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SECONDARY SUCCESSION ON DISTURBED SITES AT YUCCA MOUNTAIN, NEVADA

by

Jay P. Angerer, W. Kent Ostler, Warren D. Gabbert,
and Brad W. Schultz

EG&G Energy Measurements, Inc.
Environmental Sciences Division
Las Vegas, Nevada

1994

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REVIEWED BY

W. K. Ostler, Director
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ABSTRACT

This report presents the results of a study of secondary plant succession on disturbed sites created during initial site investigations in the late 1970s and early 1980s at Yucca Mountain, NV. Specific study objectives were to determine the rate and success of secondary plant succession, identify plant species found in disturbances that may be suitable for site-specific reclamation, and to identify environmental variables that influence succession on disturbed sites. During 1991 and 1992, fifty seven disturbed sites were located. Vegetation parameters, disturbance characteristics and environmental variables were measured at each site. Disturbed site vegetation parameters were compared to that of undisturbed sites to determine the status of disturbed site plant succession. Vegetation on disturbed sites, after an average of ten years, was different from undisturbed areas. *Ambrosia dumosa, Chrysothamnus teretifolius, Hymenoclea salsola, Gutierrezia sarothrae, Atriplex confertifolia, Atriplex canescens,* and *Stephanomeria pauciflora* were the most dominant species across all disturbed sites. With the exception of *A. dumosa*, these species were generally minor components of the undisturbed vegetation. Elevation, soil compaction, soil potassium, and amounts of sand and gravel in the soil were found to be significant environmental variables influencing the species composition and abundance of perennial plants on disturbed sites. The recovery rate for disturbed site secondary succession was estimated. Using a linear function (which would represent optimal conditions), the recovery rate for perennial plant cover, regardless of which species comprised the cover, was estimated to be 20 years. However, when a logarithmic function (which would represent probable conditions) was used, the recovery rate was estimated to be 845 years. Recommendations for future studies and site-specific reclamation of disturbances are presented.

ACKNOWLEDGEMENTS

Many people have contributed to the completion of this report on secondary plant succession within disturbed habitats at Yucca Mountain. The following EG&G/EM Environmental Sciences Division personnel helped set up study plots, collect data, enter data, and proof data: M. Wayne Fariss, Kevin W. Blomquist, Pam F. Hall, Glen E. Lyon, P. A. Chubb, Tim A. Lindemann, Aaron. M. Ambos, Brian R. Eller, Andy E. Gabbert, Shana L. Kozusko, Larry L. Lewis, Debi L. Pitts, Juan C. Medrano, Brett A. Rea, Katherine K. Zander, Kamila R. Sharp, Greg T. Sharp, Craig A. Callison, Charles R. Stanley, Rod G. Goodwin, Greg A. Brown, Dave S. Dixon, Stephanie A. Ferra, Tracey E. Walrath, Bart C. Odegaard, Mike W. Janis, Eric A. Holt, Terrence S. Trasatti, Matt D. Walo, James S. Woollet, Alicia C. Pool, Will H. Kohn, Chris L. Sowell, Shana L. Kozusko, Richard J. Delahunty, Adam Truran, David C. Walrath, Julie E. Fontaine, Sue M. Schultz, Wendy N. Finlay, Dan C. Steen, Adrienne M. Pilmanus, K. L. Griffin, L. S. Osborn. Valuable assistance in personnel scheduling and logistics was provided by the following individuals: David C. Anderson, Ron A. Green, Danny L. Rakestraw, and Cathy A. Wills. M. Wayne Fariss assisted in the analysis of the data. Glen E. Lyon created the plant database used to generate species names, life cycles and common names from the four-letter species codes used in data collection. The assistance of the following individuals in review of the first draft of this report is appreciated: Tom P. O'Farrell, Von K. Winkel, David C. Anderson, Kevin W. Blomquist, Mark A. Hessing, and Brian Cypher.

David C. Walrath, Steve Kowalkowski, Matt D. Walo, and Rose Broderick created the maps used in this report. Their assistance is greatly appreciated.

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1.0 PURPOSE

During the late 1970s and early 1980s, drill pads, borrow areas, cutslopes, and other construction disturbances were created during site investigations to evaluate Yucca Mountain as a study site for a potential nuclear waste repository. Many of these sites had vegetation and topsoil removed or had fill material spread over them to level the site. These disturbances provide an opportunity to study natural revegetation processes (i.e., secondary plant succession) at Yucca Mountain. In 1991, EG&G/EM ESD implemented a disturbed habitat study to inventory past disturbances and to gain information on the successional processes occurring on disturbances at Yucca Mountain. Results from this study can provide insight into factors that control plant establishment on disturbances, aid in the development of reclamation studies, and ultimately aid in the development of techniques for reclaiming disturbed sites.

Three specific objectives of the study were outlined in the Reclamation Feasibility Plan (DOE 1990):

1) determine the rate and success of natural revegetation processes by comparing disturbed sites with adjacent undisturbed areas;

2) identify plant species found across all disturbances and within vegetation associations which are suitable for use in site-specific reclamation;

3) identify environmental variables at disturbances that may enhance site reclamation success.

The process of secondary plant succession can be described as the change in species composition from the time a disturbance has ceased until the vegetation at the site reaches an equilibrium and the species composition changes very little over time (Connell and Slatyer, 1977; Pickett et. al 1987). In deserts, this process can take many hundreds (Webb and Wilshire, 1980; Carpenter et al., 1986) to thousands of years for the equilibrium to occur (Vasek, 1979/80). Depending on the severity of the disturbance, secondary succession may create a plant community that is similar to the site prior to disturbance, or a plant community that is quite different (Webb et al., 1983). Plant species that occur on a site immediately after a disturbance may ameliorate the soils and microenvironment so that species that are not adapted to the harsh conditions of the disturbed site can later re-establish (Vasek, 1983).

The goal of this study is to better understand the natural succession process including the rate of succession at Yucca Mountain and what factors control or influence that rate. Application of this information may then allow reclamation scientists to develop reclamation trials that can assess if successional factors can be controlled or ameliorated to enhance reclamation success. Information from the disturbed habitat study and the reclamation trials will ultimately be used in the development of site-specific reclamation plans to successfully restore disturbances at Yucca Mountain.

2.0 LITERATURE REVIEW

Natural succession in the Mojave Desert appears to be a slow process (Vasek et al., 1975a b; Vasek, 1979/80; Romney et al., 1980; Wallace et al., 1980; Webb and Wilshire, 1980; Carpenter et al., 1986). Carpenter et al. (1986) reported that secondary succession on old fields in the eastern Mojave Desert require approximately 65 to 100 years for perennial plant cover to be comparable to that of undisturbed areas. Lathrop and Archbold (1980) estimated that the average recovery time for sites disturbed by utilities construction was 100 years and that more than 300 years may be required for long-lived perennials to re-establish. Vasek (1983) stated that natural revegetation of disturbed areas in the Mojave Desert is a process that may require centuries for the disturbed site to have comparable species composition and abundance, biomass, and structure to that of the original plant community.

Secondary succession studies conducted in the Mojave Desert have indicated that in the early seral stages, disturbed sites are dominated by short-lived and intermediate-lived plant species (Wells, 1961; Vasek et al., 1975a; Webb and Wilshire, 1980). Vasek (1979/80) reported that a severely disturbed borrow pit was dominated by short-lived shrubs such as *Encelia frutescens* and *Stephanomeria pauciflora*, whereas undisturbed areas surrounding the borrow pit were dominated by long-lived perennials such as *Larrea tridentata* and *Opuntia bigelovii*. The author concluded that the long-lived perennials were removed during disturbance and approximately 9 years was required for long-lived perennial seedlings to appear in the disturbed area. Vasek (1979/80) outlined three categories of plant species response to soil disturbance in the Mojave desert. The first group included pioneer or invader species such as *Stephanomeria pauciflora* and *Encelia frutescens*. These species tended to be short lived shrubs, suffrutescent or herbaceous perennials. The second group included long-lived opportunists such as *Ambrosia dumosa* that are eliminated after soil disturbance, but are present again shortly after the disturbance has ceased. The third group contained long-lived perennials species such as *Larrea tridentata, Krameria grayii* and *Eriogonum fasciculatum* which react negatively to deep soil disturbance and are generally removed from the site. Many years may be required for seedlings of these long-lived perennials to reappear in the disturbance; however, once established, these plants can persist for a great many years.

Several plant succession studies have been conducted on the Nevada Test Site (NTS). One such study was conducted at the Wahmonie ghost town (located in Area 25 of NTS, 20 kilometers east of Yucca Mountain). Wells (1961) reported that after 31 years, the disturbed areas at the Wahmonie site had greater numbers of *Stipa speciosa, Hymenoclea salsola,* and *Ephedra nevadensis* than undisturbed areas. *Larrea tridentata* and *Grayia spinosa* were absent in the disturbance, but were dominants in the undisturbed areas adjacent to the site. Webb and Wilshire (1980) visited the Wahmonie sites 24 years after the study conducted by Wells (1961). They noted that after 51 years, the most severely disturbed areas (former streets) had reduced densities of long-lived perennials such as *Larrea tridentata, Grayia spinosa,* and *Lycium andersonii,* which were dominant in the adjacent undisturbed areas. Cover of *Hymenoclea salsola* and *Stipa speciosa* was greater in the disturbed areas than in the adjacent undisturbed control. The authors noted that cover and density of perennials was greater in the disturbed area; however the species diversity was less in the disturbed site. The authors suggested that the rate of revegetation at the old town site was related to the soil compaction levels. Areas with high compaction levels had higher densities and cover of short-lived perennials, and lacked long-lived species such as *Larrea* and *Grayia*.

On land disturbed by grading to a depth of 15-20 cm in Area 25, Romney et al. (1989) reported an increase in the densities of *Larrea tridentata* and *Ambrosia dumosa* after above average rainfall during summer and winter months. The authors also noted that species such as *Larrea tridentata* , *Ephedra nevadensis*, and *Lycium andersonii* resprouted from exposed roots in the disturbed area. Plant succession studies were conducted at NTS to determine the effects of aboveground nuclear testing (Shields and Wells,1962; Shields et al., 1963). The annual species, *Salsola kali*, was found to have the highest density in areas with greatest soil disturbance created by nuclear blasts; however, the abundance of this species declined after 4 years (Shields et al., 1963). Within four years , perennial species such as *Atriplex canescens*, *Hymenoclea salsola*, *Oryzopsis hymenoides*, and *Stipa speciosa* increased in numbers on areas disturbed by atmospheric tests when compared with adjacent undisturbed areas (Shields et al., 1963).

Although the studies described above provide insight into the successional processes that occur in post-disturbance habitats of the Mojave Desert, they do not provide adequate information about successional processes at Yucca Mountain. Past studies did not examine and measure specific environmental variables (with the exception of soil compaction measurements of Webb and Wilshire, 1980) and how these relate to secondary plant succession. Past studies of Mojave Desert secondary plant succession tended to be restricted to only one disturbance type and speculations were made as to how environmental variables influenced successional patterns. In this study, the attempt was made to collect information to determine successional patterns at Yucca Mountain and assess how disturbance type, surrounding vegetation association and specific environmental variables influence these successional patterns.

3.0 STUDY AREA DESCRIPTION

Yucca Mountain lies within the arid Basin and Range Province, a geographical region characterized by generally linear mountain ranges dissecting alluvial piedmont valleys with rugged, complex terrain features. Major topographical features of the area include Yucca Mountain itself, a long north-south aligned volcanic ridge, 1,494 m (4,855 ft) in elevation that slopes steeply (15 to 30 degrees) toward the west to Crater Flat (elevation 1,189 m ; 3,864 ft.), and gradually (5 to 10 degrees) toward the east in a series of highly dissected ridges to valleys of approximately 915 m (2,973 ft) in elevation (Figure 1). A large basin, Jackass Flats, and its associated Fortymile Canyon drainage, lie to the east of Yucca Mountain.

The climate of the Yucca Mountain area is characterized by strong solar insolation, limited and erratic precipitation, low relative humidity, and large diurnal temperature differences. No National Weather Service weather recording stations are present in the study area; however, precipitation data were collected from 1968 to 1992 at NTS monitoring gauge 4JA in Area 25. Average annual precipitation was 136.6 mm ($\pm$ 68.9 SD). The greatest monthly average precipitation (25.0 mm $\pm$ 27.1 SD) was in March and the lowest average monthly precipitation (2.4 mm $\pm$ 4.9 SD) was in June (Figure 2). Temperatures for the warmest month (July) averaged 35.6 °C (96.1 °F), while the coldest month (December) averaged 1.8 °C (35.2 °F).

Two major floristic zones occur within the Yucca Mountain Project Area: the Mojave Desert zone, a warm desert occurring below 1,220 m (3,965 ft.); and a transition zone, often called the Transition Desert, which extends in a broad east-west corridor between the Mojave and the cooler, wetter Great Basin Desert found to the north of the site at elevations above 1,525 m (4,956 ft) (Beatley 1976). Four primary vegetation associations (assemblages of areas with similar species composition and physiognomic characteristics) occur throughout the study area within these two floristic regions: *Larrea-Ambrosia* (Creosotebush-Bursage), *Larrea-Lycium-Grayia* (Creosotebush-Boxthorn-Hopsage), *Coleogyne* (Blackbrush), and *Lycium-Grayia* (Boxthorn-Hopsage) (Beatley, 1976; O'Farrell and Collins,1984). Each association is actually a mosaic of sub-associations consisting of dominant, co-dominant, and less abundant species of shrubs, grasses, and forbs; however, each association generally has similar physical characteristics and species composition that tend to differentiate it from other vegetation associations.

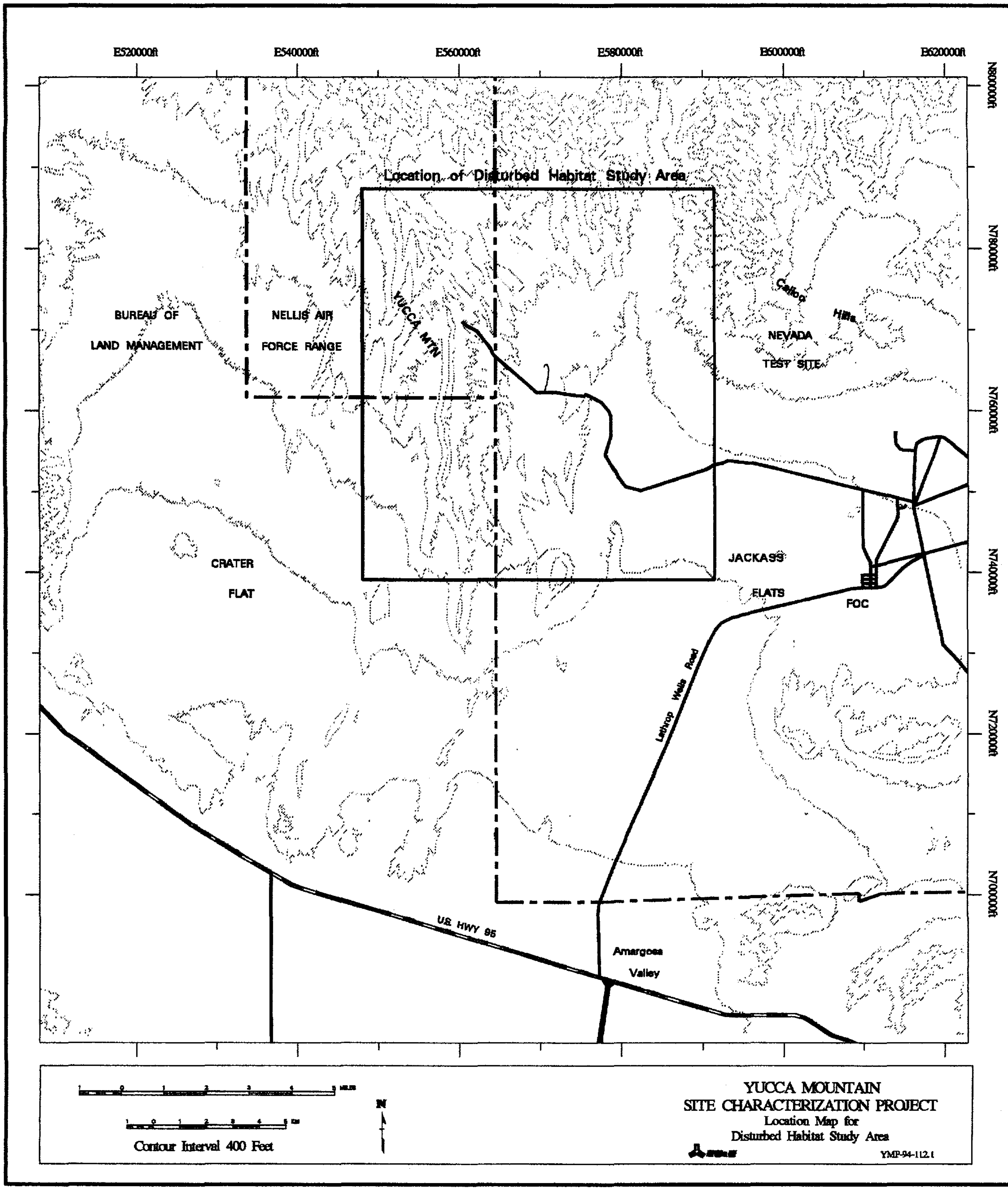


Figure 1. Location of Yucca Mountain, the disturbed habitat study area, and major topographical features.

