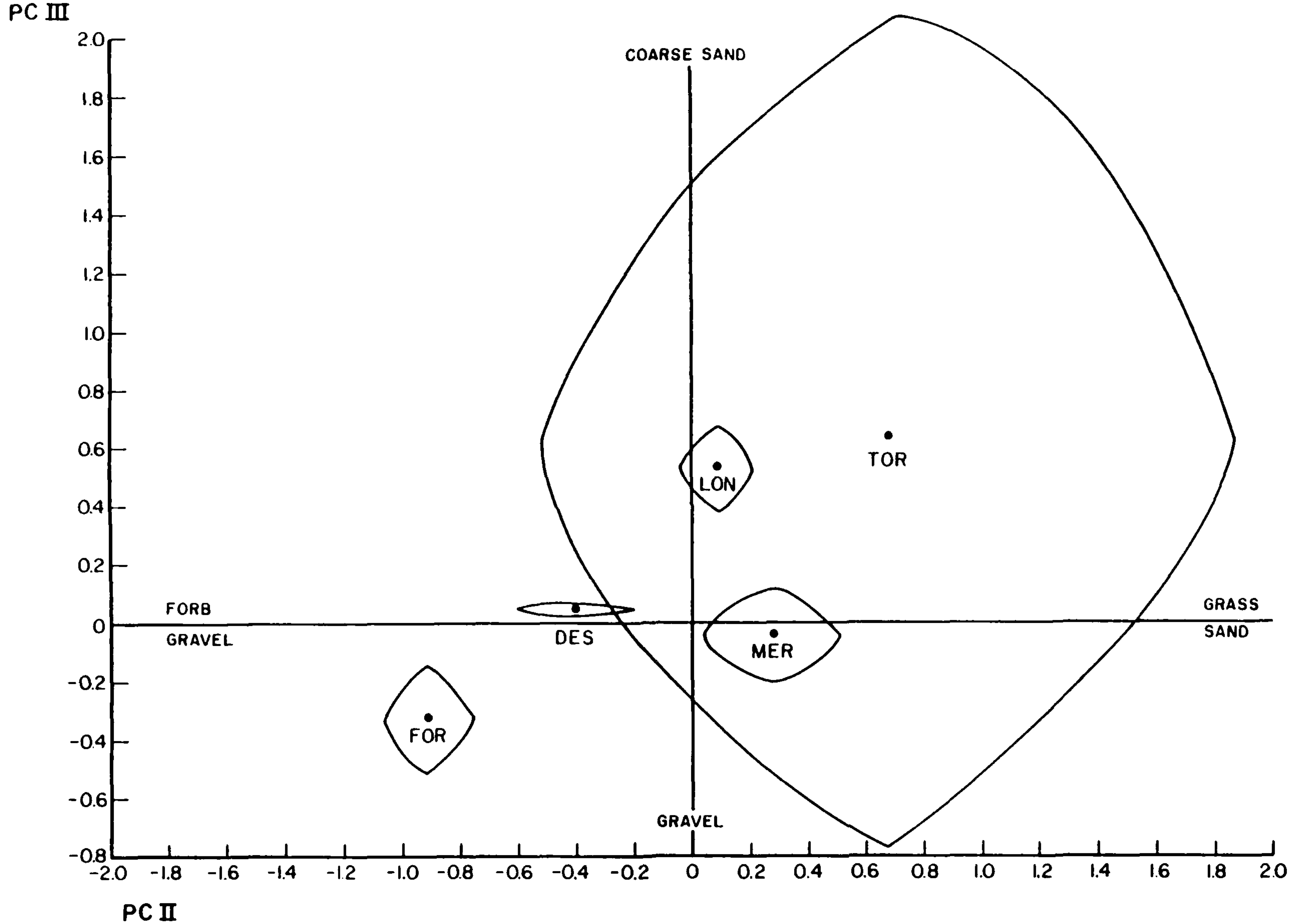

Figure 31. (Cont'd).

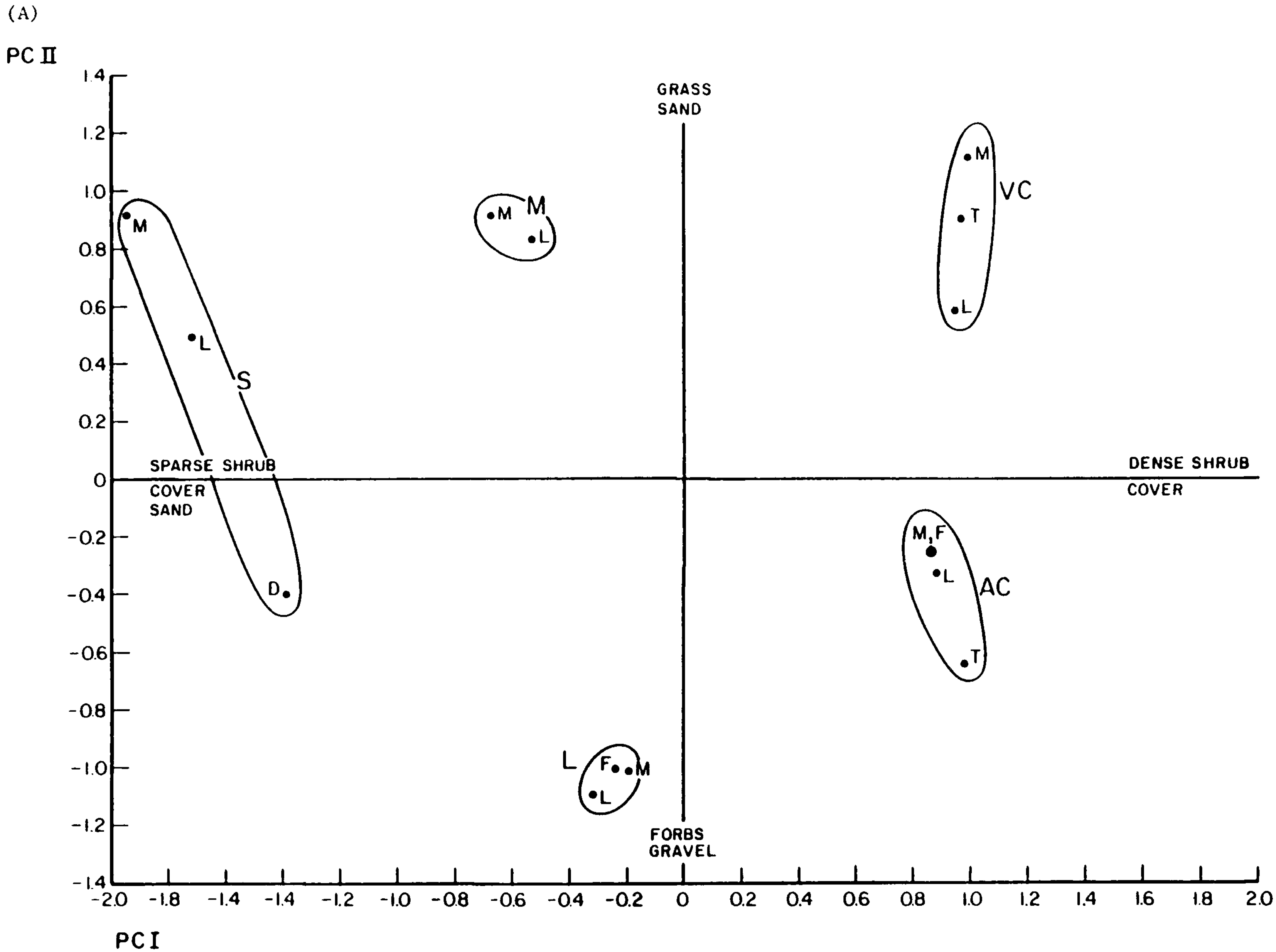

Figure 32. Ordination of individual mammal species within each study site.

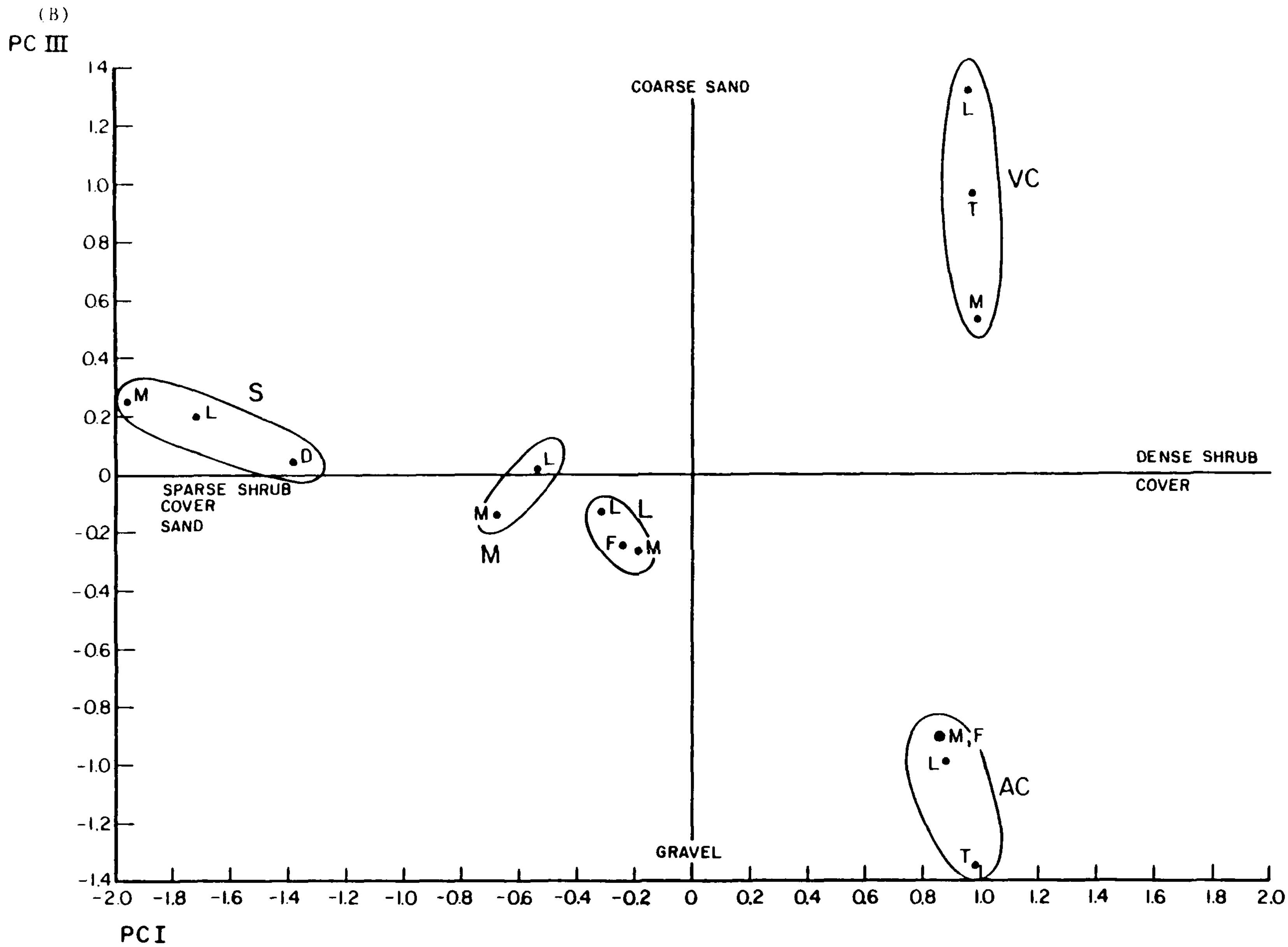

Figure 32. (Cont'd).

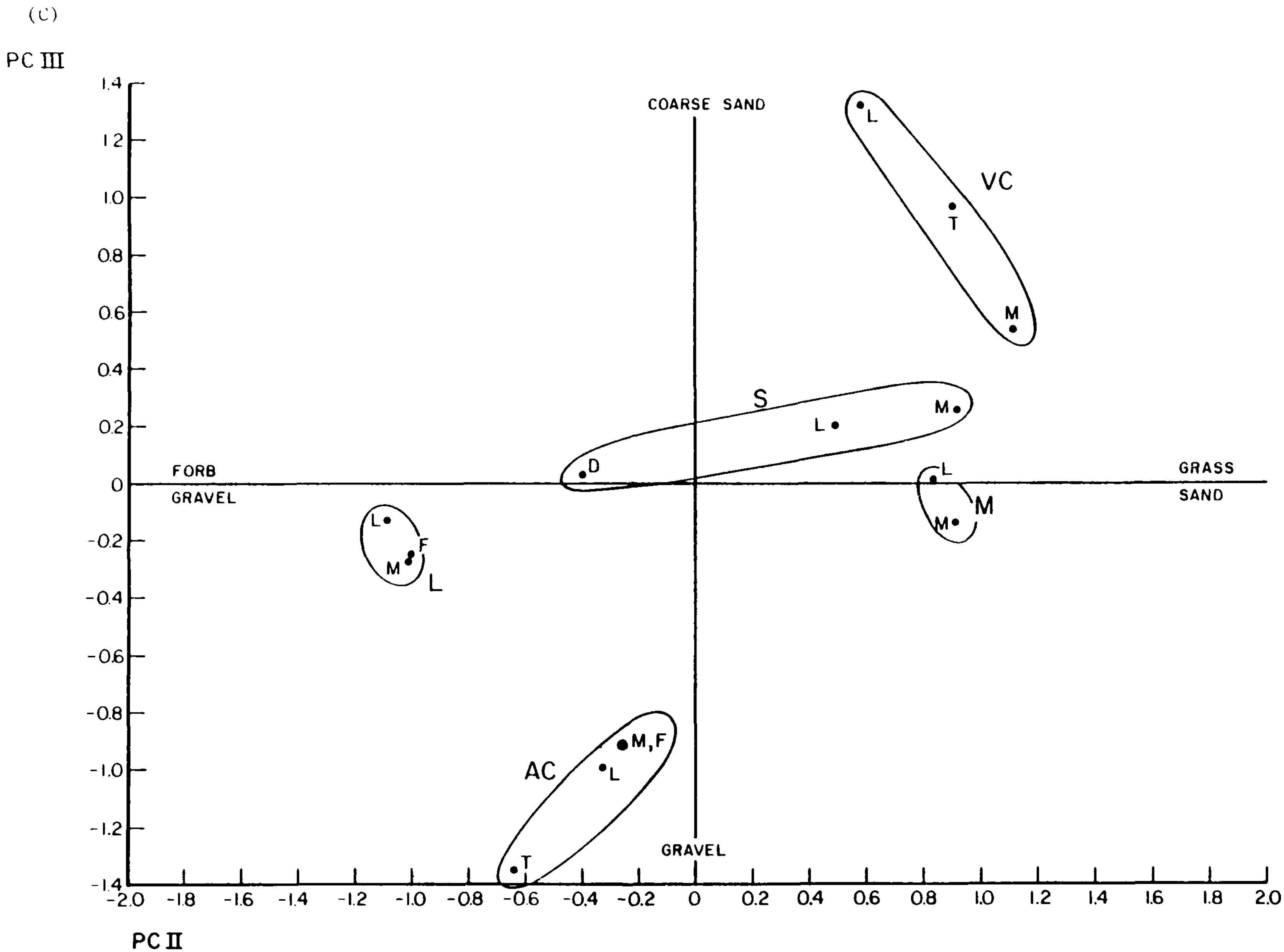

Figure 32. (Cont'd).

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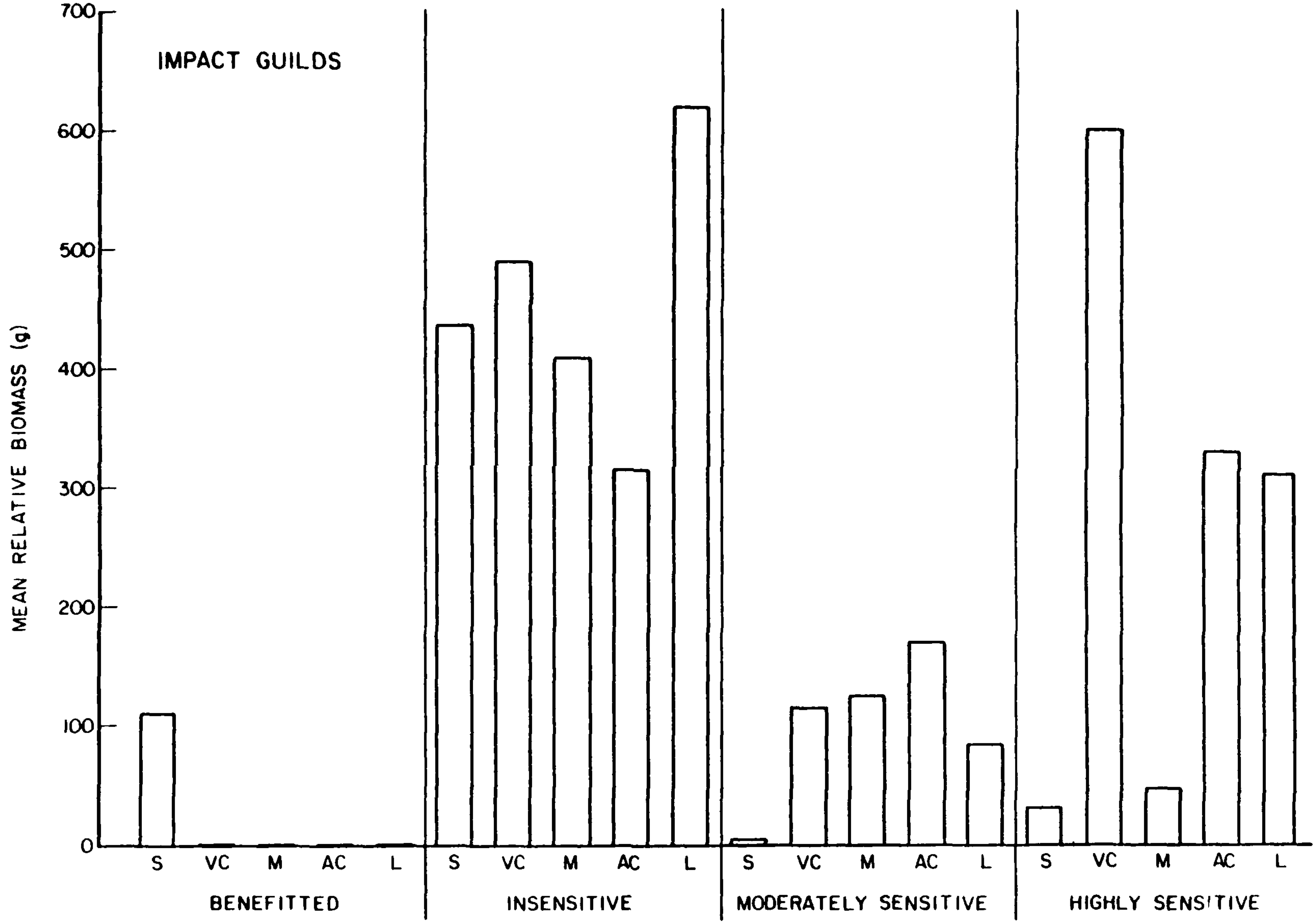


Figure 37. Impact guild structure at each study site.