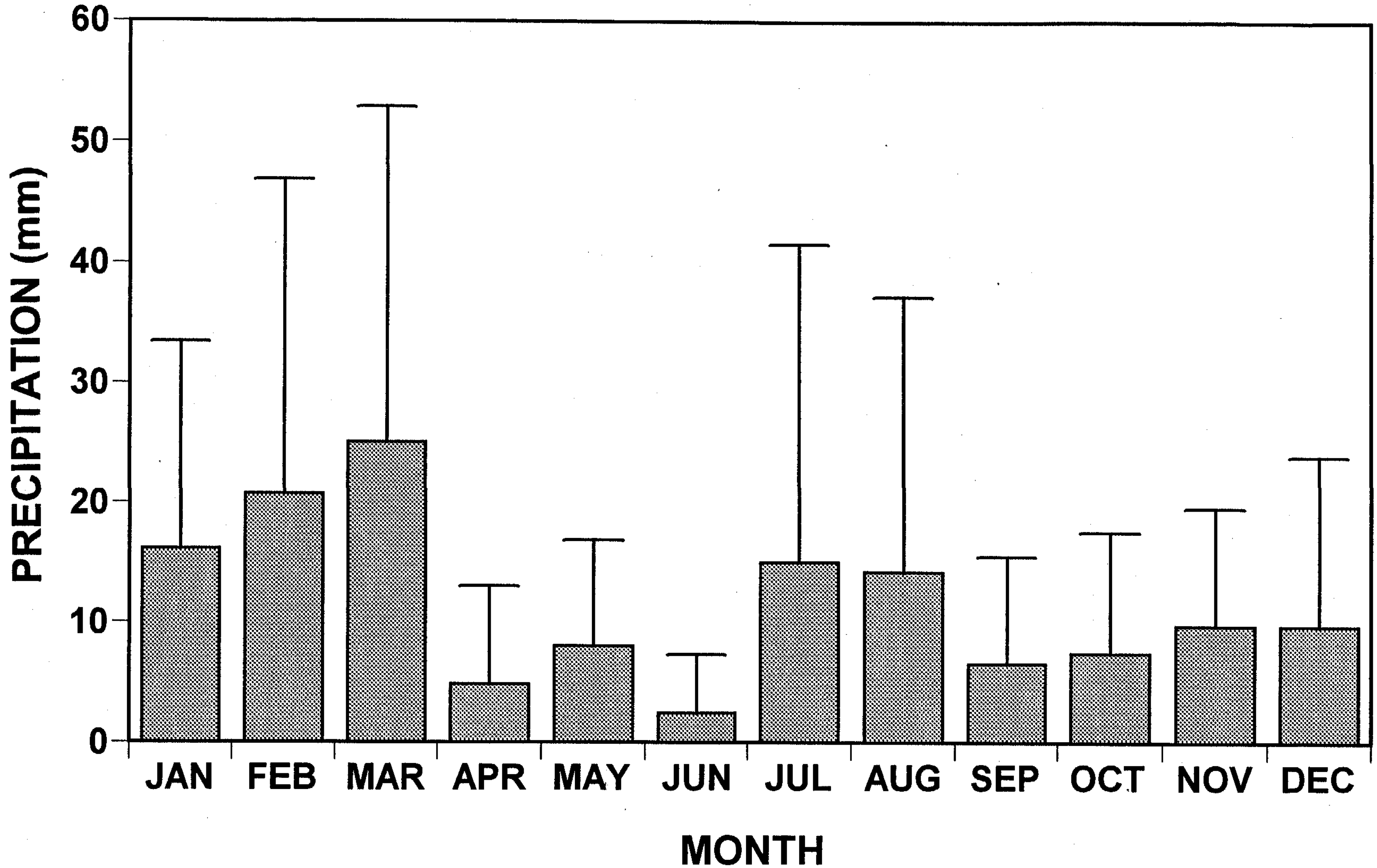


Figure 2. Mean monthly precipitation (±SD) for gauge 4JA in Area 25 of the Nevada Test Site. Means were averaged between 1968 and 1992.

4.O MATERIALS AND METHODS

During 1991, disturbances that were created prior to 1987 at Yucca Mountain were inventoried to determine their suitability for use in this study. Sites were chosen if the size and shape of the disturbance would accommodate a sufficient number of transects. Also, sites chosen were not active disturbances. Fifty-seven disturbed sites (Figure 3) were selected across all vegetation associations and the sites were classified by disturbance types (i.e. drill pads, cutslopes, etc.) that occur in the Yucca Mountain area.

Line and belt transects were established and quantitative vegetation measurements of cover and density were collected during July through October in 1991 and 1992. Depending on the size of the disturbance area, three to six line and belt transects were established. Transects were established at random distances from a defined baseline edge, and at one random distance from an edge perpendicular to the baseline edge (Figure 4). Line transects for cover measurements were 20-m long and were generally established parallel to each other with distances between them exceeding 3 m. Transects were installed perpendicular and downhill (if sloping) to the perceived direction of water runoff (Figure 4). Belt transects (2 x 20 m) for density measurement were adjacent to each line transect.

4.1 DENSITY

For disturbance areas, density sampling occurred in belt transects (2 x 20 m) adjacent to each 20-m cover transect. Each belt transect was divided into ten 2- x 2-m quadrats. Live perennial species present in each quadrat (annual species were not recorded) were counted and summed. The summed values for a species were divided by the quadrat size and density was expressed as plants/m^2.

As with cover, 1992 density measurements from the ESPs were used for undisturbed area density. Density measurements collected on ESPs were similar to that of disturbance areas except that sampling occurred on eight to ten 2- x 50-m belt transects containing twenty-five 2- x 2-m quadrats. As with disturbed areas, density was expressed as plants/m^2.

4.2 COVER

Within disturbed areas, at 1-m intervals a long each line transect, five points were sampled using the ocular point cover technique. The ocular point cover technique was used because it has greater accuracy, improved efficiency, repeatability, and reduced sampler error (Buckner, 1985). One hundred points were sampled on each transect. When the ocular point intersected any living plant tissue, the plant species was recorded. If the point intersected dead plant material (e.g., a dead branch on a living plant) litter was recorded. If ground cover was intersected, either bare ground, gravel (0.5 to 8 cm size fraction), cobble (8 to 25 cm), or rock (>25 cm) was recorded. The number of points for each species or ground cover attribute were summed and divided by the total number of points for each transect and expressed as a percentage.

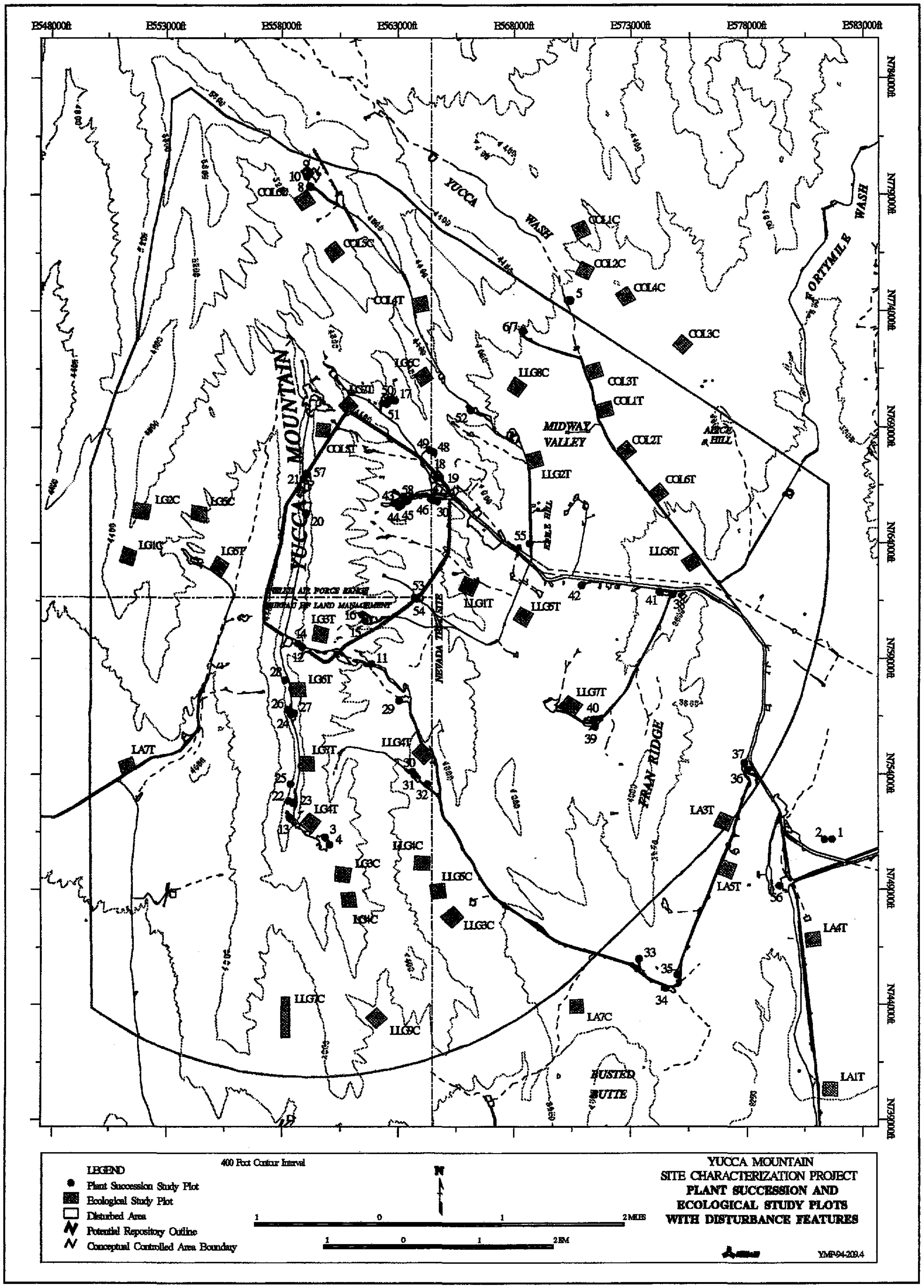


Figure 3. Location of plant succession study plots (disturbed sites) and Ecological Study Plots (ESPs; undisturbed sites) used for plant density and cover data collection at Yucca Mountain, NV.

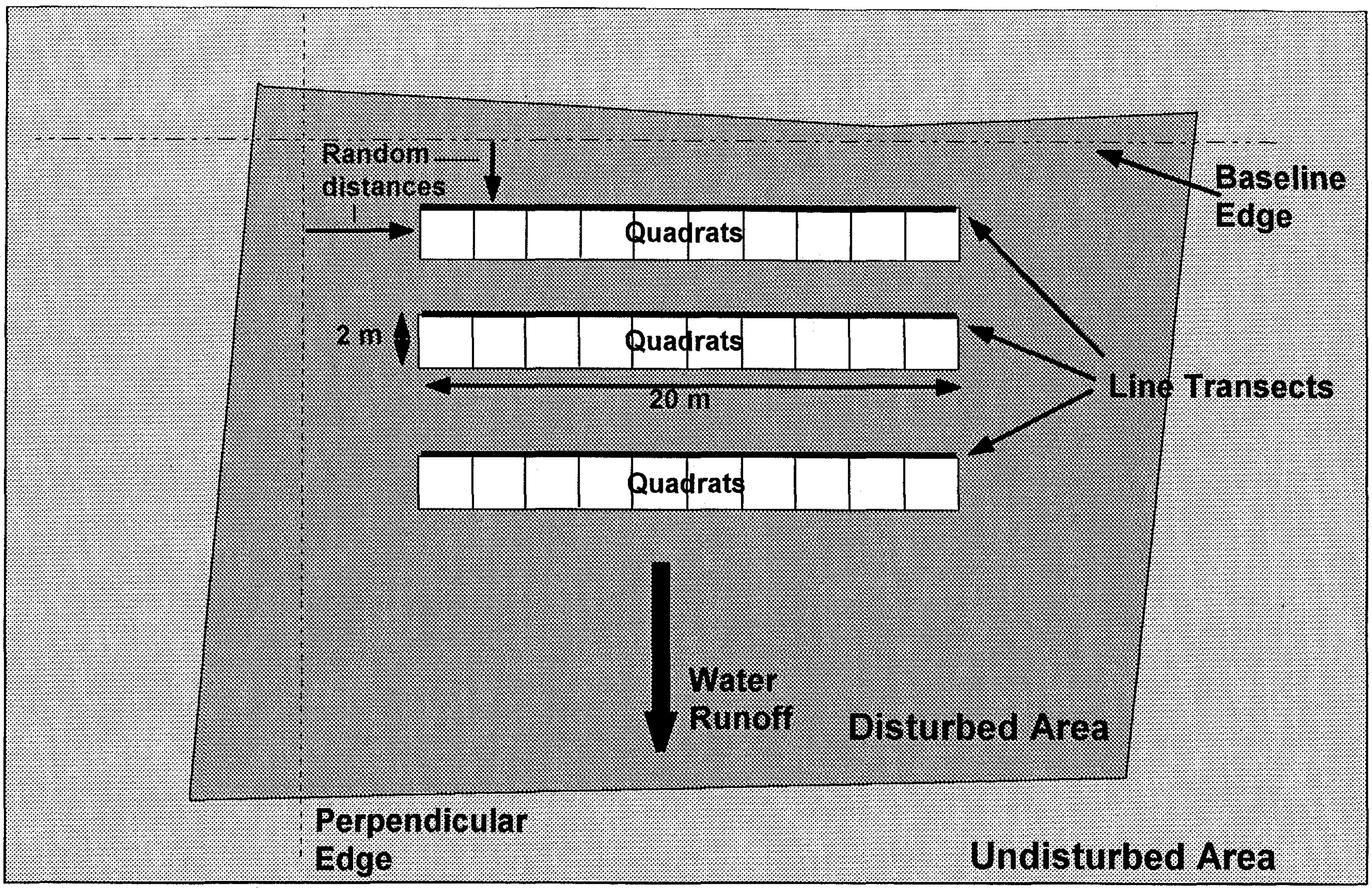


Figure 4. Generalized layout of transects and quadrats for cover and density measurements on disturbed areas at Yucca Mountain.

Cover measurements collected in 1992 on the 48 Ecological Study Plots (ESPs) (Figure 3) as part of site characterization effects studies on vegetation were used as the undisturbed cover values to allow comparisons to be made with disturbed areas. Cover sampling on ESPs was similar to that in disturbed areas except that sampling occurred on eight to ten 50-m line transects randomly located within each ESP.

4.3 ENVIRONMENTAL VARIABLES

After transects were established, site characteristics of the disturbed areas were recorded. Elevation, slope, aspect, size of the disturbance, and vegetation association of adjacent undisturbed areas were recorded for each site. Age of the disturbance was determined by site atlas records and phone interviews with supervisors for the construction activity that occurred on a particular disturbed area. Precipitation amounts since cessation of disturbance were calculated from daily precipitation at NTS gauge 4JA in Area 25.

At each disturbed site, soil samples were collected along each transect for soil physical and chemical properties analysis. Depending on uniformity of the soil, soil down to 30 cm, or to bedrock, whichever was shallower, was collected at one or more locations along the transect and combined into a sample that represented the transect. A random portion of each transect sample was removed and combined with the other transect samples at each site. This combined sample represented the site soil sample and was sent to Utah State University Soil Testing Laboratory in Logan, UT for analysis. Specific physical properties analyzed included: percent sand, silt, and clay and percent gravel >2 mm. Specific chemical properties analyzed included: pH; electrical conductivity; water soluble calcium, magnesium, and sodium; sodium absorption ratio; NH_4 extractable calcium, magnesium, and sodium; phosphorus; nitrate-nitrogen; potassium; organic matter; cation exchange capacity (CEC); and exchangeable calcium, magnesium and sodium.

In order to determine degree of compaction and soil penetrability at each disturbed site, soil penetrometer readings were obtained. Two types of penetrometers were used. A depth penetrometer was used to record the depth of penetration into the soil surface. A cone penetrometer was used to record the penetration resistance (kg/cm2) of the soil surface. Penetrometer readings were taken at 2-m intervals along each transect, within each disturbed area. Penetrometer readings were averaged across transects within a disturbed site and the average was used as the penetrometer value for a site.

4.4 STATISTICAL ANALYSES

For disturbed sites and undisturbed (ESPs) sites, individual quadrats acted as the experimental unit for calculation of density, and individual transects acted as the experimental unit for calculation of cover in the statistical analyses. For comparisons of sites, vegetation associations, and disturbance types, means and standard errors were calculated from the density and cover values for the experimental units.

Individual disturbed sites acted as the experimental unit for analyses used to explore relationships among site density and cover, and environmental variables. Individual sites were chosen as experimental units for these analyses because soil analyses were for individual sites and because environmental variables such as elevation, slope, aspect, age and precipitation generally do not change from one quadrat or transect to another. CANOCO, a multivariate statistical package, was used to examine relationships among individual disturbed sites and their associated environmental variables. CANOCO uses canonical correspondence analysis (CCA) ordination (a method of arranging plant species or sites relative to their similarity to each other or to associated environmental factors (Kent and Coker,1992)) and multiple regression (ter Braak, 1986) to relate patterns of similarity in sites or plant species with environmental variables that are correlated to this pattern (Kent and Coker,1992). CANOCO then tests the significance of this relationship using a Monte Carlo permutation test (ter Braak, 1986).