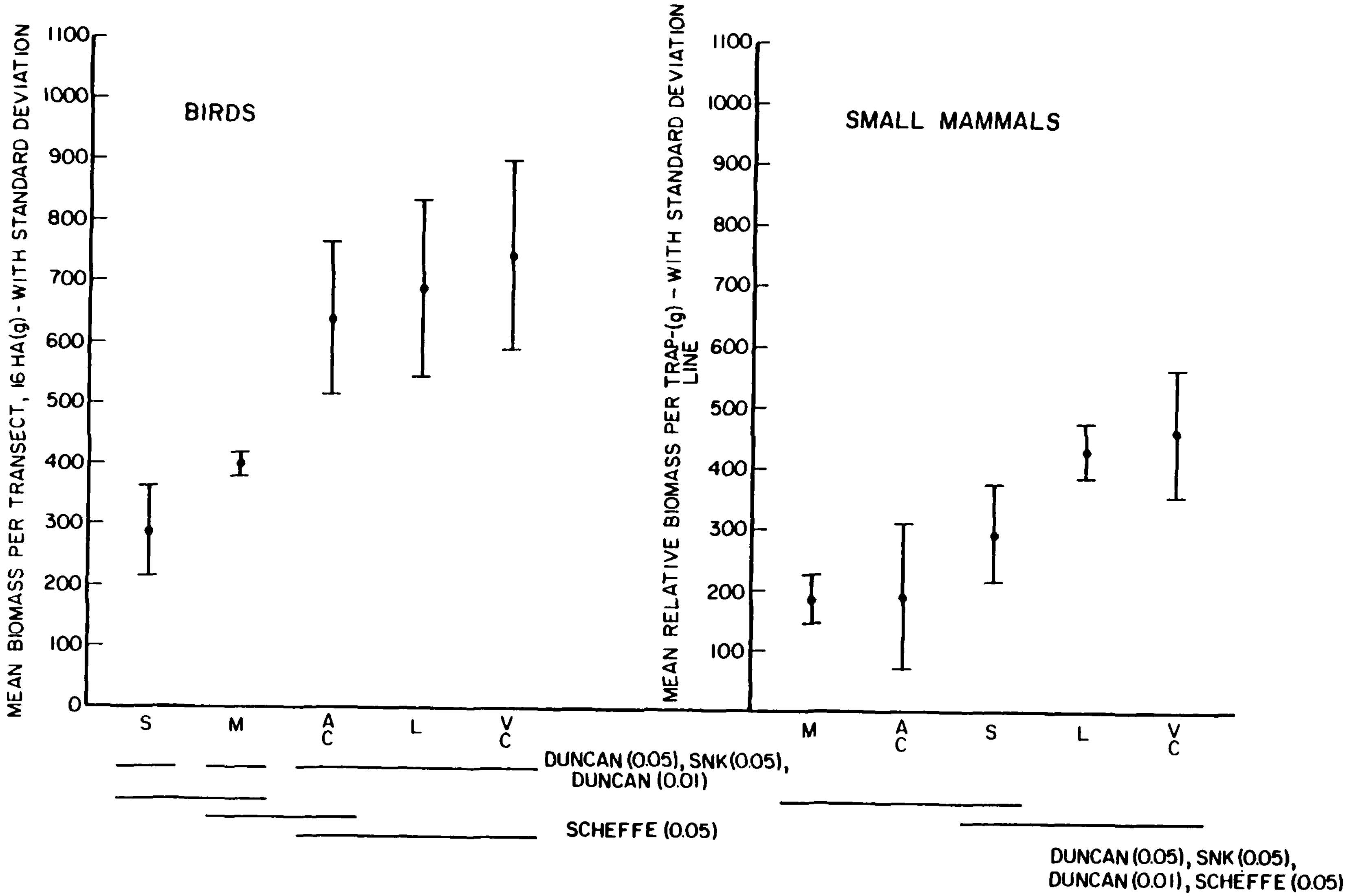
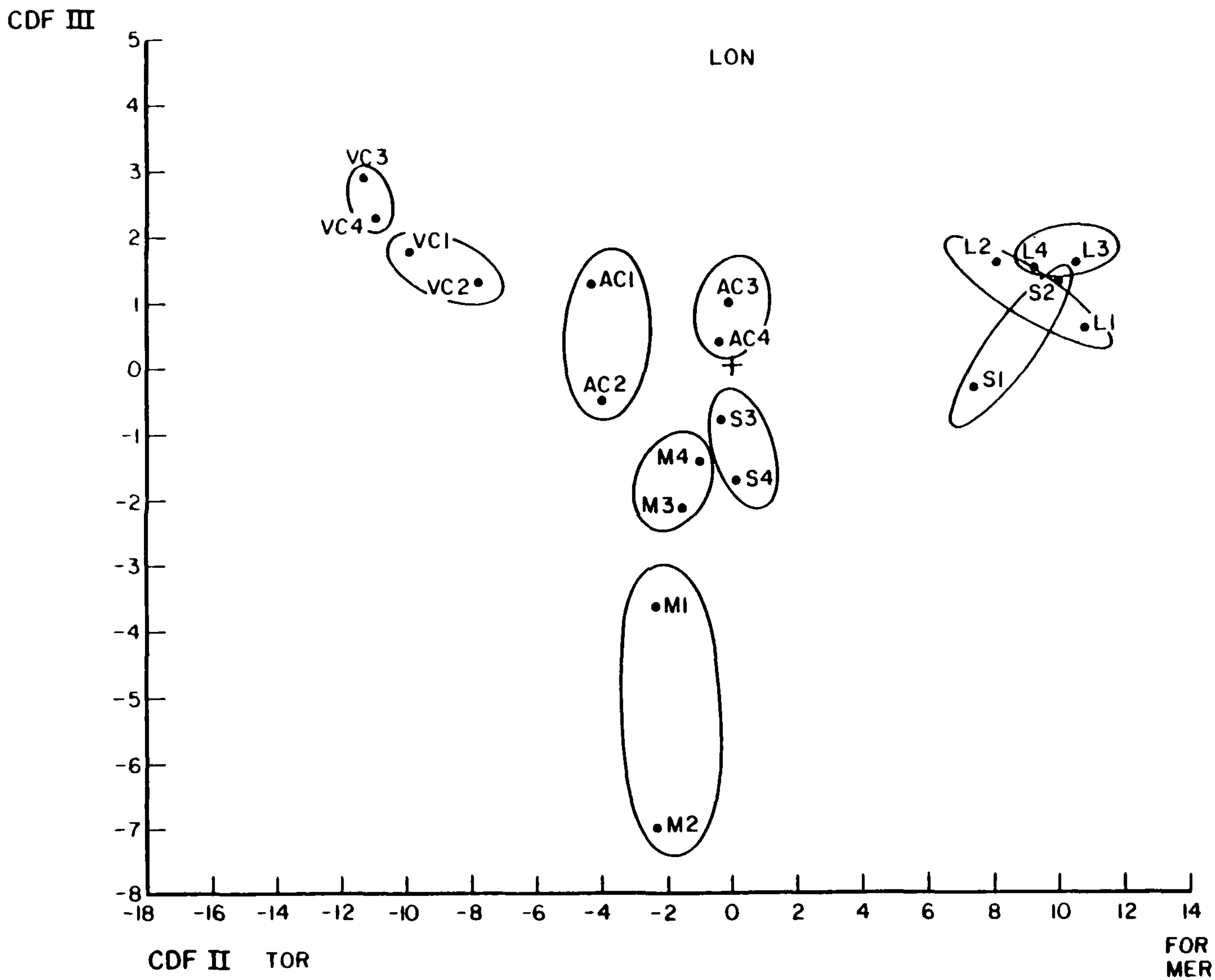


Figure 36. Biomass of birds and small mammals at each study site.

(C)



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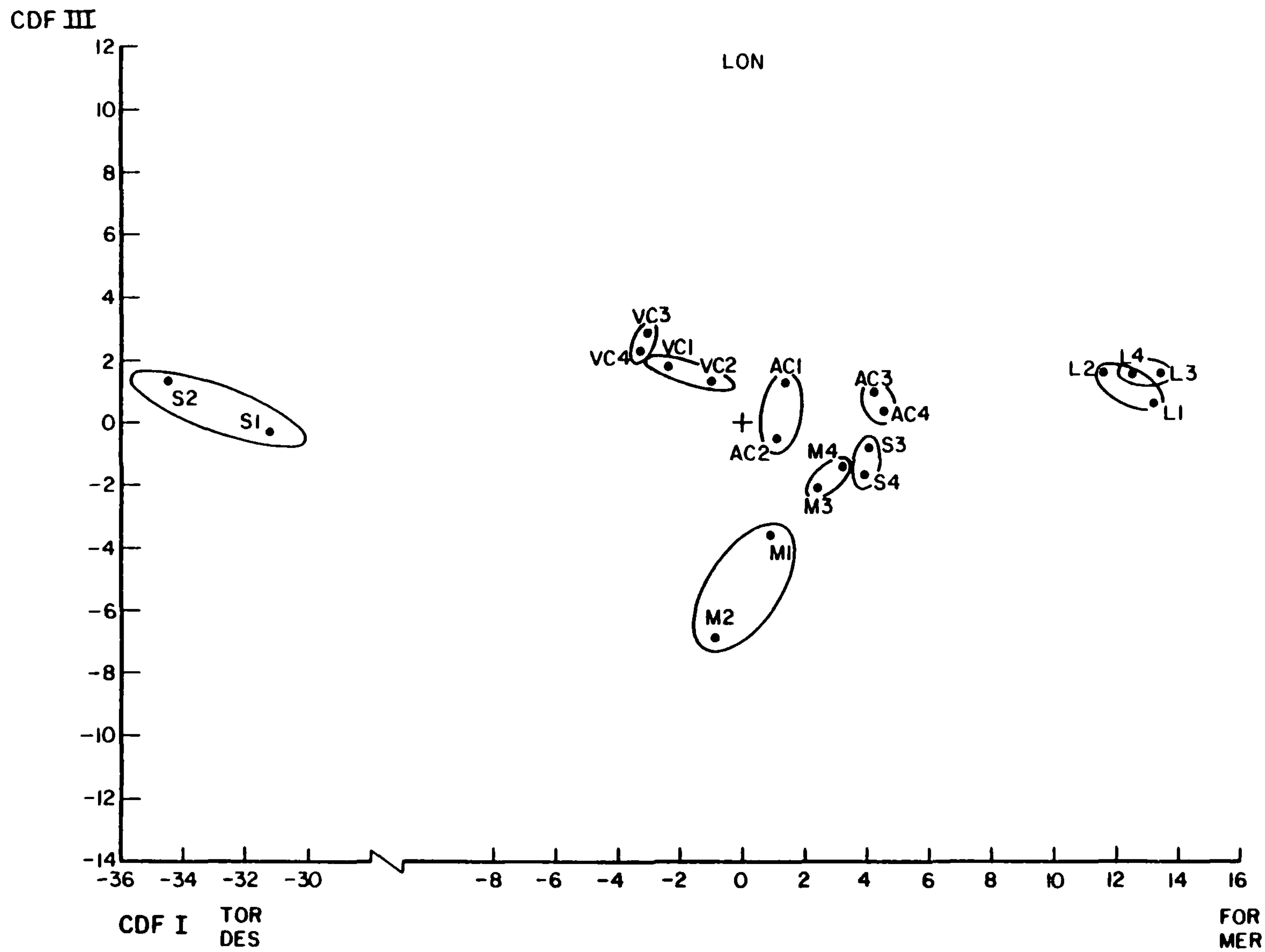
(B)



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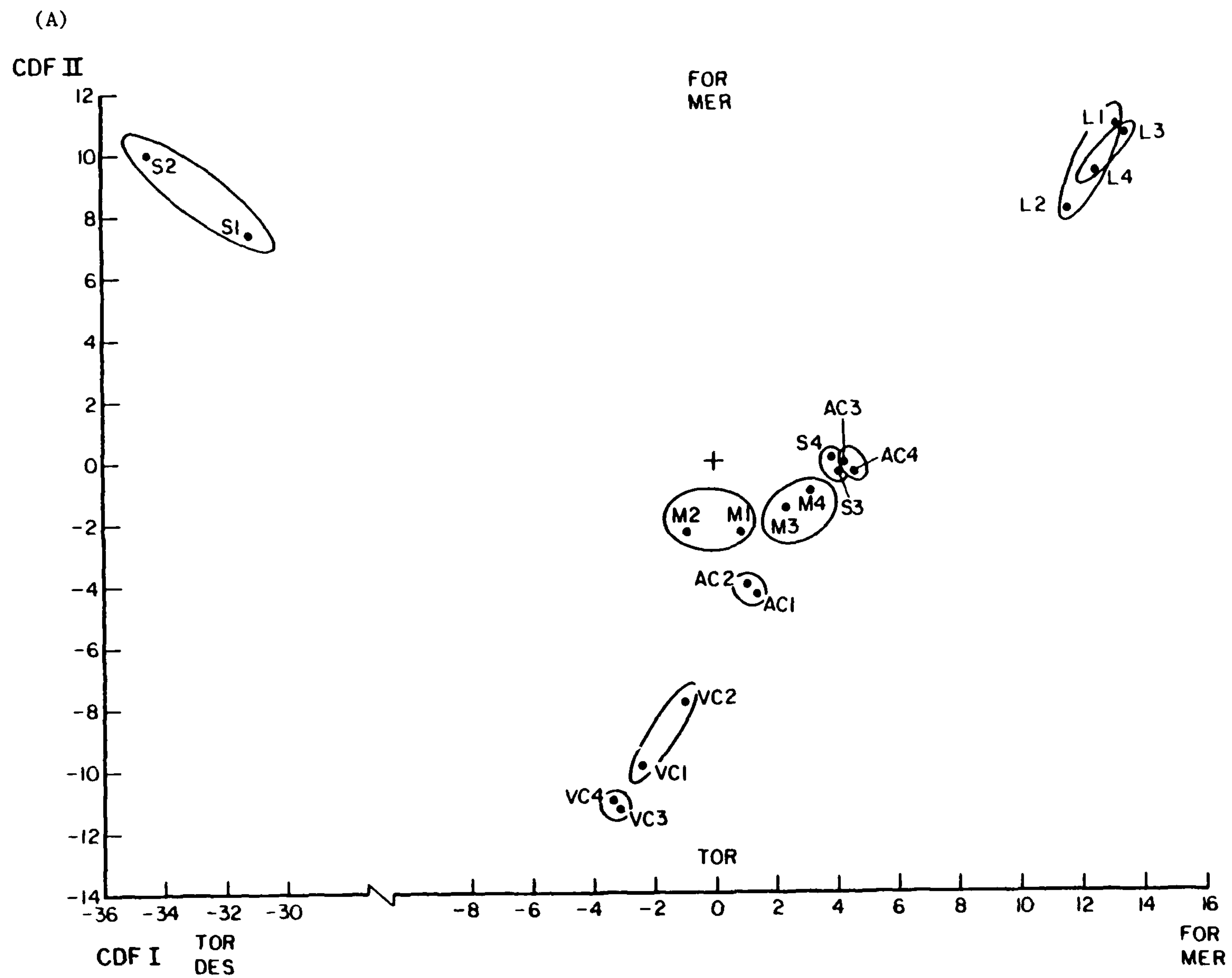
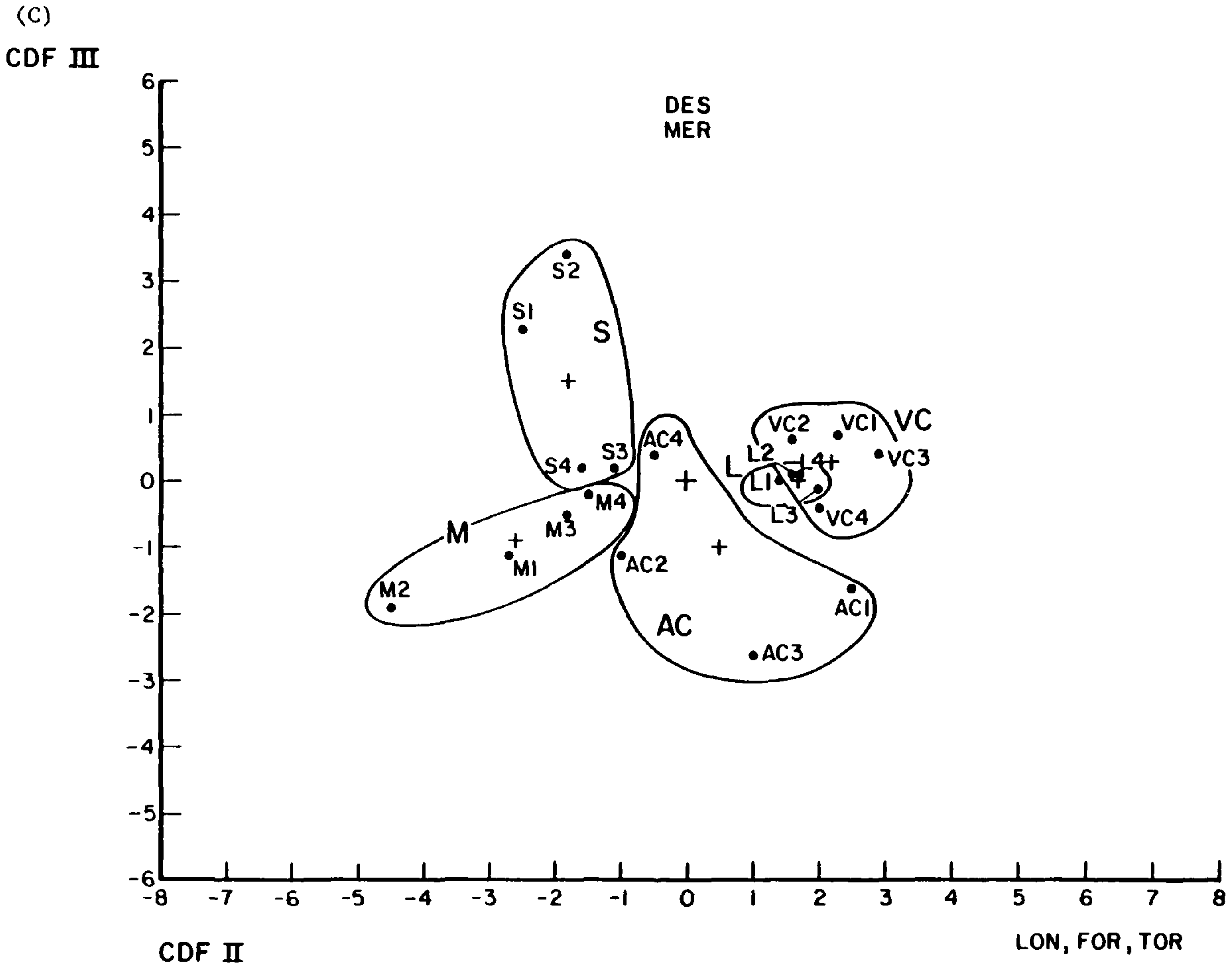