4.5 DOMINANCE DIVERSITY CURVES

Dominance-diversity (also know as rank-abundance) curves were used to examine the successional status of disturbed sites compared to that of undisturbed sites. A dominance-diversity curve integrates species richness, diversity, and evenness (how equal species abundances are to one another) into one diagram and allows comparisons of these attributes to other sites. The curve is a plot of the relative or proportional abundances of species for a site or sites on a log scale against their rank from most to least abundant, thus forming a curve that can be used in describing the evenness of species distribution and relative species dominance (Kent and Coker, 1992). If a site has a dominance diversity curve that is comparable to that of another site, then the sites are relatively close in their successional status. However, if the species on one site has completely different species ranks and shape of the dominance-diversity curve than that of another site, this may indicate that these sites are in different successional trajectories.

4.6 SUCCESSION RATE CALCULATIONS

For this report, successional rate will be defined as the time required (in years) for a given vegetation parameter at a disturbed site to recover to a point that meets or exceeds that of adjacent undisturbed areas. Generally, in past studies of succession in the Mojave desert, the succession rate was calculated from the ratio of undisturbed to disturbed cover, density or biomass multiplied by the age of the disturbed site (e.g. Vasek et al., 1975a b; Lathrop and Archbold, 1980; Webb and Wilshire, 1980; Lathrop, 1983; Webb et al., 1988). The assumption behind this calculation is that the relationship between disturbed site age and the amount of a vegetation parameter is linear. In actuality, the relationship could be linear, exponential, or logarithmic due to species composition and environmental factors at a site. Vasek et al. (1975b) state that the relationship between age and a vegetation parameter is most likely not a linear relationship because plant growth curves are usually sigmoidal. The authors conclude that linear estimates are crude and are "far too optimistic". The linear calculation, based on the disturbed to undisturbed vegetation parameter ratio, is used by many researchers because of the lack of data points to conduct regression. Many of these studies represent the status of a disturbed site at a single point in time; therefore, only two data points can be regressed, time zero and the time at which data are collected.

In this study, the linear relationship was used to determine succession rates of individual species because this was a single point in time study and the window of disturb site ages was narrow (7 to 13 years since disturbance). Because of these two limitations, there were insufficient data points to conduct a statistically significant regression for individual species. Individual species succession rates were calculated by multiplying the cover or density undisturbed to disturbed ratio for a species by the average age of the disturbed sites.

Because succession rates calculated from the undisturbed to disturbed ratio is viewed as a crude and optimistic estimate, the succession rate for all sites was determined by conducting linear and nonlinear (logarithmic function) regression on disturbed site age and disturbed site perennial plant cover. The assumption was made that at zero time, cover of all disturbances was also zero. The resulting regression equations were then used to extrapolate the amount of time required for disturbed sites to reach the cover of undisturbed sites.

5.0 RESULTS

Data on perennial plant density, perennial plant cover, annual plant cover and various cover attributes (bare ground, rock, litter, etc) were analyzed to determine vegetational characteristics of disturbed sites at Yucca Mountain. These characteristics were compared and contrasted to the surrounding undisturbed vegetation to determine the rate of recovery and the successional status of the disturbed areas. Disturbed area vegetation data were also analyzed to examine influences of environmental variables on disturbed site succession. Vegetation associations and disturbance types were investigated to determine their influence on patterns of vegetation at disturbed sites.

5.1 VEGETATION CHARACTERISTICS OF DISTURBED vs. UNDISTURBED SITES

5.1.1 DENSITY

Total perennial plant density means were 30% greater in undisturbed areas when compared to disturbances (Figure 5). Average shrub and grass density was higher in undisturbed areas than in disturbances; however, average forb densities were 200% greater in the disturbances (Figure 5). Plant species having the highest mean density across all disturbed sites were *Chrysothamnus teretifolius*, *Gutierrezia sarothrae*, *Ambrosia dumosa*, *Stephanomeria pauciflora*, and *Eriogonum inflatum* (Figure 6). With the exception of *A. dumosa,* these species generally had low mean densities in the undisturbed areas. *Ephedra nevadensis* , *Coleogyne ramosissima*, *Menodora spinescens*, *Haplopappus cooperi*, and *Lycium andersonii* had high mean densities across all undisturbed areas, but were minor components of the vegetation in disturbed areas (Figure 6).

5.1.2 COVER

Total perennial plant cover results were similar to that of density. Mean perennial plant cover on disturbed sites was 37% less than that of undisturbed sites (Figure 7). Mean shrub, forb and grass cover on disturbed area was 1.5 to 2.2 times less than that on undisturbed sites (Figure 7). *A. dumosa*, *C. teretifolius*, *Hymenoclea salsola*, *G. sarothrae*, *Atriplex canescens*, and *Atriplex confertifolia* had the highest mean plant cover in the disturbed areas (Figure 8). Of these species, *C. teretifolius, G. sarothrae,* and *A. canescens* were minor components in the undisturbed areas; however, average cover of *H. salsola* and *A. confertifolia* at disturbed sites was comparable to that of undisturbed areas (Figure 8). As with density, the species having highest cover means across all undisturbed areas were *A. dumosa*, *E. nevadensis*, *C. ramosissima, M. spinescens*, and *L. andersonii* with the additions of *Larrea tridentata* and *Grayia spinosa* (Figure 8). Perennial species richness (number of separate species) was greater on undisturbed sites (Figure 9). Fifty eight perennial species were found across all undisturbed sites, whereas 43 species were found across all disturbances.

Bare ground, gravel, and cobble cover means were greater in disturbed areas. In contrast, plant litter cover was greater in the undisturbed areas (Figure 7). These differences are a

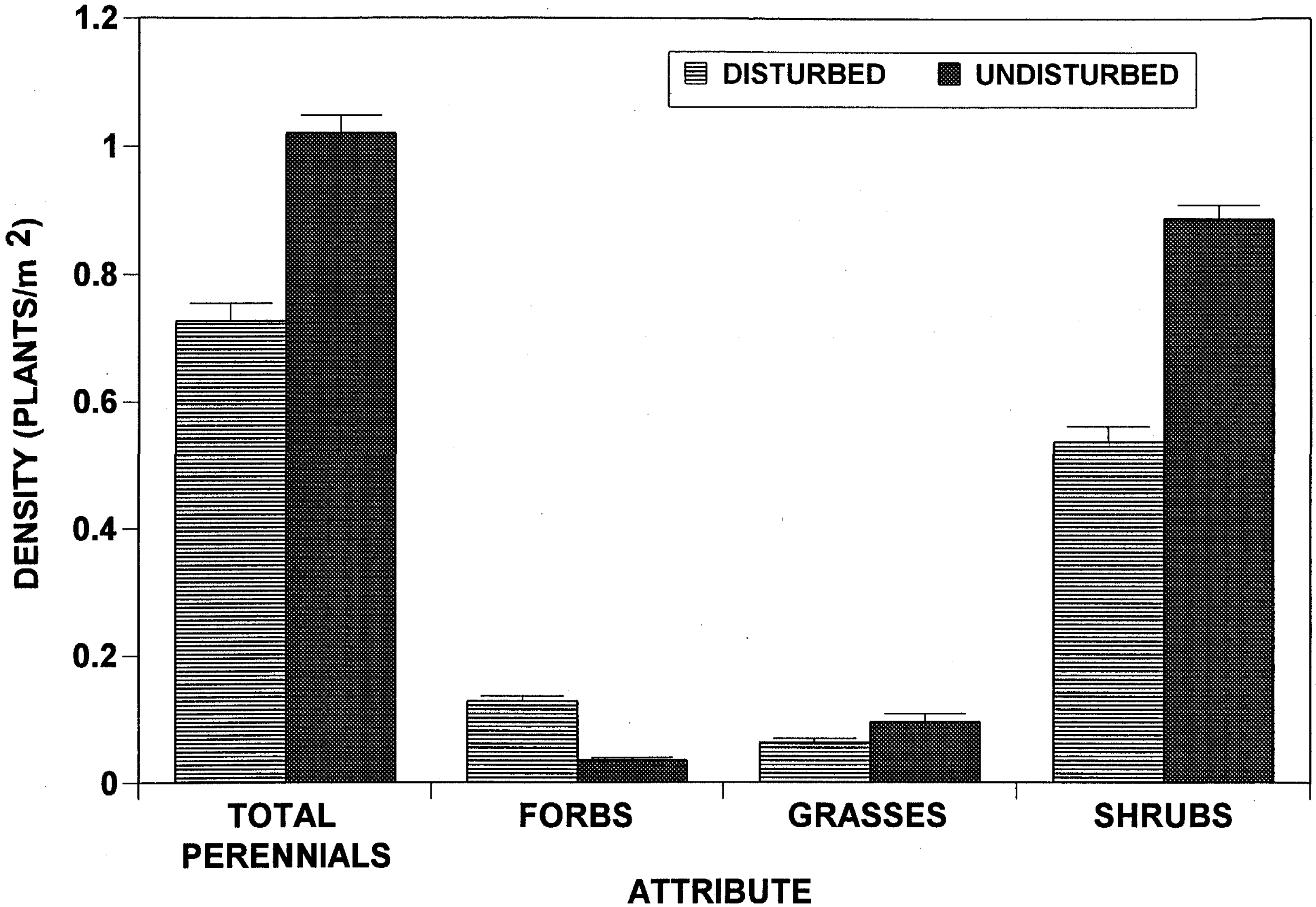


Figure 5. Mean density (±SE) of total perennials, forbs, grasses and shrubs found on all disturbed and undisturbed sites inventoried in the disturbed habitat study at Yucca Mountain, NV.

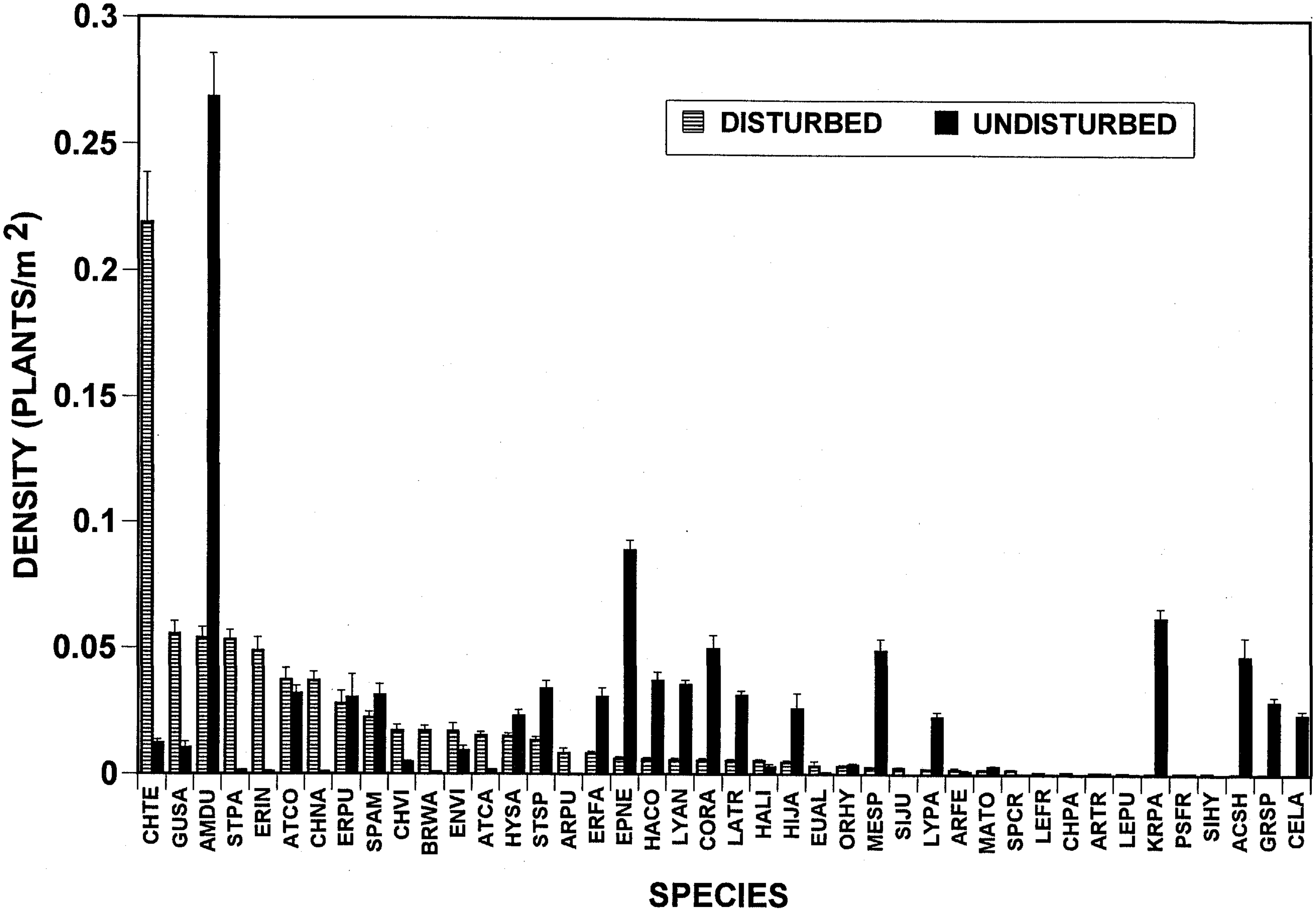


Figure 6. Mean density (± SE) of perennial plants found in disturbed and undisturbed sites at Yucca Mountain, NV. Species with densities less than 0.0003 plants/m2 are not shown. See Appendix Table 1 for species code information.

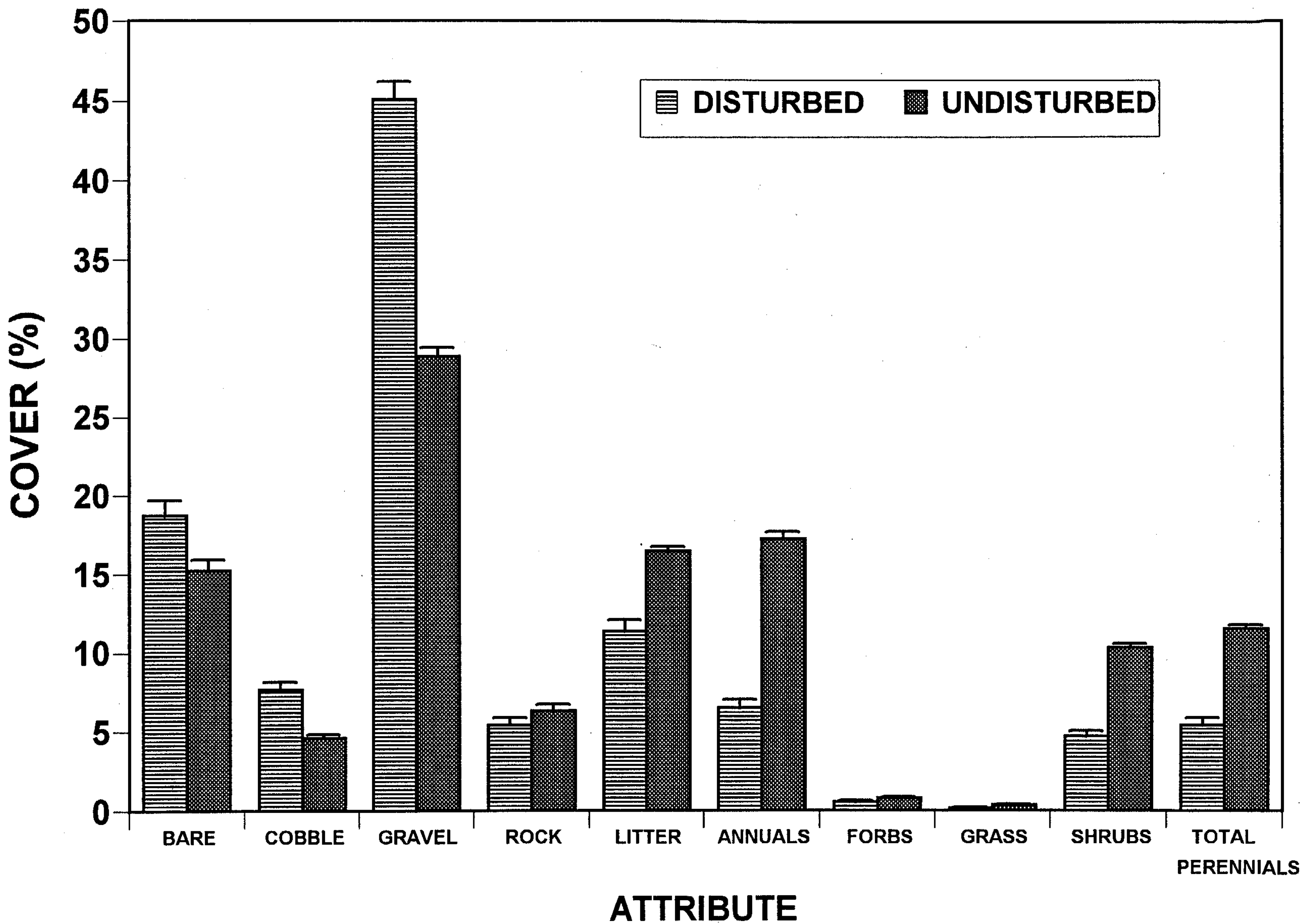


Figure 7. Mean cover attributes (±SE) for all disturbed and undisturbed sites inventoried for the disturbed habitat studies at Yucca Mountain, NV.