Figure 35. Canonical analysis of discriminance of the five study sites based on pairing adjacent small mammal trap-lines.



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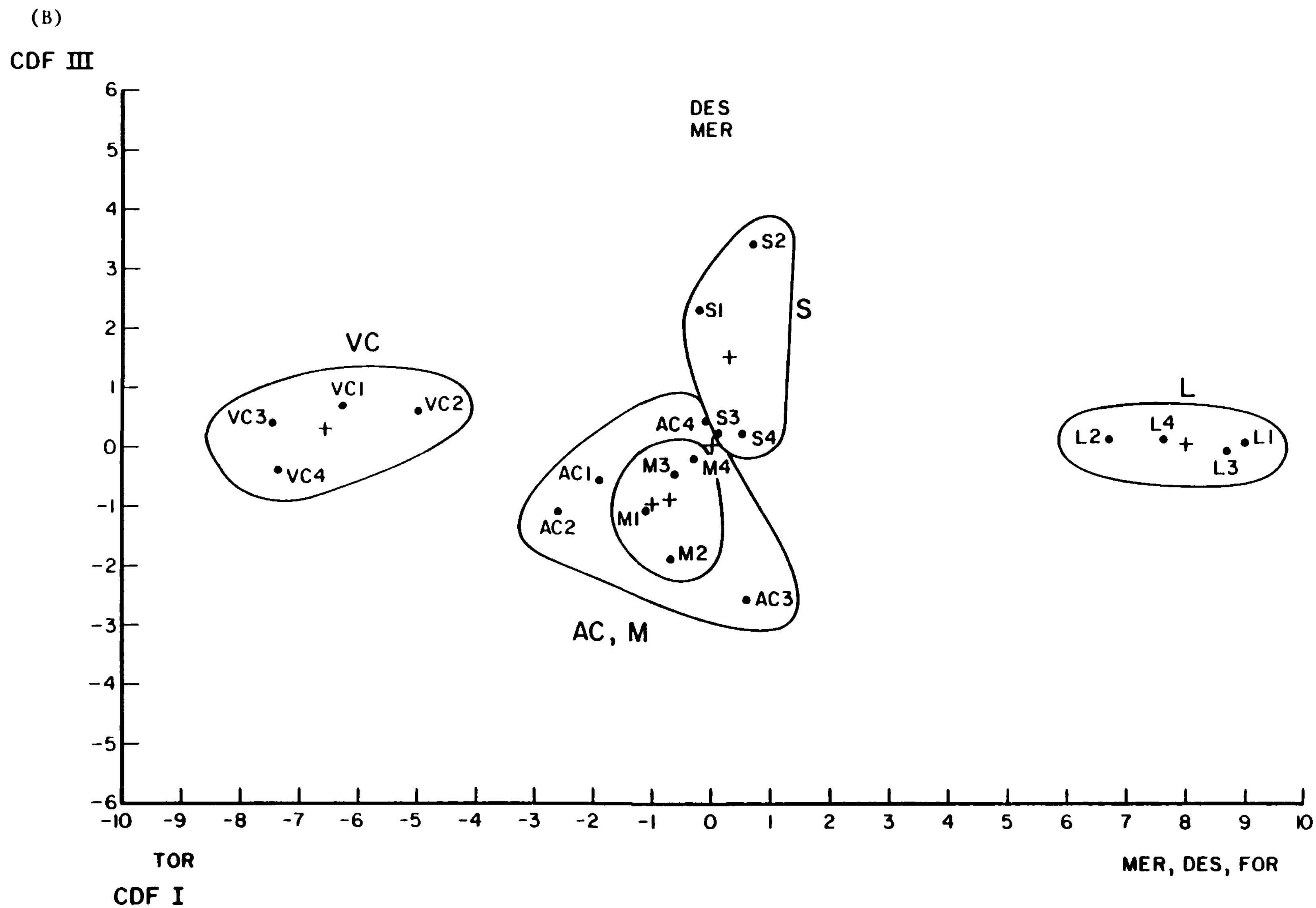

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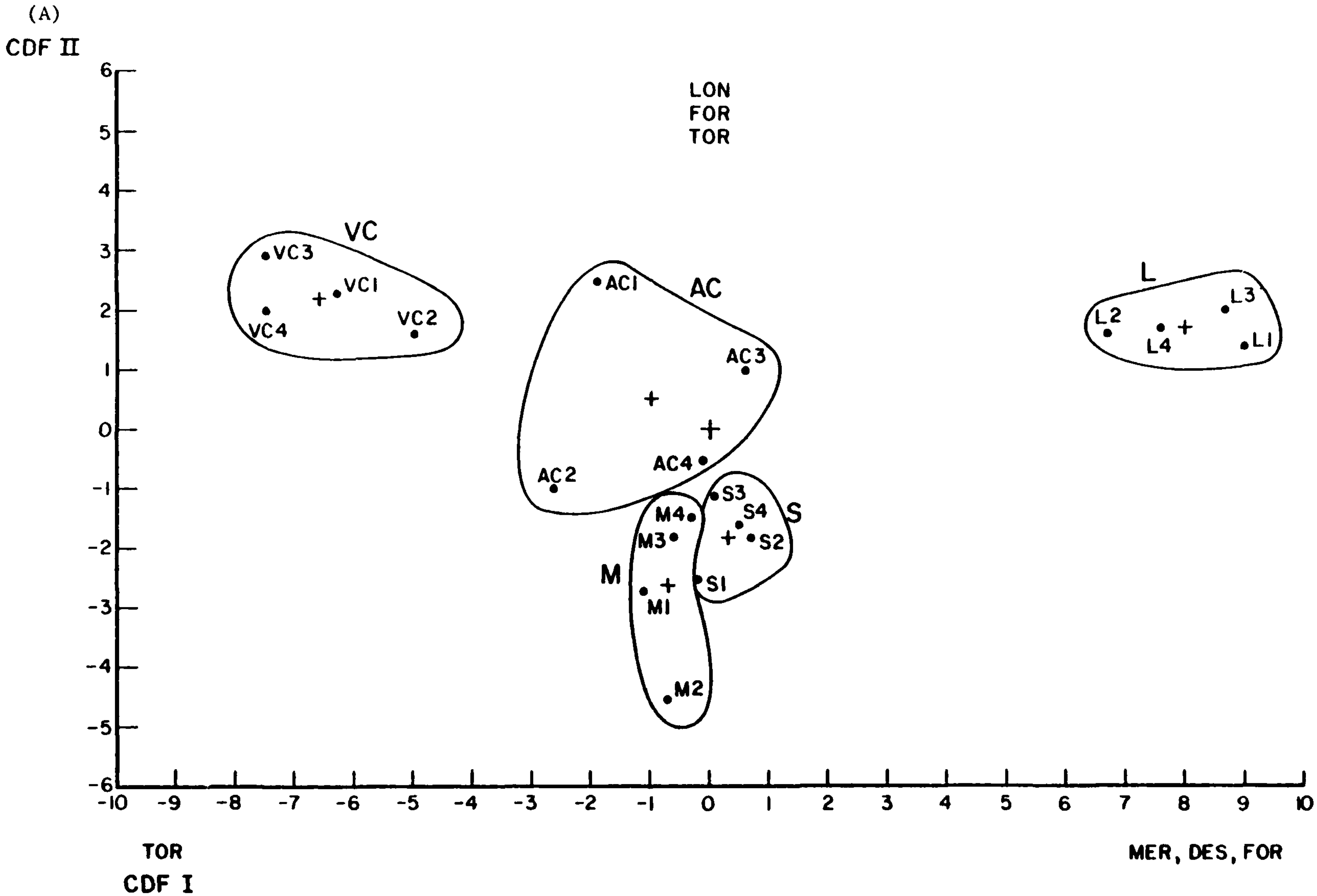

Figure 34. Canonical analysis of discriminance of the five study sites based on small mammal community structure.

(B)

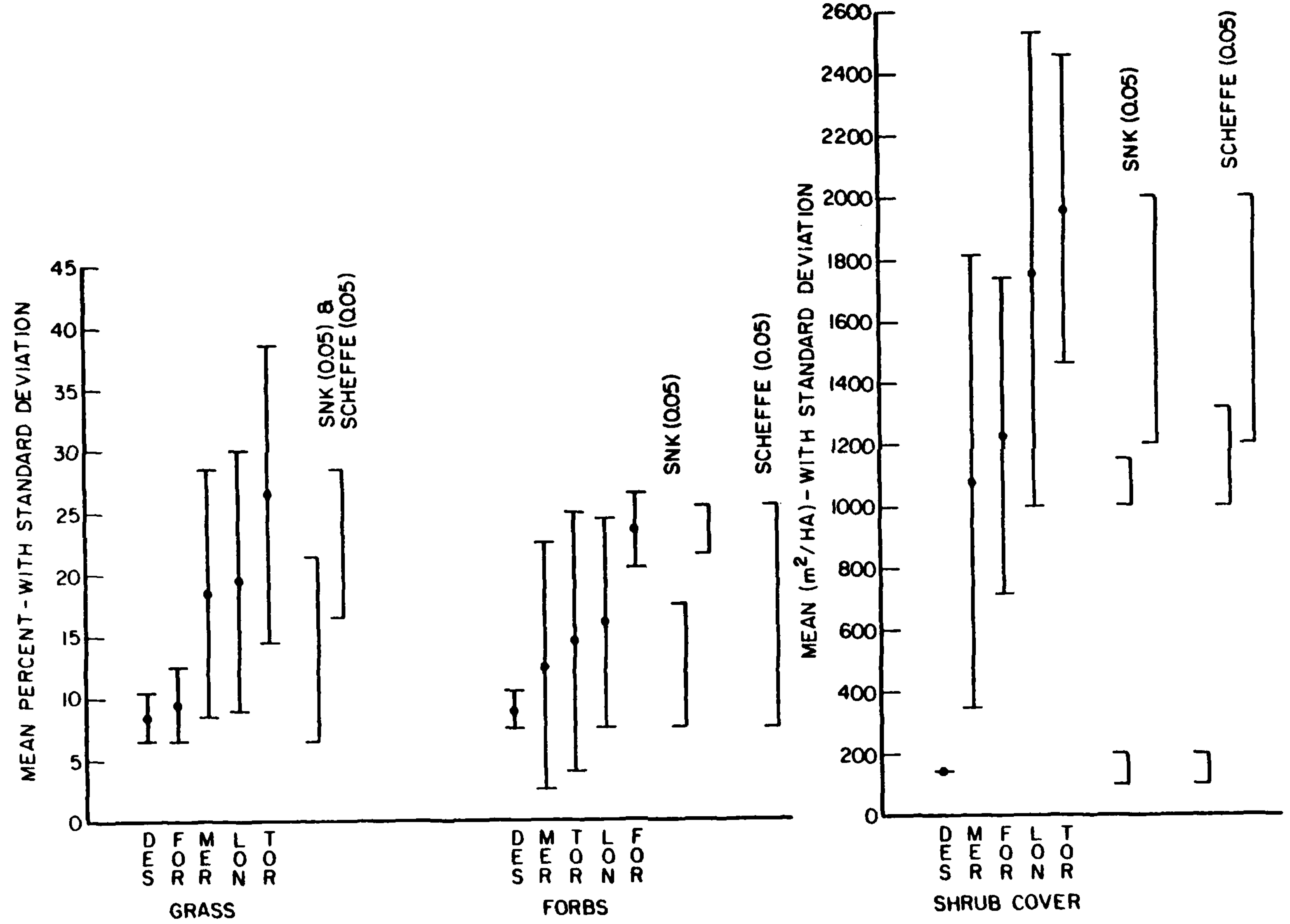

Figure 33. (Cont'd).

(A)

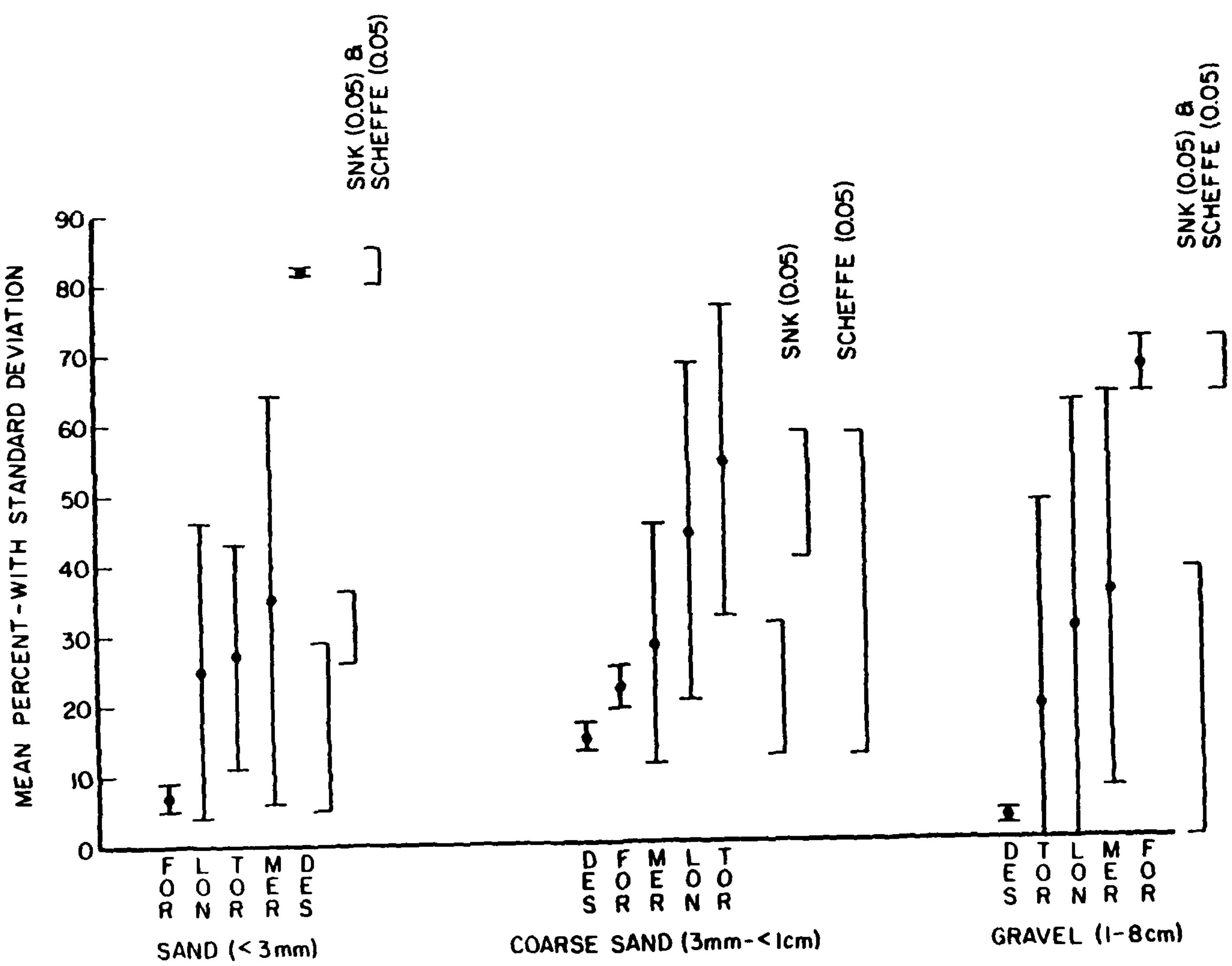

Figure 33. Statistical evaluation of mammal species-habitat variable associations.

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APPENDIX A:

STUDY SITE LOCALITIES, ELEVATION, AND DEGREE OF ENVIRONMENTAL IMPACT

Study Site	Transect	Map Coordinate*	Elevation (m)	Transect Bearing** (Degrees)	Relative*** Habitat Disturbance (%)	Mean
VC	1	190057	910	129.5	0	
VC	2	189055	910	129.5	0	0
VC	3	188056	940	246.5	0	
VC	4	187058	940	243.5	0	
AC	1	182074	960	144.5	0	
AC	2	184076	970	148.	0	0
AC	3	175077	990	96.5	0	
L	1	123197	1000	276.5	-	
L	2	123199	1000	274.5	-	8
L	3	123202	1010	277.	-	
L	4	124205	1010	274.	-	
M	1	460010	460	57.5	39.	
M	2	460013	470	60.	35.5	
M	3	452012	470	61.5	57.	39
M	4	450014	480	60.5	45.	
M	5	458020	490	54.5	33.	
M	6	456022	500	57.5	26.	
S	1	467991	450	70.	76.	
S	2	466993	450	71.	80.5	
S	3	458992	450	76.5	88.	86
S	4	457994	450	72.	93.	
S	5	465999	440	59.5	85.	
S	6	465002	440	63.5	94.	

* Army grid coordinates locating the 0 locus of the bird transects. Accuracy ±100 m. From Fort Irwin Military Installation Map, Series V795S, edition 1-DMA.