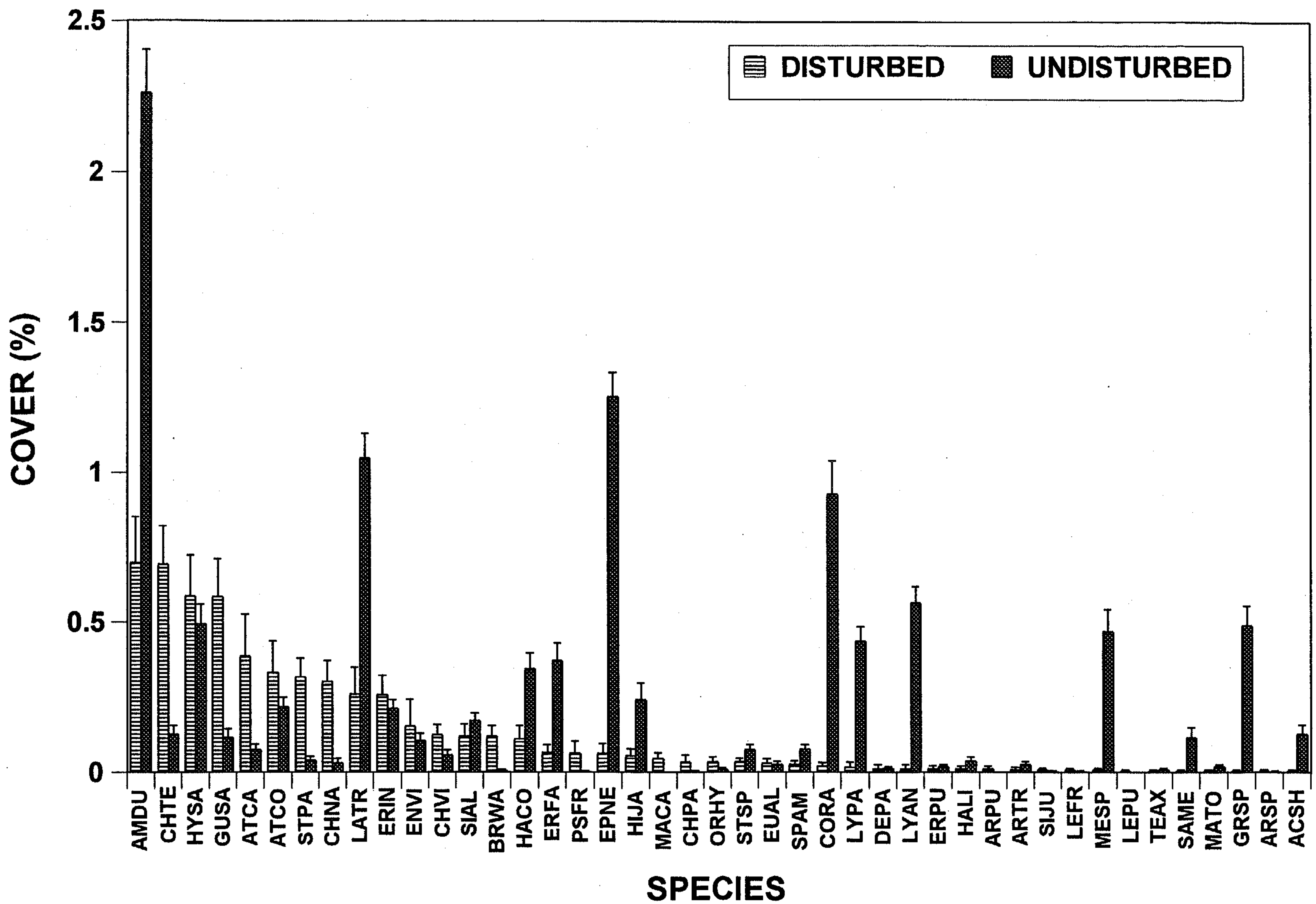


Figure 8. Mean cover (±SE) of perennial plant species found across all disturbed and undisturbed sites inventoried for the disturbed habitat studies at Yucca Mountain, NV. Eighteen species found on undisturbed sites but not on disturbed sites are not shown. For explanation of species codes, see Appendix Table 1.

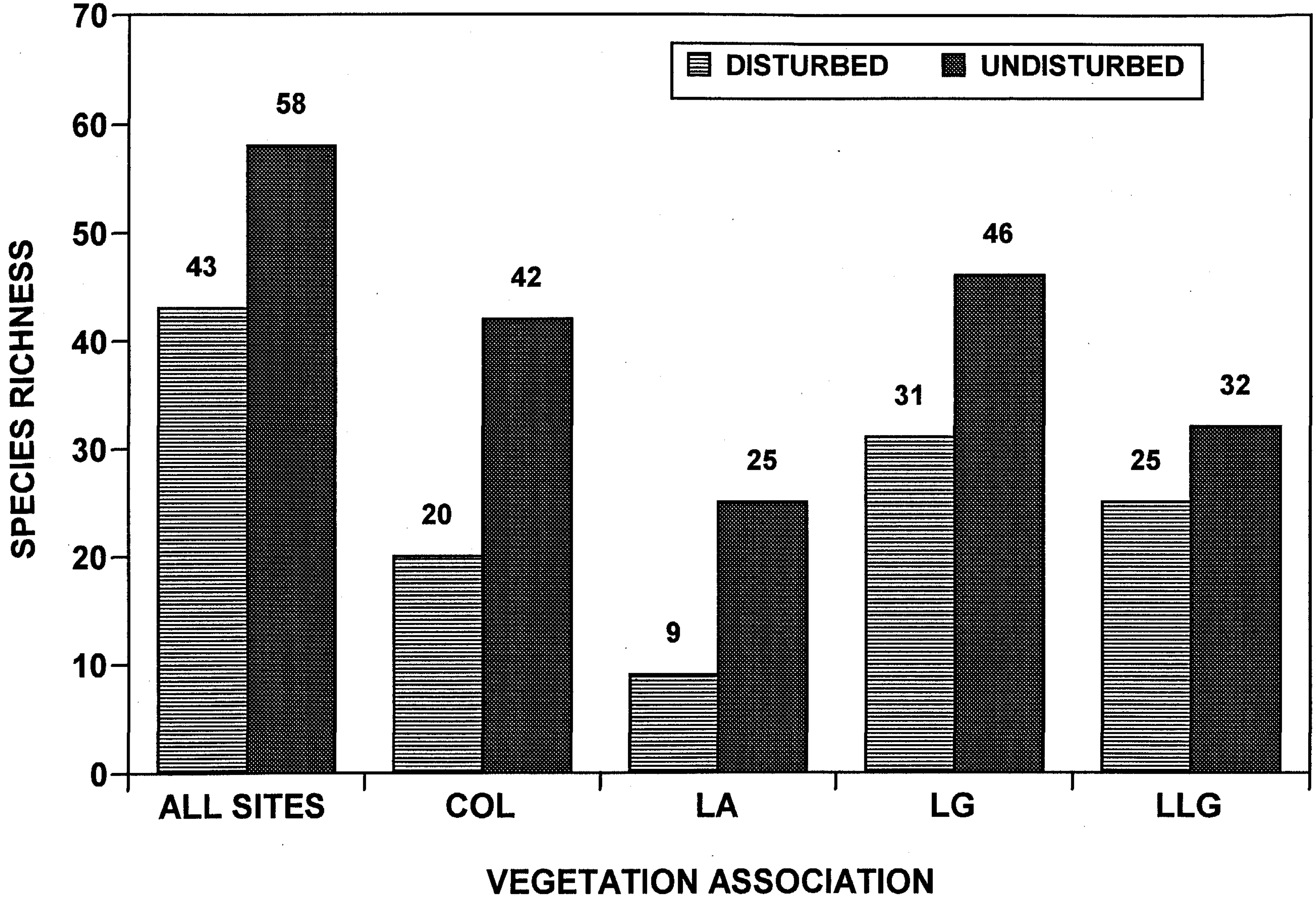


Figure 9. Species richness (number) of perennial plant species found across all disturbed and undisturbed sites and in the *Coleogyne* (COL), *Larrea-Ambrosia* (LA), *Lycium-Grayia* (LG), and *Larrea-Lycium-Grayia* (LLG) vegetation associations at Yucca Mountain, NV.

reflection of the effects that soil and vegetation disturbance have on these cover attributes. The scraping or removal of soil at the time of disturbance has led to decreases in plant litter due to the destruction of the perennial vegetation.

Average annual plant cover was surprisingly greater on the undisturbed areas when compared to disturbed areas (Figure 7). This may be a artifact of the data collection. Annual species data on undisturbed areas was collected during the early spring, when many of the annual plants were actively growing. Annual plant cover on the disturbed sites was collected during the summer and early fall when many of the annuals probably had died and disappeared by this time. Another reason for the larger amount of annual cover on the undisturbed areas may be the influence of *Bromus rubens*, which had the highest plant cover on undisturbed sites (Figure 10). This cover mean was almost 3 times greater than *Salsola iberica* which had the highest annual plant cover in disturbed areas. *S. iberica, Eriogonum deflexum*, and *Halogeton glomeratus* had the highest annual plant cover in the disturbed sites, but were minor components or completely absent from undisturbed sites (Figure 10). *B. rubens* and *Amsinckia tessellata* had the highest cover in undisturbed areas, and were major components of the annual plant densities in disturbed sites (Figure 10).

5.1.3 SUCCESSION RATES

Using the perennial cover means for all disturbed and undisturbed sites, secondary succession rates were estimated using linear and non-linear (logarithmic function) regressions (Figure 11). The linear regression is meant to represent an "optimistic" rate and the logarithmic function regression is meant to represent a probable succession rate since this function is more representative of plant growth and successional processes. An extrapolation of the linear regression indicated that perennial cover on disturbances would reach that of undisturbed areas after 20 years. Extrapolation with the logarithmic function indicated that disturbed site perennial cover will be 80 percent of the undisturbed site cover after 130 years, 90 percent after 330 years, and 100 percent after 845 years. The gap in the number of years required for disturbed sites to achieve 100 percent cover of the undisturbed sites for the linear and logarithmic estimates is quite large and a result of the differences in these functions. For the linear function, the increase in perennial cover is equal over time. However, for the logarithmic function, perennial cover increases at an increasing rate during the first three years, then increases at a decreasing rate for the remaining time. The results of the regressions in Figure 11, whether linear or logarithmic, should be interpreted with caution. The succession rates depicted are for total perennial cover of the disturbed and undisturbed sites and does not take into consideration what species comprise the cover of the sites.

For individual species across all sites, estimated succession rates calculated from the ratio of undisturbed to disturbed cover/density multiplied by the average age of the disturbed sites were quite variable (Table 1). For example, the estimated succession rate for A. dumosa and *L. tridentata* cover to approach that of undisturbed sites was 31 and 39 years, respectively. However, rates for *C. ramosissima, L. andersonii,* and *G. spinosa* were 418, 425 and 1,101 years, respectively. Species such as *A. confertifolia* and *H. salsola* had

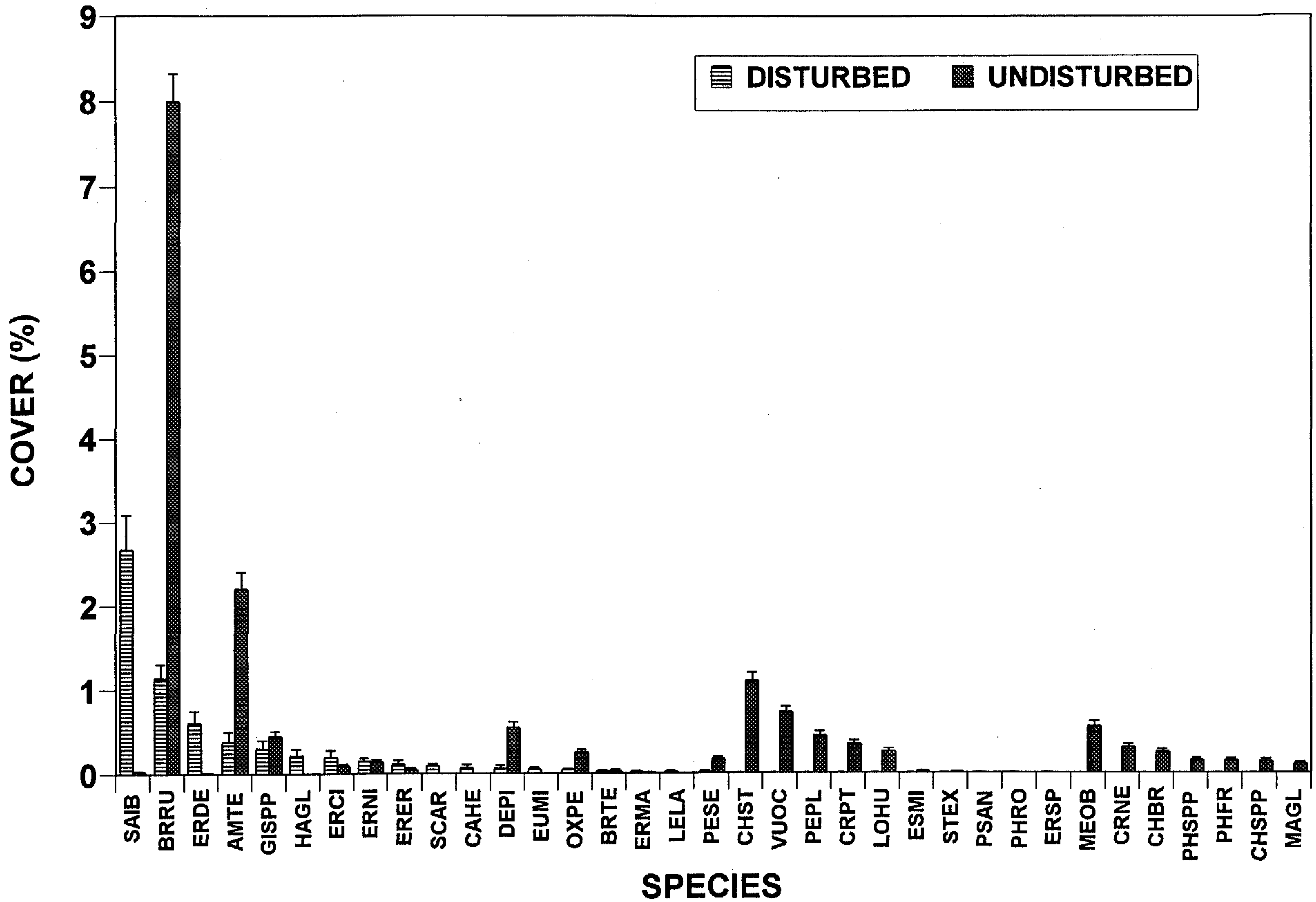


Figure 10. Mean cover (±SE) of annual plant species found across all disturbed and undisturbed sites inventoried for the disturbed habitat studies at Yucca Mountain, NV. Seventeen species having cover values less than 0.1 % are not shown. For explanation of species codes, see Appendix Table 1.

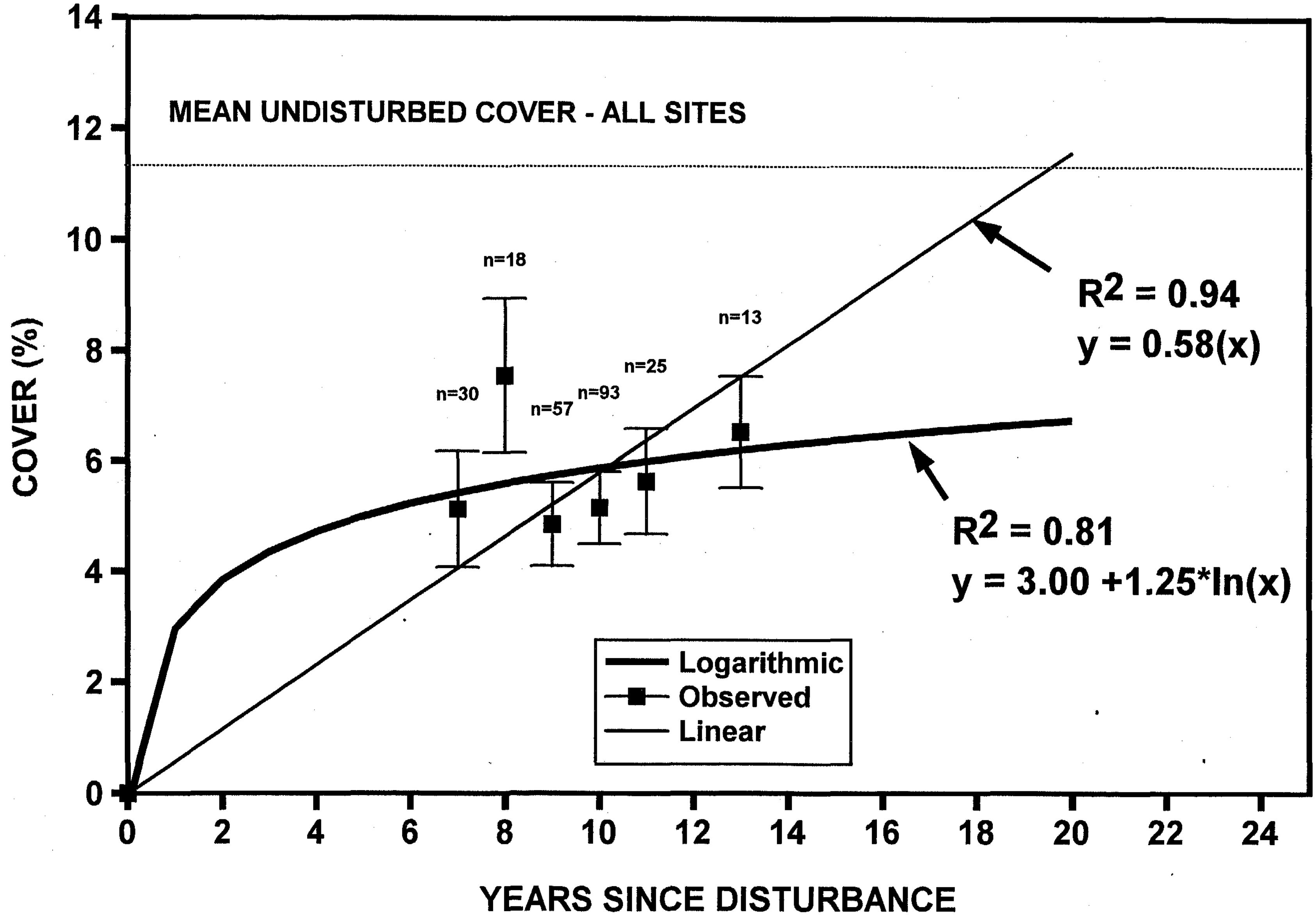


Figure 11. Linear and logarithmic regressions of the relationship between disturbed site cover (mean ±SE) and years since disturbance. Regression equations were used to estimate succession rates for disturbances.