** Grid azimuth from the O locus. To convert to magnetic azimuth, subtract 14.5 degrees.

*** Percent vehicle tracks (track or tire) encountered when walking 600 m with 1 m paces, 30 m away and parallel to each bird transect. At the valley control site (VC), several washes were used in the past for roads. However, tracks quickly disappear in washes, and in two seasons of field work tracks have never been observed at the control sites. At the severely impacted site (S), wind-blown sand made it difficult to observe tracks. Therefore, the relative habitat disturbance was probably higher.

APPENDIX B:

BIRD AND MAMMAL WEIGHTS USED TO ESTIMATE BIOMASS

Species	Weight (g)	N*	Locality	Season	Reference**
Horned Lark	31.6	22	Montana	Summer	121
Black-throated sparrow	13.5	2	Death Valley	Spring	46
Brewer's sparrow	11.0	8 60	Death Valley Arizona	Spring Winter and Spring	46, 121
Sage sparrow	18.0	1 33	Death Valley Oregon	Spring Summer	46, 121
White-crowned sparrow	26.0	7	Death Valley	Spring	46
Chipping sparrow	12.6	4	Death Valley	Spring	46
Western Meadowlark	113	2	Death Valley	Spring	46
LeConte's Thrasher	61.0	7	Death Valley	Spring	46
Desert Kangaroo rat	101	54	Mojave and Great Basin Deserts	Spring and Summer	17
Merriam's Kangaroo rat	37.6	194	Mojave and Great Basin Deserts	Spring and Summer	17
Little Pocket mouse	7.1	92	Mojave and Great Basin Deserts	Spring and Summer	17
Long-tailed Pocket mouse	21.0	21	Nevada	--	51
Southern Grass-hopper mouse	28.9	16	Sonoran Desert Arizona	Spring and Summer	17

*N = sample size
**See reference list on p 119.

APPENDIX C:

VARIABLE TRANSFORMATIONS USED IN THIS STUDY

Variable (X)	Transformation of Variable X
Habitat variables:	
CCB to Crest and L2 to SHCOV (see Appendix E)	$LOG_e(X+1)$
HCB to HREST (see Appendix E)	$LOG_e(100X+1)$
Shrub diameter and height	$LOG_e(100X)$
Shrub density	$X^{1/2}$
Ground cover and substrate size	ARCSINE p_x*
Horizontal heterogeneity CVDCB to CVNR (see Appendix E)	$LOG_e(100X)$
Population estimates for mammals	$LOG_e(X + 1)$
Population estimates for birds	$(X + 0.5)^{1/2}$
Biomass	$LOG_e(X)$

*Variable X is expressed as a proportion (decimal). Since the arcsine transformation is unavailable with many statistical packages, an equivalent form was used:

$$\text{ARCTAN}[p_x/(1 - p_x^2)^{1/2}]$$

APPENDIX D:

DENSITY AND COVER OF THE 14 SHRUB SPECIES SAMPLED IN THE VEGETATION TRANSECTS AND RELATIVE ABUNDANCES OF CACTUS SPECIES AND JOSHUA TREES: SCIENTIFIC NAMES

	Density (Shrubs/ha)					Cover (m^2/ha)				
	VC	S	AC	M	L	VC	S	AC	M	L
Shrubs										
Creosote Bush-*Larrea tridentata*	559	225	687	212	388	1152	131	1088	269	686
Burroweed-*Ambrosia dumosa*	1594	173	1617	828	403	562	22.8	384	138	118
Cheesebush-*Hymenoclea salsola*	[illegible].1	119	62.5	72.9	43.8	0.62	21.5	10.8	18.6	17.8
Spiny Hopsage-*Grayia spinosa*	40.6	0	121	0	57.8	19.9	0	41.4	0	19.8
Turpentine Broom-*Thamnosma montana*	3.1	0	0	0	114	0.39	0	0	0	30.1
Mormon Tea-*Ephedra* spp.	0	0	8.3	49.0	9.4	0	0	3.2	21.6	4.7
Desert Cassia-*Cassia armata*	0	2.1	0	60.4	0	0	0.41	0	23.9	0
Mojave Dalea-*Dalea arborescens*	0	0	0	14.6	0	0	0	0	4.7	0
Goldenhead-*Acamptopappus sphaerocephalus*	56.3	0	150	0	7.8	7.8	0	30.6	0	5.2
Paperbag Bush-*Salzaria mexicana*	0	1.0	16.7	0	26.6	0.29	0	9.0	0	9.1
Wild Buckwheat-*Eriogonum fasciculatum*	0	0	37.5	0	0	0	0	5.0	0	0
Chaffbush-*Amphipappus fremontii*	0	15.6	0	4.2	0	0	2.8	0	0.61	0
Bush Encelia-*Encelia frutescens*	0	18.7	0	3.1	0	0	3.1	0	0.61	0
Cooper Goldenbush-*Haplopappus cooperi*	0	3.1	0	0	0	0	0.54	0	0	0
Cactus										
Beaver Tail Cactus-*Opuntia basilaris*	P	X	P	P	P					
Silver Cholla-*Opuntia echinocarpa*	P	X	P	P	P					
Pencil Cactus-*Opuntia ramosissima*	X	X	R	X	X					
Cottontop Cactus-*Echinocactus polycephalus*	R	X	P	R	R					

P = present
R = rare
X = absent or very rare

Trees

	VC	S	AC	M	L
Joshua Tree-*Yucca brevifolia*	X	X	X	X	R

R = rare
X = absent

APPENDIX E:

HABITAT [ENVIRONMENTAL] VARIABLES

Number	Code	Habitat Variable	
1	CCB	cover of *Larrea tridentata* (creosote bush)	(m^2/ha)
2	CBW	cover of *Ambrosia dumosa* (burroweed)	(m^2/ha)
3	CCHE	cover of *Hymenoclea salsola*	(m^2/ha)
4	CSH	cover of *Grayia spinosa*	(m^2/ha)
5	CTB	cover of *Thamnosma montana*	(m^2/ha)
6	CMT	cover of *Ephedra* spp.	(m^2/ha)
7	CCAS	cover of *Cassia armata*	(m^2/ha)
8	CMD	cover of *Dalea arborescens*	(m^2/ha)
9	CA	cover of *Acamptopappus sphaerocephalus*	(m^2/ha)
10	CCD	cover of *Salazaria mexicana* + *Eriogonum fasciculatum*	(m^2/ha)
11	C123	cover of *Amphipappus fremontii* + *Haplopappus cooperi* + *Encelia frutescens*	(m^2/ha)
12	CREST	cover of CCHE to C123 combined (subdominant shrubs)	(m^2/ha)
13	HCB	mean height of *Larrea tridentata*	(cm)
14-24	HBW-HREST	mean height of HBW-HREST	(cm)
25	CL1	cover of shrubs $<$ 0.5 m in height	(m^2/ha)
26	CL2	cover of shrubs $\geq$ 0.5 m to $<$ 1 m in height	(m^2/ha)
27	CL3	cover of shrubs $\geq$ 1 m to $<$ 1.5 m in height	(m^2/ha)
28	CL4	cover of shrubs $\geq$ 1.5 m in height	(m^2/ha)
29	GRASS	grass cover	(%)
30	FORB	forb cover	(%)
31	LIT	litter cover	(%)
32	SAND	sand (particle sizes $<$ 3 mm)	(%)
33	CSAND	coarse sand (particle sizes $\geq$ 3 mm to $<$ 1 cm)	(%)
34	GRAV	gravel (particle sizes 1 to 8 cm)	(%)
35	ROCK	rock (particle sizes $\geq$ 8 cm)	(%)
36	CVDCB	coefficient of variation, diameter of creosote bush	
37	CVDBW	coefficient of variation, diameter of burroweed	
38	CVDR	coefficient of variation, diameter of subdominant shrubs	
39	CVHCB	coefficient of variation, height of creosote bush	
40	CVHBW	coefficient of variation, height of burroweed	
41	CVHR	coefficient of variation, height of subdominant shrubs	
42	CVNCB	coefficient of variation, density of creosote bush	
43	CVNBW	coefficient of variation, density of burroweed	
44	CVNR	coefficient of variation, density of subdominant shrubs	
45	L2	density of shrubs 0.2 m in height	$(shrubs/1600\ m^2)$
46	L4	density of shrubs 0.3 - 0.4 m in height	$(shrubs/1600\ m^2)$
47	L6	density of shrubs 0.5 - 0.6 m in height	$(shrubs/1600\ m^2)$
48	L8	density of shrubs 0.7 - 0.8 m in height	$(shrubs/1600\ m^2)$
49	L10	density of shrubs 0.9 - 1.0 m in height	$(shrubs/1600\ m^2)$
50	L12	density of shrubs 1.1 - 1.2 m in height	$(shrubs/1600\ m^2)$
51	L14	density of shrubs 1.3 - 1.4 m in height	$(shrubs/1600\ m^2)$
52	L16	density of shrubs 1.5 - 1.6 m in height	$(shrubs/1600\ m^2)$
53	L18	density of shrubs 1.7 - 1.8 m in height	$(shrubs/1600\ m^2)$

Number	Code	Habitat Variable	
54	L20	density of shrubs 1.9 - 2.0 m in height	(shrubs/1600 m^2)
55	L22	density of shrubs 2.1 - 2.2 m in height	(shrubs/1600 m^2)
56	L27	density of shrubs > 2.2 m in height	(shrubs/1600 m^2)
57	SHCOV	total shrub cover	(m^2/ha)
58	NSP	number of shrub species	(N)
59	L4J*	L4 + L6	(shrubs/1600 m^2)
60	L12J*	L12 + L14	(shrubs/1600 m^2)

Habitat variables were measured in four evenly spaced but randomly oriented transects located along each of the 23 bird transects. See methods section.