Table 1. Estimated rates of succession (years) for perennial plant species found in disturbed and undisturbed sites at Yucca Mountain, NV. Rates were calculated by multiplying the ratio of undisturbed to disturbed cover or density by the average age of the site. Succession rates are given for individual species averaged across sites and within the *Lycium-Grayia* (LG), *Larrea-Lycium-Grayia* (LLG), *Coleogyne* (COL), and the *Larrea-Ambrosia* vegetation associations. Succession rates based on perennial plant density are for all sites combined. Species having a "?", indicate that this species occurred in the undisturbed area but not in the disturbed area represented by the column, therefore a rate cannot be determined. Species having a blank indicate that they did not occur in either the disturbed or undisturbed areas represented by the column.

		Cover					Density
Scientific name	Species Code	All Sites	LG	LLG	COL	LA	All Sites
Acamptopappus shockleyi	ACSH	287	?	?		109	1487
Ambrosia dumosa	AMDU	31	65	14	471	16	48
Aristida longiseta	ARFE		6				
Aristida purpurea	ARPU	0	0				0
Artemesia spinescens	ARSP	5	0	?			25
Artemesia tridentata	ARTR	29	?		0		9
Astragalus layneae	ASLA	?			?	?	?
Atriplex canescens	ATCA	2	8	4	0		1
Atriplex confertifolia	ATCO	6	16	?	16	?	8
Brickellia watsonii	BRWA	0	1	0			0
Castilleja chromosa	CACH		?				
Calochortus flexuosus	CAFL	?	?		?		?
Ceratoides lanata	CELA	?	?	?	?	?	752
Chrysothamnus nauseosus	CHNA	1	4	0	2		0
Chrysothamnus paniculatus	CHPA	1	0			1	0
Chrysothamnus teretifolius	CHTE	2	10	0	3		1
Chrysothamnus viscidiflorus	CHVI	4	15	0	8		3
Coleogyne ramosissima	CORA	418	?	?	241	?	89
Delphinium parishii	DEPA	10	?	0	?		?
Descurainia sophia	DESO		?				
Dichelostemma pulchellum	DIPU	?			?		
Echinocereus engelmanii	ECEN	?			?		?
Echinocactus polycephalus	ECPO	?	?				?
Encelia virginensis	ENVI	7	4	9	125		5
Ephedra nevadensis	EPNE	188	400	226	?	?	139
Ephedra viridis	EPVI	?	?		?		143
Eriogonum fasciculatum	ERFA	53	730	4	?	0	36
Eriogonum inflatum	ERIN	8	6	18	?	13	0
Eriogonum microthecum	ERMI		64				
Erioneuron pulchellum	ERPU	14	20	?			10
Eriogonum umbellatum	ERUM	?			?		
Euphorbia albamarginata	EUAL	8	20	7	?		2
Grayia spinosa	GRSP	1101	?	51	?	?	912

Table 1. Continued

Scientific name	Species Code	Cover					Density
		All Sites	LG	LLG	COL	LA	All Sites
Gutierrezia sarothrae	GUSA	2	7		11		2
Haplopappus cooperi	HACO	30	202	7	2	?	61
Haplopappus linearifolius	HALI	28	148		4		5
Hilaria jamesii	HIJA	42	454		5		54
Hymenoclea salsola	HYSA	8	50	5	6		15
Juniperus osteosperma	JUOS		?				
Krameria parvifolia	KRPA	?	?	?	?	?	1475
Larrea tridentata	LATR	39	93	29	?	54	56
Lepidium densiflorum	LEDE	?	?	?	?	?	
Lepidium fremontii	LEFR	3	20		0		1
Leptodactylon pungens	LEPU	0	0				6
Lycium andersonii	LYAN	425	?	66	?	?	62
Lycium pallidum	LYPA	245	?	?	?	51	108
Machaeranthera canescens	MACA	0	0	0	0		
Machaeranthera tortifolia	MATO	42	0		?	?	18
Menodora spinescens	MESP	528	?	165	14	?	179
Mirabilis bigelovii	MIBI	?	?	?			20
Muhlenbergia porteri	MUPO	?	?				?
Opuntia basilaris	OPBA		126				
Opuntia echinocarpa	OPEC		?				
Oryzopsis hymenoides	ORHY	3	3	0		?	12
Psorothamnus fremontii	PSFR	0		0		?	14
Psorothamnus polydenius	PSPO	?		?			
Salazaria mexicana	SAME	261	?	176	?		?
Sclerocactus polyancistrus	SCPO	?	?				?
Sisymbrium altissimum	SIAL	14	13	6	?	?	
Sitanion hystrix	SIHY	?	?		?		2
Sitanion jubatum	SIJU	3		?	0		0
Sphaeralcea ambigua	SPAM	29	204	3	4		13
Stephanomeria pauciflora	STPA	1	4	1	2	0	0
Stipa speciosa	STSP	21	67	?	?	?	24
Tetradymia axillaris	TEAX	21	?	?	?	0	?
Yucca brevifolia	YUBR	?			?		4
Average site age		9.6	9.4	9.6	10.4	9.4	9.6

succession rates of 6 and 8 years, respectively, indicating how quickly these species recover from disturbance. Again, these estimates are based on the assumption that the rate of succession is linear, so these values should be interpreted as optimistic.

5.2 ENVIRONMENTAL CHARACTERISTICS OF DISTURBANCES

For determination of the influence of important environmental variables on disturbed site plant succession, perennial plant cover was chosen as the analysis variable. Perennial plant cover was chosen over density and total plant cover because it does not fluctuate widely from year to year. Total plant cover fluctuates yearly due to the influence of annual plants, and plant density numbers can be skewed by an abundance of seedlings in one year that may die before the next year. Therefore, perennial plant cover is probably the best variable for point in time comparisons such as in this study. Also, perennial plant cover integrates plant frequency, density, and size (canopy area) into one analysis variable.

5.2.1 SITE CHARACTERISTICS

Using the perennial plant cover species means and the mean values for environmental variables for individual sites, ordination was conducted to determine patterns of similarity in sites and the environmental variables that influence these patterns. Canonical correspondence analysis (CCA) ordination indicated that elevation, soil potassium, percent sand in the soil, percent gravel >2 mm in the soil, and soil penetration resistance (compaction) were significant ($p < 0.05$) environmental variables (Figure 12). In Figure 12, a biplot of the sites and influencing environmental variables is presented. The disturbed sites are represented by geometric shapes in the graph. The closer the sites are to each other, the more similar they are in regard to perennial plant species composition and abundance. The greater the distance between the sites on the graph, the more dissimilar they are, thus having differing species composition and abundances. The arrows projecting from the origin are the correlated environmental variables and are indicative of the direction and proportion of maximum change of the environmental variable (Kent and Coker, 1992). The greater the length of the arrow, the greater the amount of change in the environmental variable for that direction (thus, the arrow can be projected backward for change in that direction) and the more highly correlated that variable is to the site ordination. If lines are drawn perpendicular from the projection of a particular environmental variable arrow toward each of the sites, the sites having perpendiculars close to or past the end of the environmental variable arrow are more closely correlated to that variable. The variability in disturbed sites in relation to the dominant environmental variables can be seen in the CCA biplot. A portion of the sites were correlated to low elevations with high soil potassium and sand content (e.g. sites 1, 35, 39, 40, and 56). Other sites were highly correlated with high elevations and compacted soils (e.g. sites 8, 13, and 10).

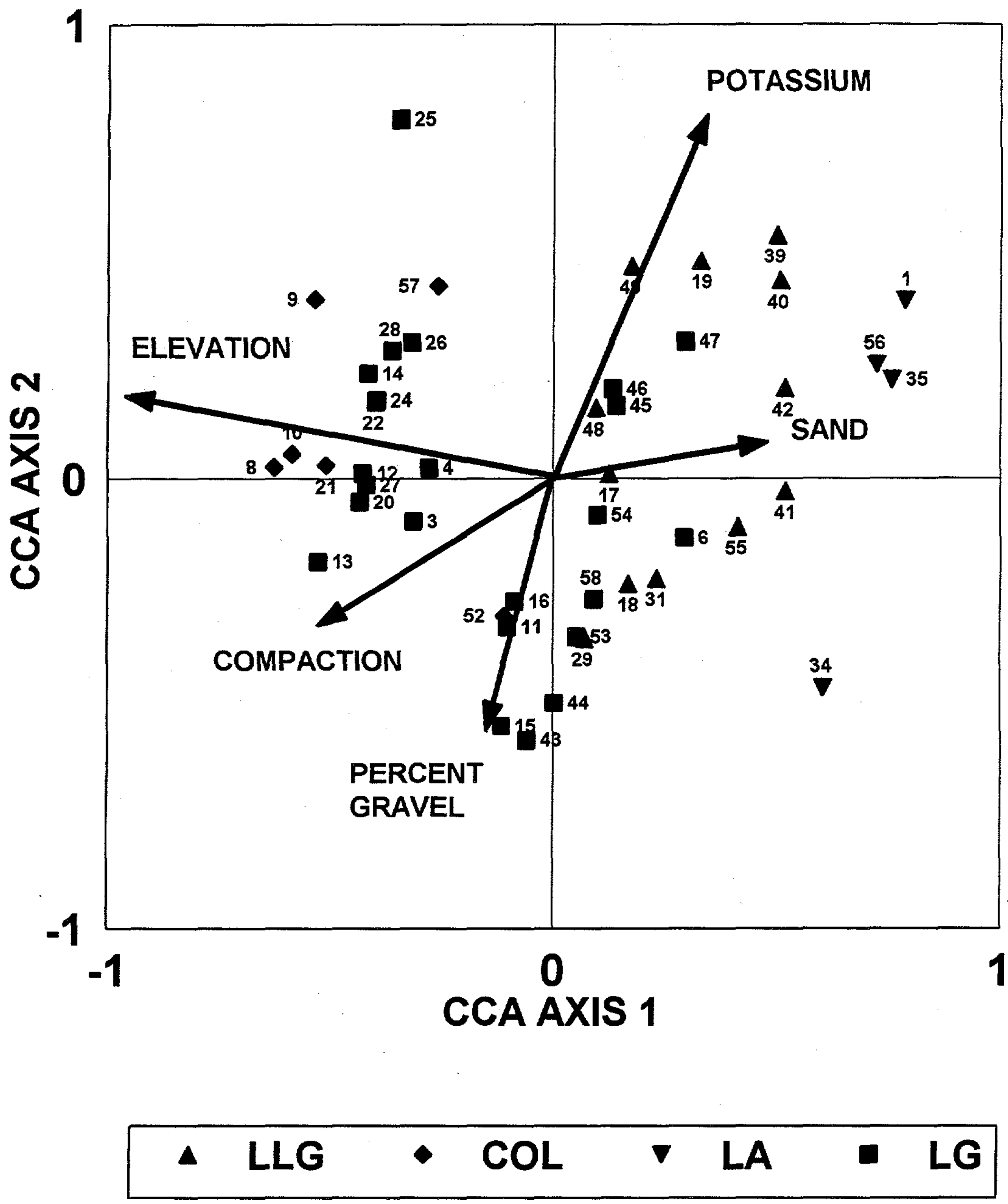


Figure 12. Canonical correspondence analysis (CCA) biplot for disturbed sites and significant environmental variables for Yucca Mountain, NV. Sites are classified by the vegetation association in which they occurred (*Larrea-Lycium-Grayia* =LLG, *Coleogyne* = COL, *Larrea-Ambrosia* = LA, and *Lycium-Grayia* = LG). For location of the sites, see Figure 3.

5.2.2 SPECIES CHARACTERISTICS

The influence of environmental variables on the plant species ordination is presented in Figure 13. The influence of a particular variable on a species can be interpreted the same as described above for sites. *Acamptopappus shockleyi*, *L. andersonii, L. tridentata,* and *A. dumosa* occupied disturbed sites at low elevations, with sandy soils having relatively high potassium. In contrast, *C. ramosissima, Artemisia spinescens*, *Haplopappus linearifolius*, *Machaeranthera canescens*, and *A. canescens*, inhabited disturbed sites at higher elevations having low percentages of sand and potassium in the soil. *Brickellia watsonii*, *Erioneuron pulchellum*, *Lepidium fremontii*, and *Chrysothamnus nauseosus* were more prevalent on disturbed sites having high percentages of gravel > 2 mm, low soil penetrability, and low soil potassium (Figure 13). *Delphinium parishii* and *Psorothamnus fremontii* occupied disturbed sites having high percentages of sand and potassium in the soil, high soil penetrability and small amounts of gravel. Notice that species such as *C. teretifolius, H. salsola, E. inflatum,* and *S. pauciflora* that had relatively high cover values in the disturbed areas (Figure 8) are clustered near the origin. This may indicate that these species occur in a variety of disturbances, and are not strongly influenced by a particular environmental variable.

The environmental variables presented in Figures 12 and 13 were by no means the only variables influencing species composition and abundance on disturbed sites. These environmental variables were correlated with other variables (see Appendix Table 2); however, those shown in the diagrams had the highest correlations with the species and site CCA ordinations.

5.3 CHARACTERISTICS OF DISTURBANCES WITHIN VEGETATION ASSOCIATIONS

The influence of environmental variables on site species composition and mean cover was highly variable among sites (Figure 12). Because of this high variability, characteristics of disturbances at Yucca Mountain are not equal and cannot be treated as such when planning revegetation. Because much of the vegetation work at Yucca Mountain has been conducted on a vegetation association scale, it may be appropriate to examine disturbance characteristics within vegetation associations. Vegetation associations are plant assemblages having similar species composition and physiognomic characteristics. Vegetation associations have similar soils, moisture, and temperature regimes that have allowed similar plants species to grow and thrive. In Figure 12, the vegetation association of each site is represented. As one moves left to right on the graph, the vegetation associations generally follow the elevational gradient represented by the arrow projection. This elevational gradient integrates the soil, moisture, and temperature differences that exist as one moves from high to low elevation, partially explaining the grouping of vegetation associations along the elevational gradient. Since the elevation/vegetation association gradient appeared to play a strong role in the species composition and abundance at disturbed sites, sites were categorized by vegetation association and CCA ordinations were conducted to determine what environmental factors influence plant species composition and abundance within the separate vegetation associations.

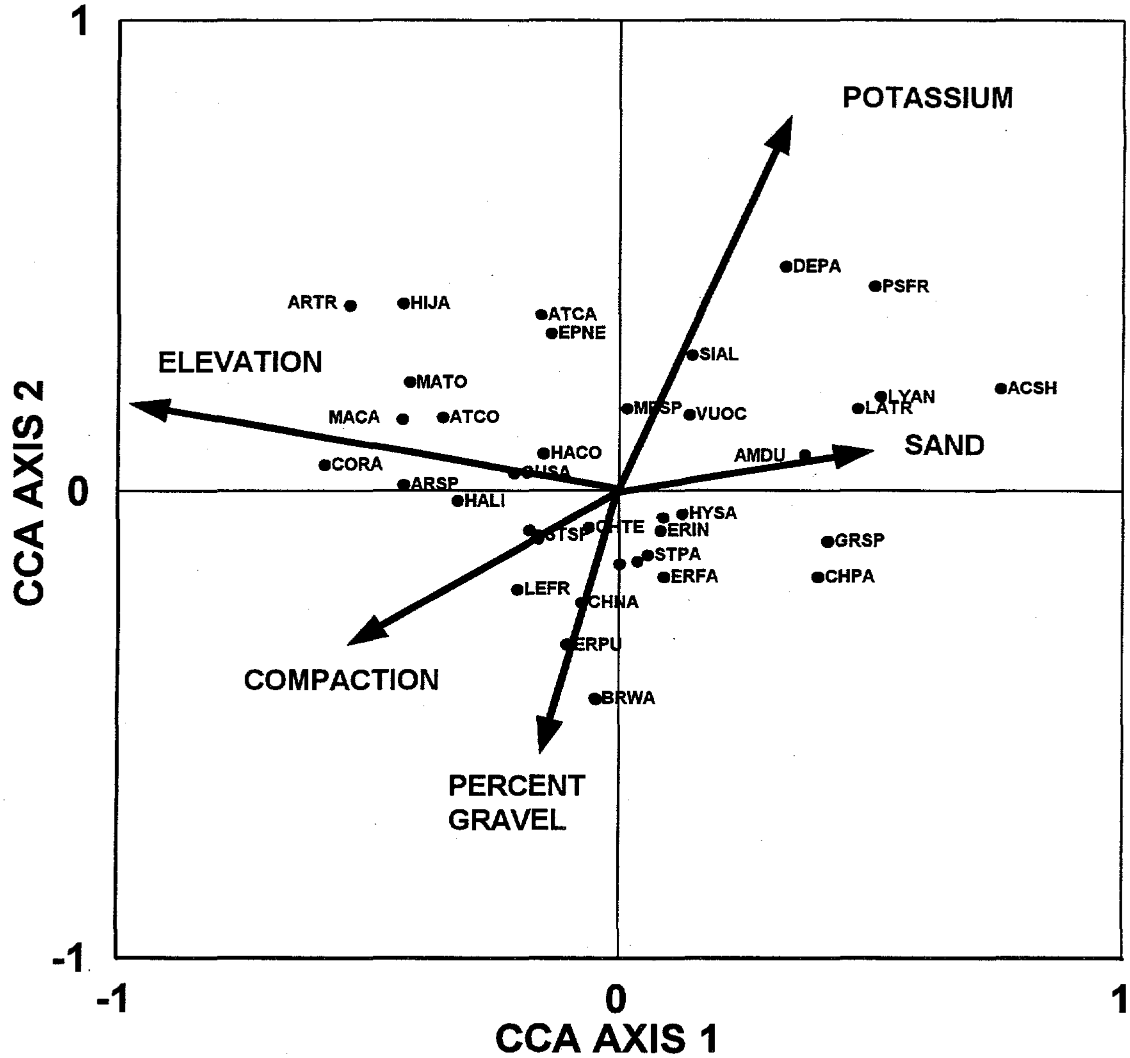


Figure 13. Canonical correspondence analysis (CCA) biplot for perennial plant species and associated significant environmental variables for disturbed sites at Yucca Mountain, NV. For explanations of species codes, see Appendix Table 1.

5.3.1 *Lycium-Grayia* Vegetation Association

For disturbed sites where perennial cover data was collected, approximately half of the sites (25) were located in the *Lycium-Grayia* (LG) vegetation association. Disturbed site cover of forbs, grasses and shrubs was substantially less than that of undisturbed sites in this vegetation association (Figure 14). Bare ground, cobble, and gravel cover means were greater for the disturbed LG sites. However, plant litter was less on disturbed sites and this may be a result of the lower shrub cover on these sites (Figure 14).

Undisturbed LG sites had more perennial species present (46) than that of disturbed sites (31) (Figure 9). *G. sarothrae, A. confertifolia, C. teretifolius, A. canescens, C. nauseous* and *H. salsola* had the highest perennial plant cover means in the disturbed areas (Figure 15), whereas *E. nevadensis, G. spinosa, L. andersonii, Eriogonum fasciculatum*, *Haplopappus cooperi*, and *H. salsola* had the highest perennial plant cover on undisturbed sites (Figure 15). Two of these species, *G. spinosa* and *L. andersonii*, for which the vegetation association is named, were completely absent from the cover measurements at disturbed sites. Cover of *E. nevadensis*, *E. fasciculatum* and *H. cooperi* in the undisturbed areas was 21, 38, and 10 times greater, respectively, than the cover of these species in the disturbed LG sites.

Dominance-diversity curves (also called rank abundance diagrams) for undisturbed and disturbed LG sites are presented in Figure 16. In this study, dominance-diversity curves were used to examine the successional status of disturbed sites compared to that of undisturbed sites. If disturbed sites have comparable curves to that of undisturbed sites, then the disturbed sites are relatively close in their successional status to the undisturbed sites. If species having high cover values in the undisturbed areas are at least present in disturbed site curve, this may be an indication that the disturbed sites are on a successional trajectory towards the species composition and abundance of the undisturbed site. In Figure 16, *G. sarothrae* is clearly the dominant species on disturbed LG sites but is not one of the dominant species in undisturbed LG sites. *A. confertifolia, C. teretifolius,* and *A. canescens* had high cover rankings in the disturbed areas, but are found much lower in the rankings of undisturbed LG sites. *E. nevadensis, G. spinosa, L. andersonii,* and *E. fasciculatum* had the highest ranking cover on undisturbed sites, but had very low rankings or were completely lacking in the disturbed LG sites.

Average age of LG disturbances was 9.4 ($\pm$ 0.3) years. Estimated succession rates of individual species encountered on LG sites was highly variable (Table 1). Generally, species such as *G. sarothrae, A. confertifolia, C. teretifolius,* and *A. canescens,* that were dominants on the disturbed sites, had estimated succession rates of 8 to 16 years. However, species such as *E. nevadensis* and *E. fasciculatum*, that were dominants of undisturbed LG areas, had estimated succession rates of 400 to 700 years.

CCA ordination of the LG sites indicated that soil potassium, elevation, and the sum of the growing season (October to March) precipitation for the first three years after disturbance were significant environmental variables influencing species composition and abundance

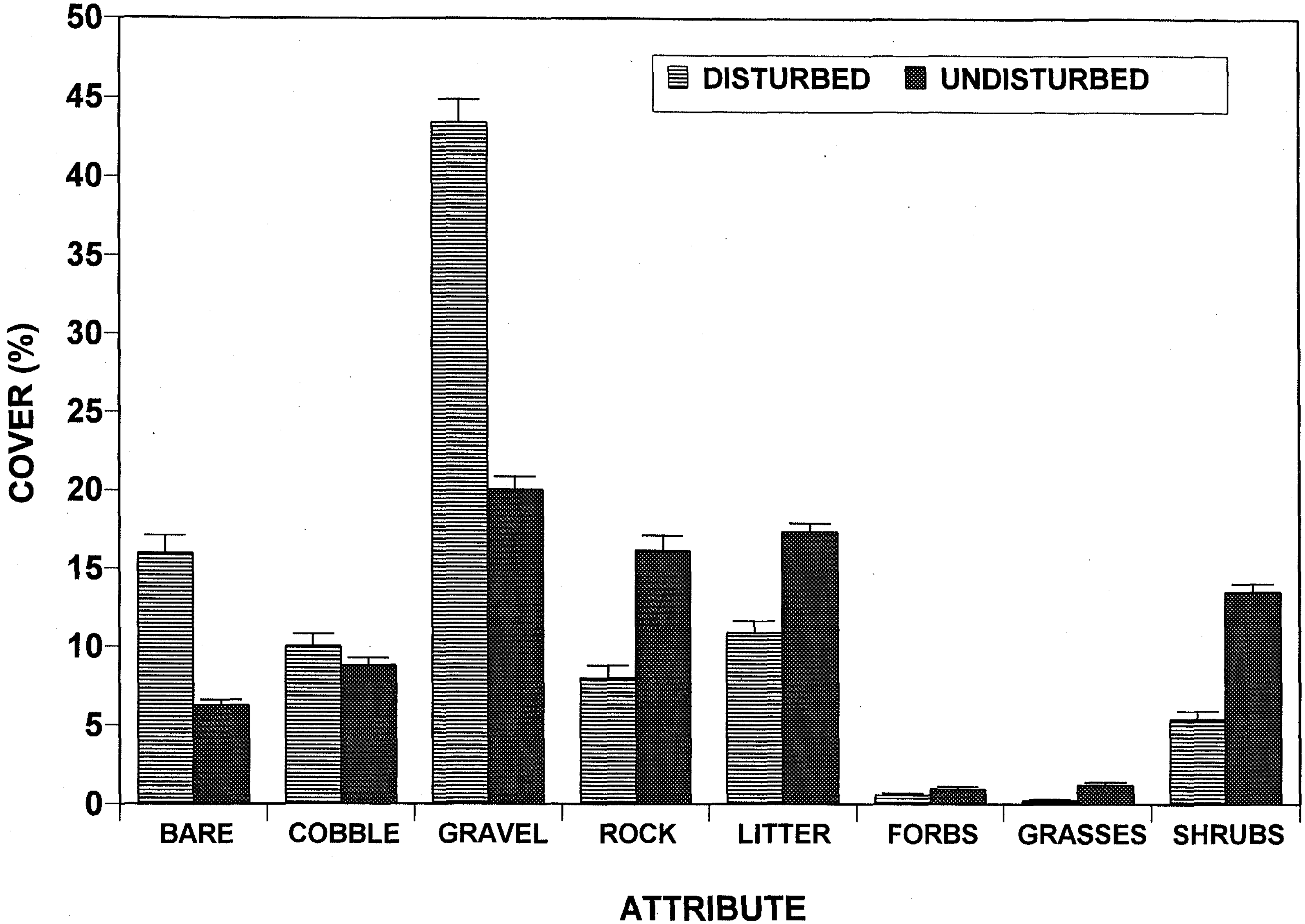


Figure 14. Mean cover attributes ($\pm$SE) for disturbed and undisturbed sites inventoried in the *Lycium-Grayia* vegetation association at Yucca Mountain, NV.

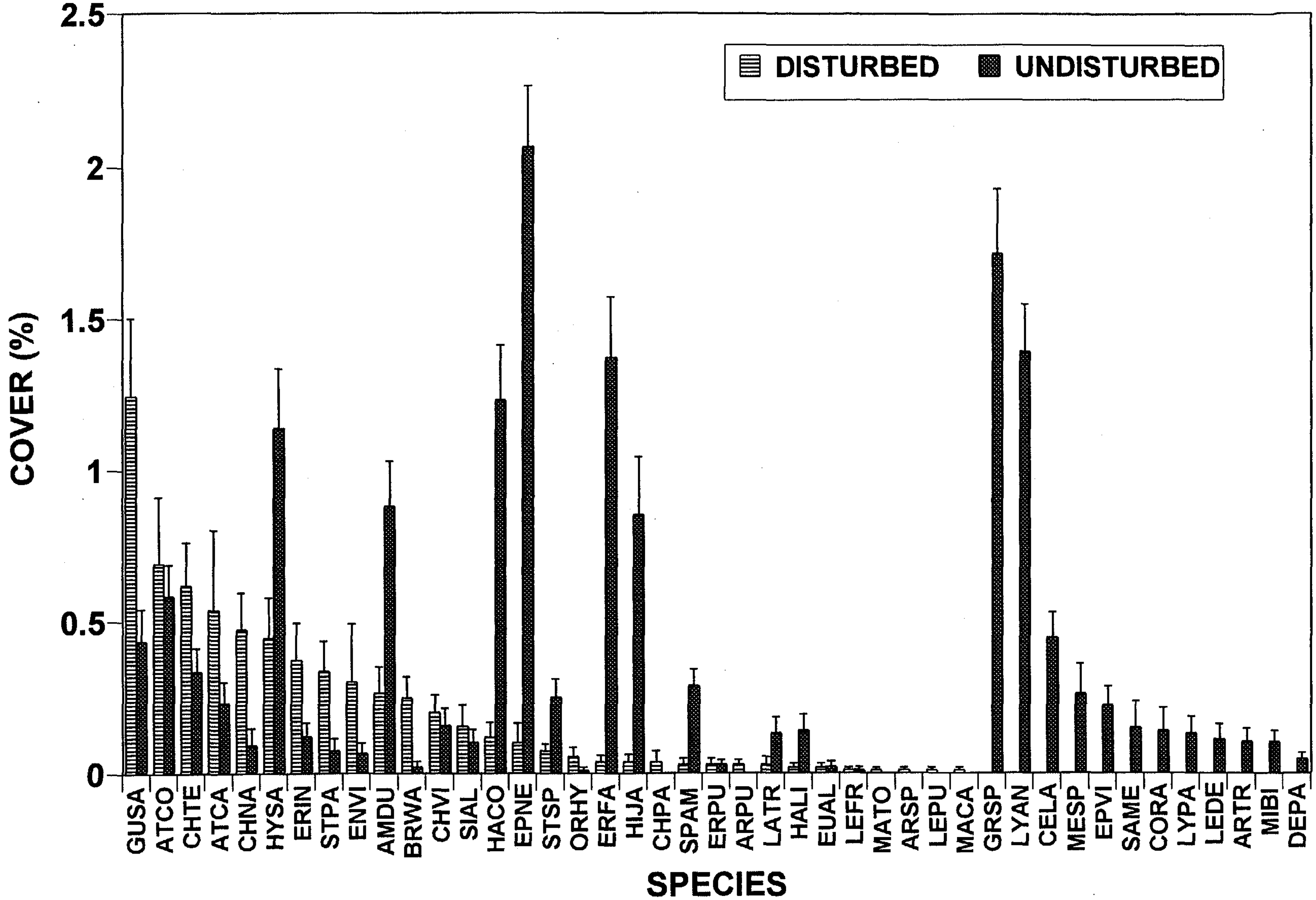


Figure 15. Mean cover (±SE) of perennial plant species found on disturbed and undisturbed sites inventoried within the *Lycium-Grayia* vegetation association at Yucca Mountain, NV. Ten species found on undisturbed sites with cover less than 0.05% are not shown. For explanation of species codes, see Appendix Table 1.

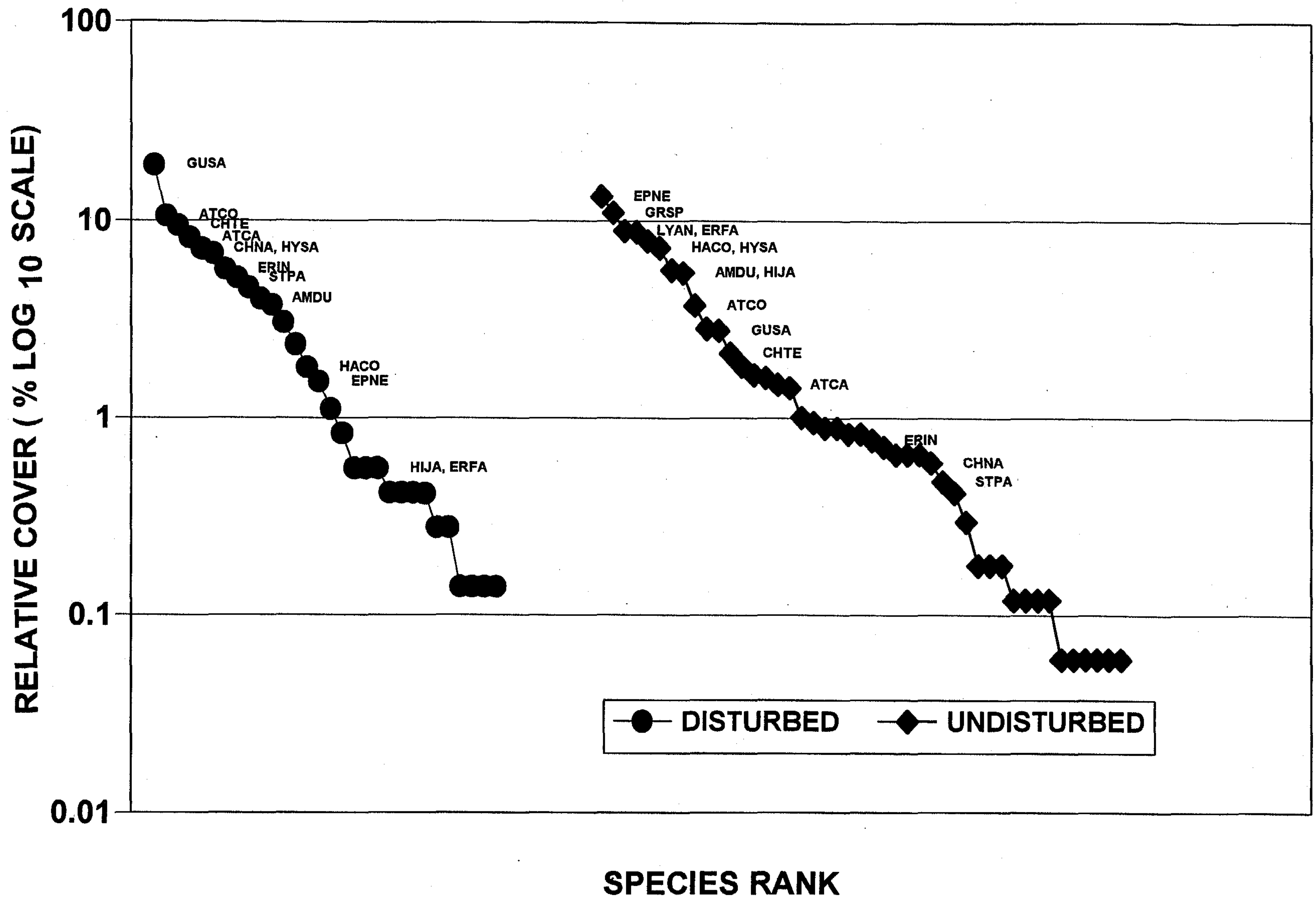


Figure 16. Dominance-diversity curves for relative cover (%) of perennial plant species in disturbed and undisturbed areas within the *Lycium-Grayia* vegetation association at Yucca Mountain, NV. Species shown were the top seven dominant species in both disturbed and undisturbed areas. For explanation of species codes, see Appendix Table 1.