*Variables created after initial data analysis because of very high correlations.

APPENDIX F:

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS OF SHRUB HEIGHT AND DIAMETER

Species*	r	N	P
Creosote Bush	0.86	1000	<0.001
Burroweed	0.80	2081	<0.001
Cheesebush	0.73	222	<0.001
Spiny Hopsage	0.70	72	<0.001
Turpentine Broom	0.78	63	<0.001
Desert Cassia	0.80	60	<0.001
Goldenhead	0.70	59	<0.001
Mormon Tea	0.67	54	<0.001
Subdominants (12 species)	0.71	617	<0.001
All Shrubs	0.88	3698	<0.001

*All sites combined
N = sample size
P = probability

Site	Creosote Bush		Burroweed		Subdominants (12 species)	
	r	N	r	N	r	N
Severely Impacted Valley(S)	0.86	216	0.65	166	0.62	153
Valley Control (VC)	0.71	179	0.77	510	0.73	33
Moderately Impacted Alluvial (M)	0.83	204	0.75	795	0.73	196
Alluvial Control (AC)	0.67	165	0.79	388	0.66	95
Lightly Impacted High Desert (L)	0.83	236	0.81	222	0.71	140

Note: All P < 0.001

APPENDIX G:

PARAMETERS FOR 20 REGRESSION EQUATIONS RELATING HEIGHT AND DIAMETER OF CREOSOTE BUSH AND BURROWEED AT EACH STUDY SITE

	HT = A + B · DIA			DIA = A + B · HT	
Site*	Regression Coefficient (B)	Intercept (A)	Site*	Regression Coefficient (B)	Intercept (A)
	Creosote Bush			**Creosote Bush**	
VC	0.3630	0.6827	VC	1.336	-0.0765
AC	0.2868	0.6583	AC	1.342	-0.00760
L	0.4547	0.4121	L	1.353	0.0196
M	0.5192	0.2741	M	1.147	0.1991
S	0.5180	0.1408	S	1.350	0.0685
	Burroweed			**Burroweed**	
VC	0.3533	0.1754	VC	1.646	-0.00845
AC	0.3288	0.1487	AC	1.821	-0.0491
L	0.3368	0.1560	L	1.791	-0.0360
M	0.4370	0.0997	M	1.391	0.0399
S	0.4546	0.0893	S	1.059	0.1205

*VC = Valley Control
AC = Alluvial Control
L = Lightly Impacted High Desert
M = Moderately Impacted Alluvial
S = Severely Impacted Valley

APPENDIX H:

ANALYSIS OF COVARIANCE, EXAMINING THE REGRESSION: HEIGHT = A + B · DIAMETER

	Creosote Bush					Burroweed			
Source of Variation	R (Components)	R^2 (Value)	Degrees of Freedom	F	Significance (p)	R^2 (Value)	Degrees of Freedom	F	Significance (P)
Full	$R^2_{x,s,xs}$	0.9035	9	1030	<0.001	0.9075	9	2258	<0.001
Additive	$R^2_{x,s}$	0.7711	5	1582	<0.001	0.6506	5	2913	<0.001
Sites (adjusted for diameter)	$R^2_{x,s}-R^2_{x}$	0.7711-0.7315 = 0.0396	4	102	<0.001	0.6506-0.6381 =0.0125	4	70.0	<0.001
Diameter (adjusted for sites)	$F^2_{x,s}-F^2_{s}$	0.7711-0.3208 = 0.4503	1	4620	<0.001	0.6506-0.1687 =0.4819	1	10789	<0.001
Interaction	$R^2_{x,s,xs}-R^2_{x,s}$	0.9035-0.07711 = 0.1324	4	340	<0.001	0.9075-0.6506 =0.2569	4	1438	<0.001
Residuals	$1-R^2_{x,s,xs}$	0.0965	990	MS 9.75×10^{-5}	----	0.0925	2071 4.47×10^{-5}	MS	----

APPENDIX I:

ANALYSIS OF COVARIANCE, EXAMINING THE REGRESSION: DIAMETER = A + B · HEIGHT

Source of Variation	Creosote Bush R^2 (Components)	R^2 (Value)	Degrees of Freedom	F	Significance (p)	Burroweed R^2 (Value)	Degrees of Freedom	F	Significance (P)
Full	$R^2_{x,s,xs}$	0.7348	9	305	<0.001	0.6560	9	439	<0.001
Additive	$R^2_{x,s}$	0.7334	5	548	<0.001	0.6481	5	780	<0.001
Sites (adjusted for height)	$R^2_{x,s}-R^2_{x}$	0.7334-0.7315 = 0.0019	4	1.8	>0.10 NS	0.6481-0.6381 = 0.0100	4	15.1	<0.001
Height (adjusted for sites)	$R^2_{x,s}-R^2_{s}$	0.7334-0.2087 = 0.5247	1	1959	<0.001	0.6481-0.1628 = 0.4853	1	2922	<0.001
Interaction	$R^2_{x,s,xs}-R^2_{x,s}$	0.7348-0.7334 = 0.0014	4	1.3	>0.25 NS	0.6560-0.6481 = 0.0079	4	11.9	<0.001
Residuals	$1-R^2_{x,s,xs}$	0.2652	990	MS 2.68×10^{-4}	----	0.3440	2071	MS 1.66×10^{-4}	----

APPENDIX J:

NUMBER OF BIRD INDIVIDUALS ESTIMATED TO BE PRESENT ON EACH BIRD TRANSECT AT EACH STUDY SITE

Species	VC*				S*						AC*			M*						L*			
	1	2	3	4	1	2	3	4	5	6	1	2	3	1	2	3	4	5	6	1	2	3	4
Horned Lark	14	12	8	8	6	10	8	8	10	12	6	10	6	8	10	10	4	6	8	12	12	12	14
Black-Throated Sparrow	6	4	4	6						2	8	6	6	6	8	8	10	8	6	4	2	8	4
Brewer's Sparrow	2	6	8	10							4	4	4							12	10	6	14
Sage Sparrow	1	1	2	2							1											1	1
LeConte's Thrasher		1		1													2	1		2			
Western Meadowlark		2	2	2							2	1	2										2
White-Crowned Sparrow			1	6									9	2					2		3		
Chipping Sparrow													1					1	1		1		
Raven	2	2	2										3	2								1	
Western Kingbird				1																			1
Lark Sparrow																				1			
Yellow-Rumped Warbler		1																					
Mocking Bird											1	1	2										
Mourning Dove													7										
Prairie Falcon																		1					
Harrier	1																						

*VC = Valley Control
S = Severely Impacted Valley
AC = Alluvial Control
M = Moderately Impacted Alluvial
L = Lightly Impacted High Desert

APPENDIX K:

ESTIMATED POPULATION DENSITIES IN EACH STUDY SITE OF ALL BIRD SPECIES ENCOUNTERED IN THE SURVEYS

Species	Individuals/Transect (16 ha) VC	S	AC	M	L	Males/100 ha VC	S	AC	M	L
Breeding Birds*										
Horned Lark - *Eremophila alpestris*	10.5	9.0	7.3	7.7	12.5	33	28	23	24	39
Black-throated Sparrow - *Amphispiza bilineata*	5.0	0.3	6.7	7.7	4.5	16	1	21	24	14
Brewer's Sparrow - *Spizella breweri*	6.5	0	4.0	0	10.5	20	0	13	0	33
Sage Sparrow - *Amphispiza belli*	1.5	0	0.3	0	0.5	5	0	1	0	2
LeConte's Thrasher - *Toxostoma lecontei*	0.5**	0	0	0.5**	0.5	2**	0	0	2**	2
Western Meadowlark - *Sturnella neglecta*	1.5	0	1.7	0	0.5	5	0	5	0	2
Sum	25.0	9.3	20.0	15.4	29.0	79	29	63	48	92
Transients										
White-crowned Sparrow - *Zonotrichia leucophrys*	1.8	0	3.0	0.7	0.8	5	0	9	2	2
Chipping Sparrow - *Spizella passerina*	0	0	0.3	0.3	0.3	0	0	1	1	1
Raven - *Corvus corax*	1.5	0	1.0	0.3	0.3	5	0	3	1	1
Western Kingbird - *Tyrannus verticalis*	0.3	0	0	0	0.3	1	0	0	0	1
Lark Sparrow - *Chondestes grammacus*	0	0	0	0	0.3	0	0	0	0	1
Yellow-rumped Warbler -*** *Dendroica coronata*	0.3	0	0	0	0	1	0	0	0	0
Mockingbird - *Mimus polyglottos*	0	0	1.3	0	0	0	0	4	0	0
Mourning Dove - *Zenaida macroura*	0	0	2.3	0	0	0	0	7	0	0
Prairie Falcon - *Falco mexicanus*	0	0	0	0.2	0	0	0	0	1	0
Harrier - *Circus cyaneus*	0.3	0	0	0	0	1	0	0	0	0
Sum	4.2	0	7.9	1.5	2.0	13	0	24	5	6

* 1:1 sex ratio assumed. This may underestimate the density of horned larks, since they are often polygynous.

** Transients

*** Audubon's race.

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