(Figure 17). As for all sites, elevation appeared to influence the LG sites even though the elevation range is much less (1,230 to 1,500 m; 4,000 to 4,880 ft) than for all sites (1,015 to 1,780 m; 3,300 to 5,800 ft). Apparently, the elevation range within LG sites still creates a gradient in the soil, moisture and temperature regimes. An indication of this is apparent in Figure 17. Sites that were positively correlated with elevation were negatively correlated with the precipitation variable. This may indicate that the species composition and abundance of species at the higher elevation LG sites were less dependent on precipitation for the first 3 years after disturbance. The species ordination for LG sites indicated that *Hilaria jamesii, Sisymbrium altissimum*, and *A. canescens* were correlated to sites having high soil potassium (Figure 17). *L. tridentata* was correlated to sites having greater amounts of growing season precipitation three years after disturbance. *A. confertifolia, Machaeranthera tortifolia,* and *A. spinescens* were correlated to high elevation sites.

5.3.2 *Larrea-Lycium-Grayia* Vegetation Association

Fourteen of the disturbed sites in this study were located in the *Larrea-Lycium-Grayia* (LLG) vegetation association. Average forb, grass, and shrub cover on the disturbed sites ranged from 1.6 to 2.4 times less than that measured in undisturbed LG sites (Figure 18). As with the LG sites, bare ground and gravel cover was substantially greater in the disturbed sites. In contrast to the LG sites, plant litter on LLG disturbed and undisturbed sites was comparable (Figure 18).

Perennial species richness in undisturbed LLG sites was slightly higher than that in disturbed LLG sites (Figure 9). *H. salsola, C. teretifolius, L. tridentata,* and *A. dumosa,* had the highest mean cover on the disturbed LLG sites (Figure 19). Of these, *C. teretifolius* was the only species that was not measured in the undisturbed LLG sites. *L. tridentata, E. nevadensis, A. dumosa* and *Krameria parvifolia* had the highest mean cover on undisturbed LLG sites. Mean cover of *E. nevadensis* in the undisturbed areas was 24 times greater than that in the disturbed sites and *K. parvifolia* was completely absent in the disturbed sites.

Dominance-diversity curve comparisons for disturbed and undisturbed LLG sites give an indication that species such *A. dumosa, E. inflatum,* and possibly *L. tridentata,* are approaching cover proportions similar to those on undisturbed LLG sites (Figure 20). Succession rates for these species, based on an average age of 9.3 years for LLG disturbances, ranged between 14 and 29 years (Table 1). However, *E. nevadensis* ranked low in the disturbed cover rankings and had an estimated successional recovery time of 226 years. *K. parvifolia* was absent from the cover measurements (Table 1). The low ranking of *E. nevadensis,* and the high ranking of *C. teretifolius* in the disturbed sites may be an indication that these sites are not yet approaching the successional status of the undisturbed sites.

CCA ordination of LLG disturbed sites indicated that elevation, percent soil organic matter, and exchangeable sodium in the soil were statistically significant ($p=0.03$) environmental variables (Figure 21). Again, elevation was a significant variable although the elevational range for the sites was 1,100 m (3,580 ft) to 1,315 m (4,280 ft). Apparently, this range

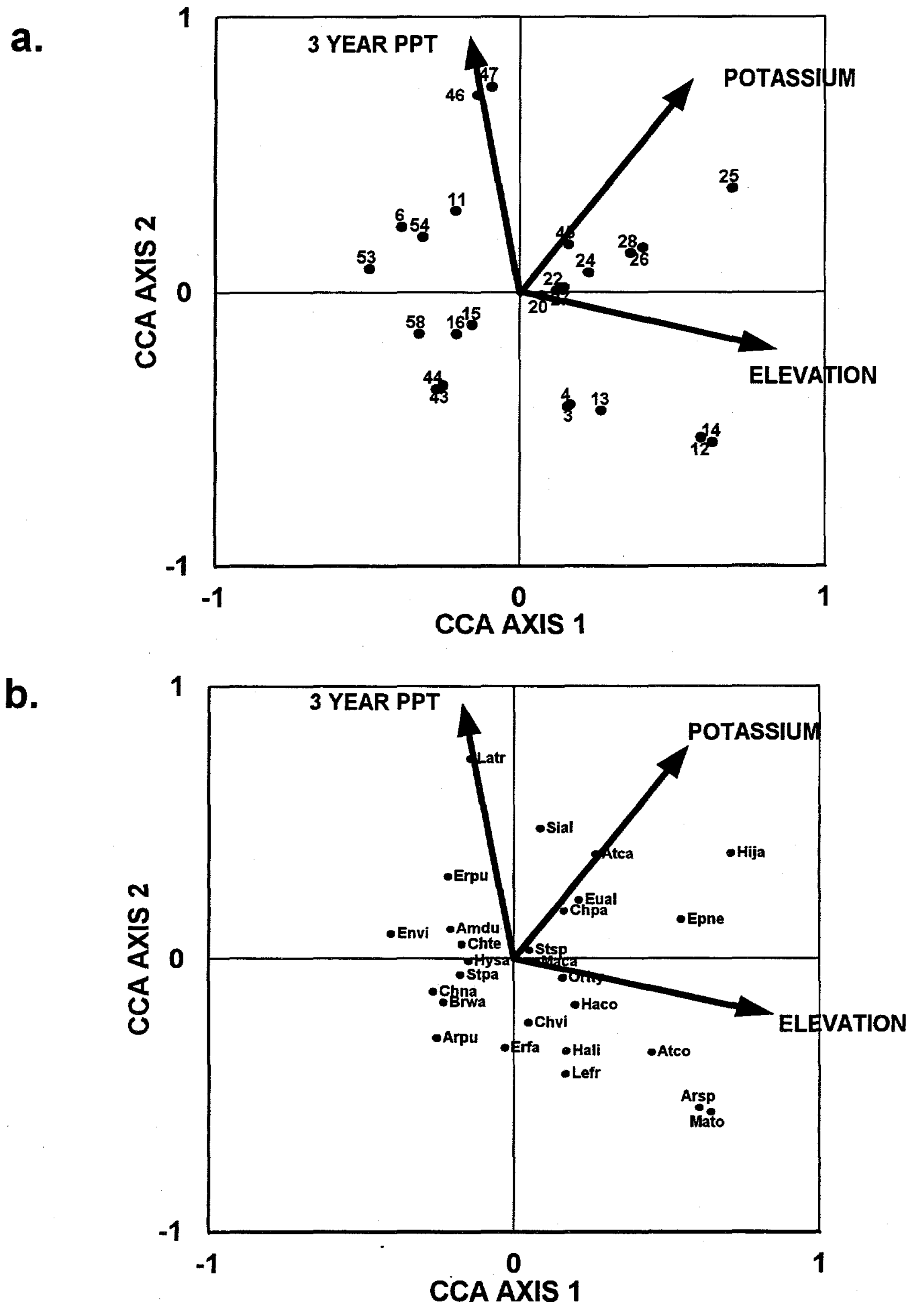


Figure 17. Canonical correspondence analysis (CCA) biplots for sites(a), perennial plant species (b) and their associated significant environmental variables for *Lycium-Grayia* disturbances at Yucca Mountain, NV. For site locations, see Figure 3. For explanations of species codes, see Appendix Table 1.

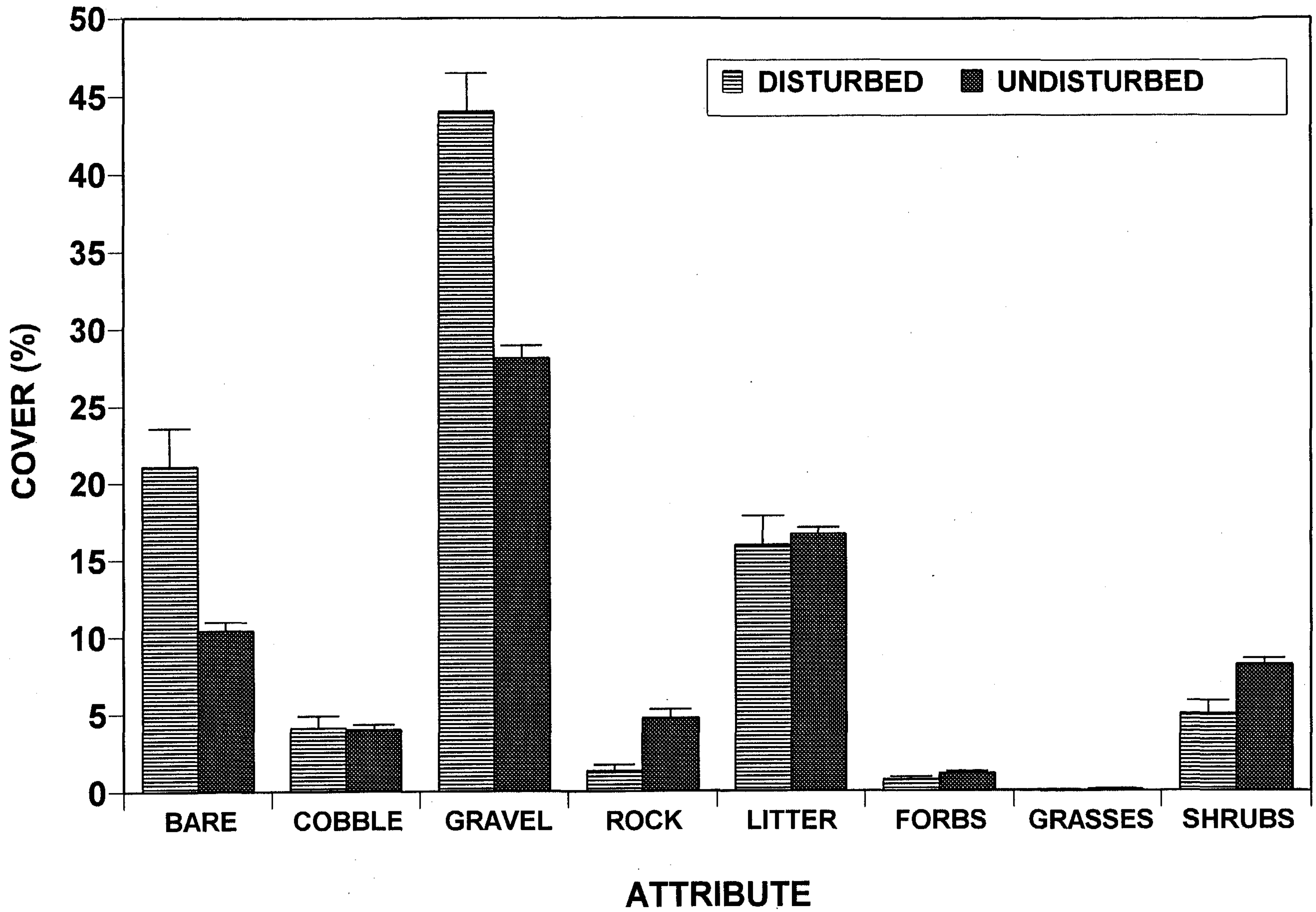


Figure 18. Mean cover attributes (±SE) for disturbed and undisturbed sites inventoried in the *Larrea-Lycium-Grayia* vegetation association at Yucca Mountain, NV.

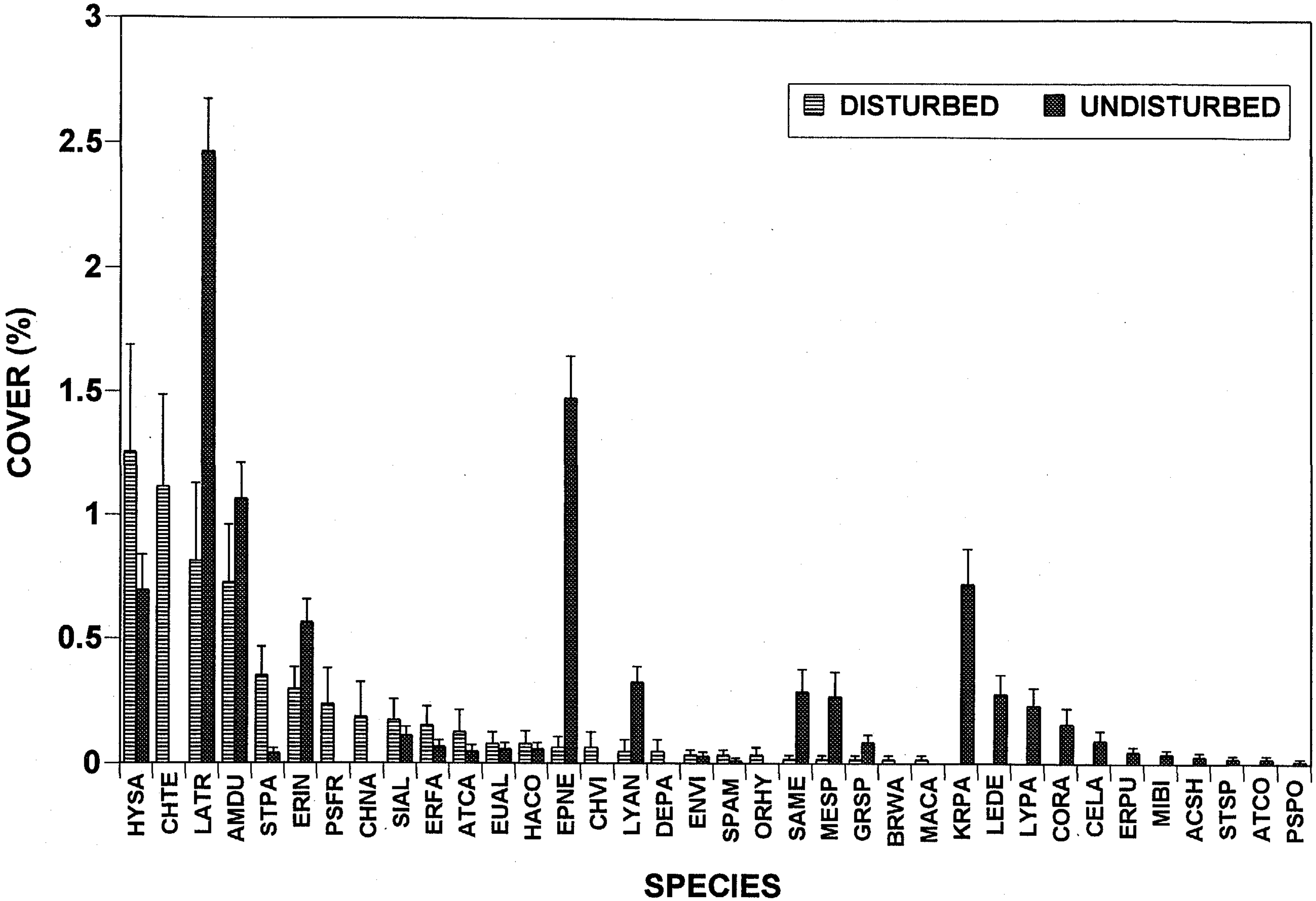


Figure 19. Mean cover (±SE) of perennial plant species found on disturbed and undisturbed sites inventoried within the *Larrea-Lycium-Grayia* vegetation association at Yucca Mountain, NV. Four species found on undisturbed sites with cover less than 0.01% are not shown. For explanation of species codes, see Appendix Table 1.

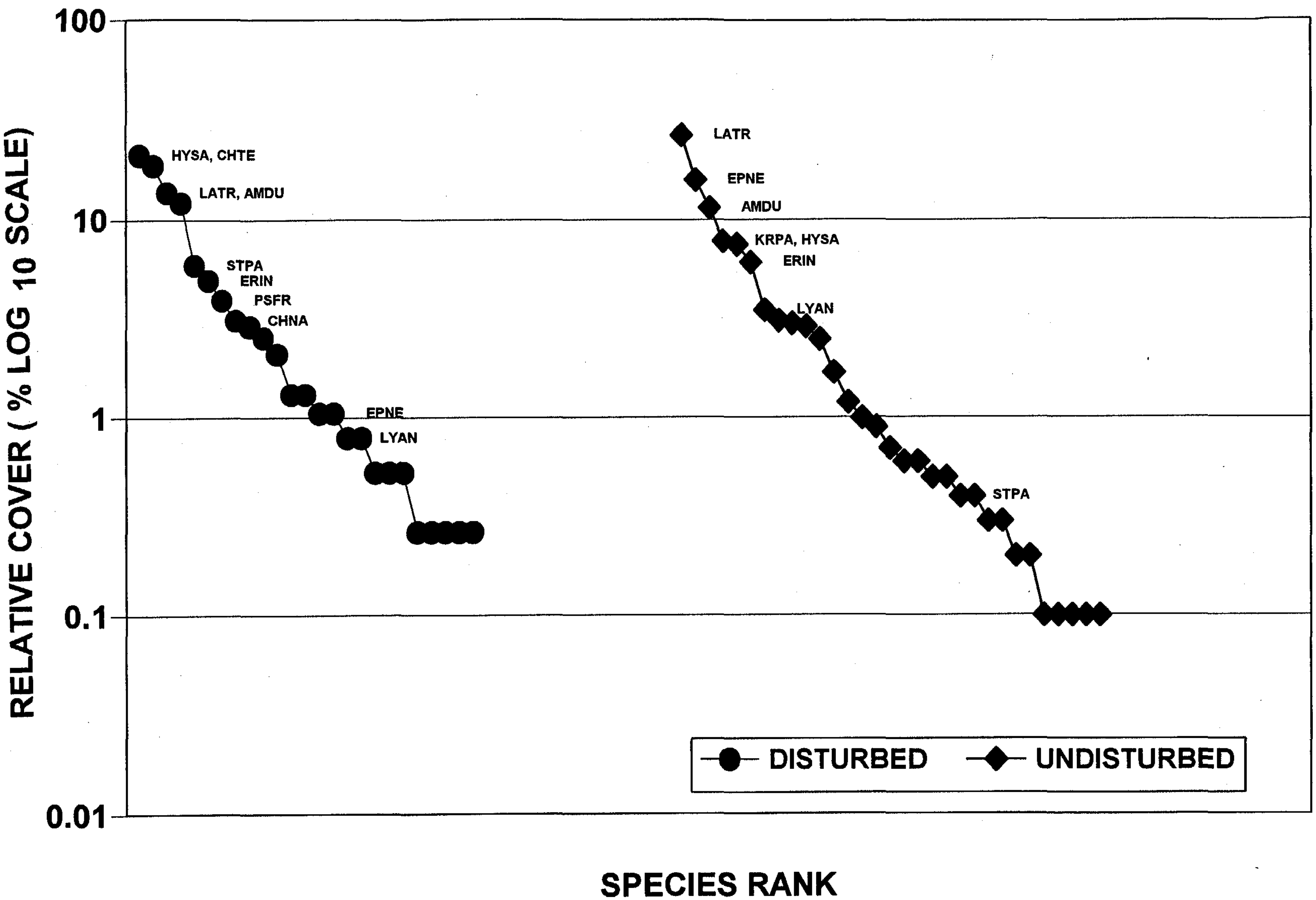


Figure 20. Dominance-diversity curves for relative cover (%) of perennial plant species in disturbed and undisturbed areas within the *Larrea-Lycium-Grayia* vegetation association at Yucca Mountain, NV. Species shown were the top seven dominant species in both disturbed and undisturbed areas. For explanation of species codes, see Appendix Table 1.

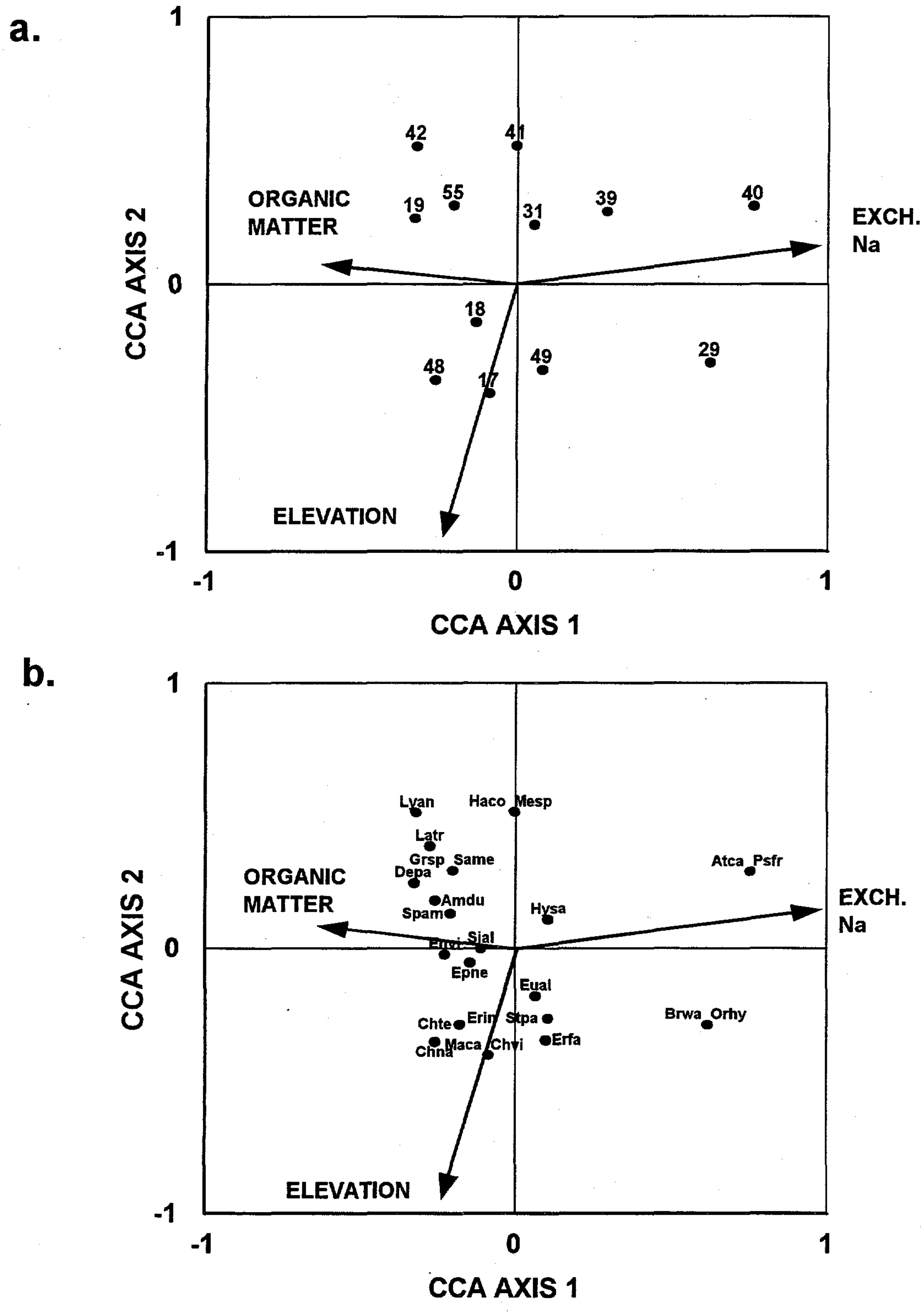


Figure 21. Canonical correspondence analysis (CCA) biplots for sites (a), perennial plant species (b) and their associated significant environmental variables for *Larrea-Lycium-Grayia* disturbances at Yucca Mountain, NV. For site locations, see Figure 3. For explanations of species codes, see Appendix Table 1.

influenced the moisture and temperature regimes enough to influence the species composition and cover of these LLG sites.

The influence of organic matter may be related to site age since disturbance (as sites increase in perennial plant density and cover over time, organic matter usually increases) or that original topsoil and vegetation may have remained at the disturbed site. In this case, sites 19 and 48 (Figure 21) were plots that had higher organic matter and this may be because these sites had crushed vegetation and little or no topsoil removed. The topsoil and remaining vegetation at these sites may have influenced the positive correlation of perennial plant cover with organic matter.

Sites 29 and 40 were correlated to exchangeable sodium. High amounts of exchangeable sodium in the soil are generally undesirable to many plants. However, plants such *Atriplex spp.* are adapted to high amounts of sodium in the soil. The species ordination for the LLG sites indicated that *A. canescens* was correlated to the exchangeable sodium in the soil (Figure 21). High soil sodium may also be detrimental to plant establishment. Sites 50 and 51 (not shown in Figure 21) had high exchangeable sodium (3.5 and 10.24%, respectively) and had no perennial species present on the site at the time of data collection.

5.3.3 *Coleogyne* Vegetation Association

Eight of the disturbed sites sampled for perennial cover were located in the *Coleogyne* (COL) vegetation association. COL undisturbed areas had approximately two times more perennial plant species present than the disturbed COL sites (Figure 9). Mean forb cover in disturbed COL sites was comparable to undisturbed sites (Figure 22). Grass cover was slightly higher in the disturbed COL sites, but shrub cover was almost 3.5 times less than that of undisturbed COL sites. As with the LLG vegetation association, bare ground, cobble, and gravel cover was greater, and plant litter cover was considerably less on the disturbed COL sites (Figure 22).

C. teretifolius, A. canescens, H. jamesii, H. salsola, and *M. canescens* had the highest mean cover in the disturbed sites (Figure 23). Of these species, *M. canescens* was completely absent and *A. canescens* was a minor component in the undisturbed COL sites. *C. ramosissima* had the highest mean cover in undisturbed COL sites, and this cover value was almost 23 times greater than that in the disturbed areas. *A. dumosa, E. nevadensis, Lycium pallidum, K. parvifolia,* and *L. andersonii* followed *C. ramosissima* in having greater mean cover on undisturbed COL sites. With the exception of *A. dumosa*, these species were completely absent in the COL disturbed sites examined in this study.

A comparison of the dominance-diversity curves for disturbed and undisturbed COL sites gives an indication of the difference in the successional status of the disturbed and undisturbed sites (Figure 24). Although *C. teretifolius* and *A. canescens* had the highest cover values in the disturbed sites, they were not major components of the undisturbed sites. The presence of *C. ramosissima* in the disturbed sites is encouraging, but this species' ranking in the disturbed

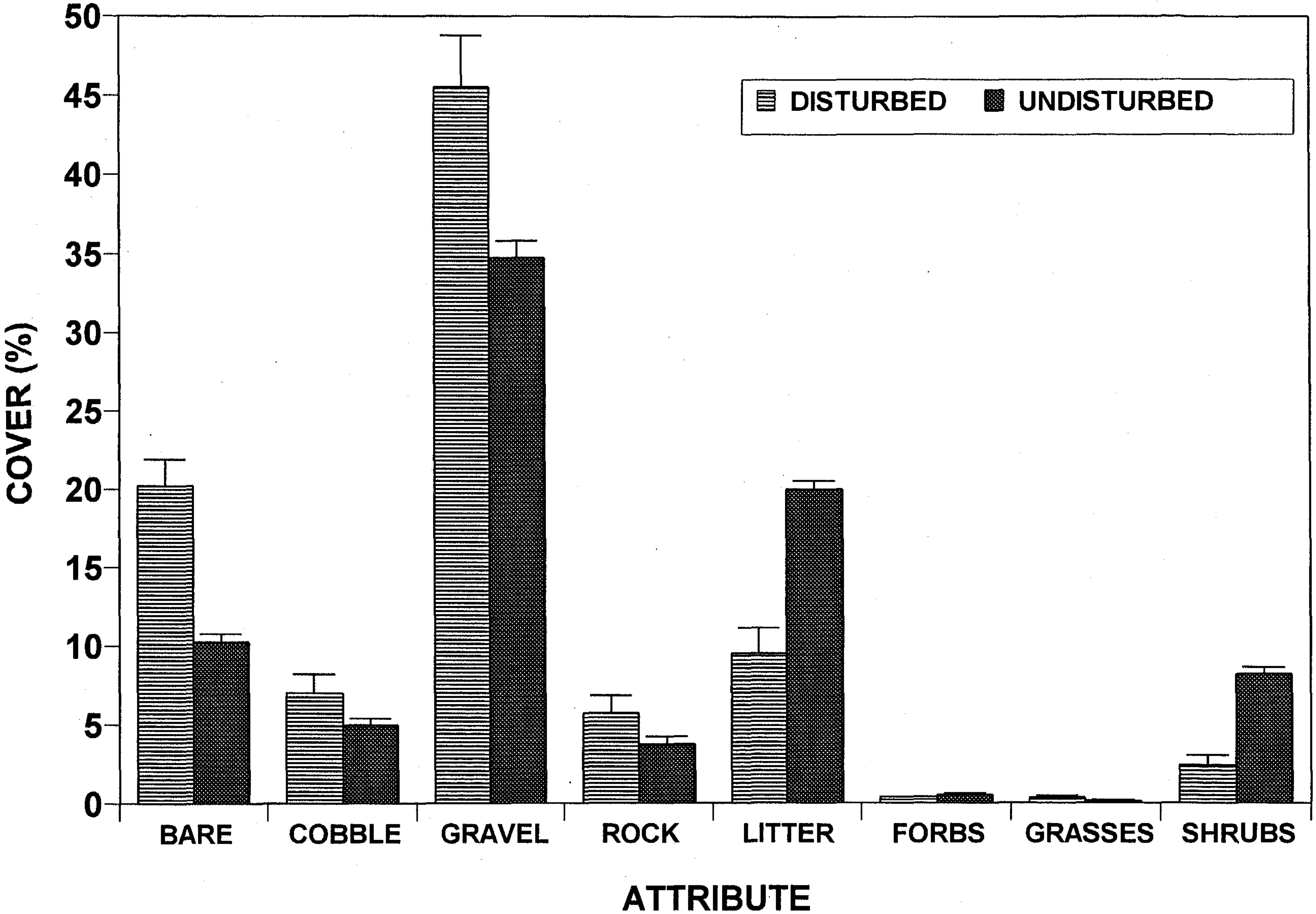


Figure 22. Mean cover attributes (±SE) for disturbed and undisturbed sites inventoried in the *Coleogyne* vegetation association at Yucca Mountain, NV.

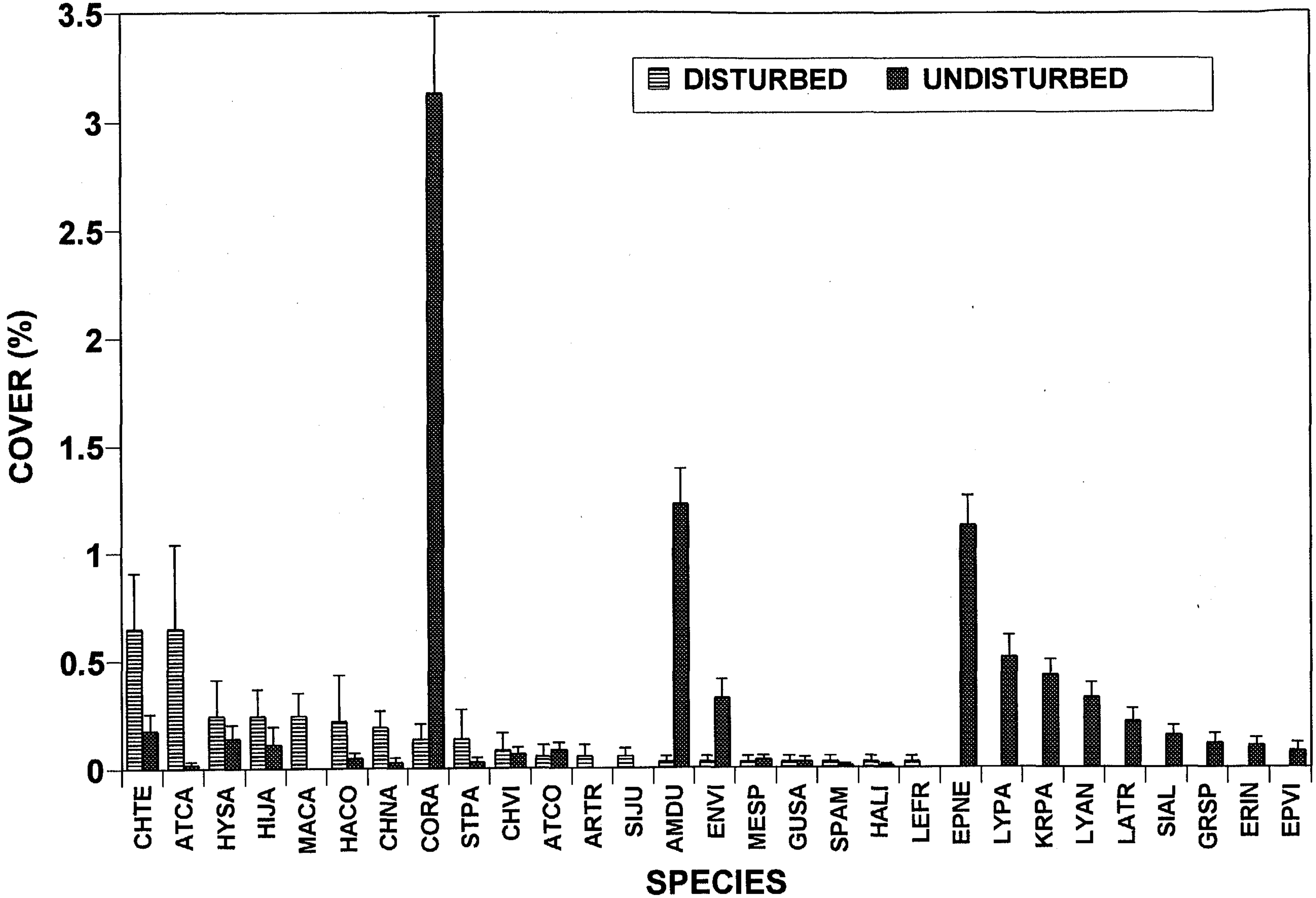


Figure 23. Mean cover (±SE) of perennial plant species found on disturbed and undisturbed sites inventoried within the *Coleogyne* vegetation association at Yucca Mountain, NV. Sixteen species found on undisturbed sites with cover less than 0.05% are not shown. For explanation of species codes, see Appendix Table 1.

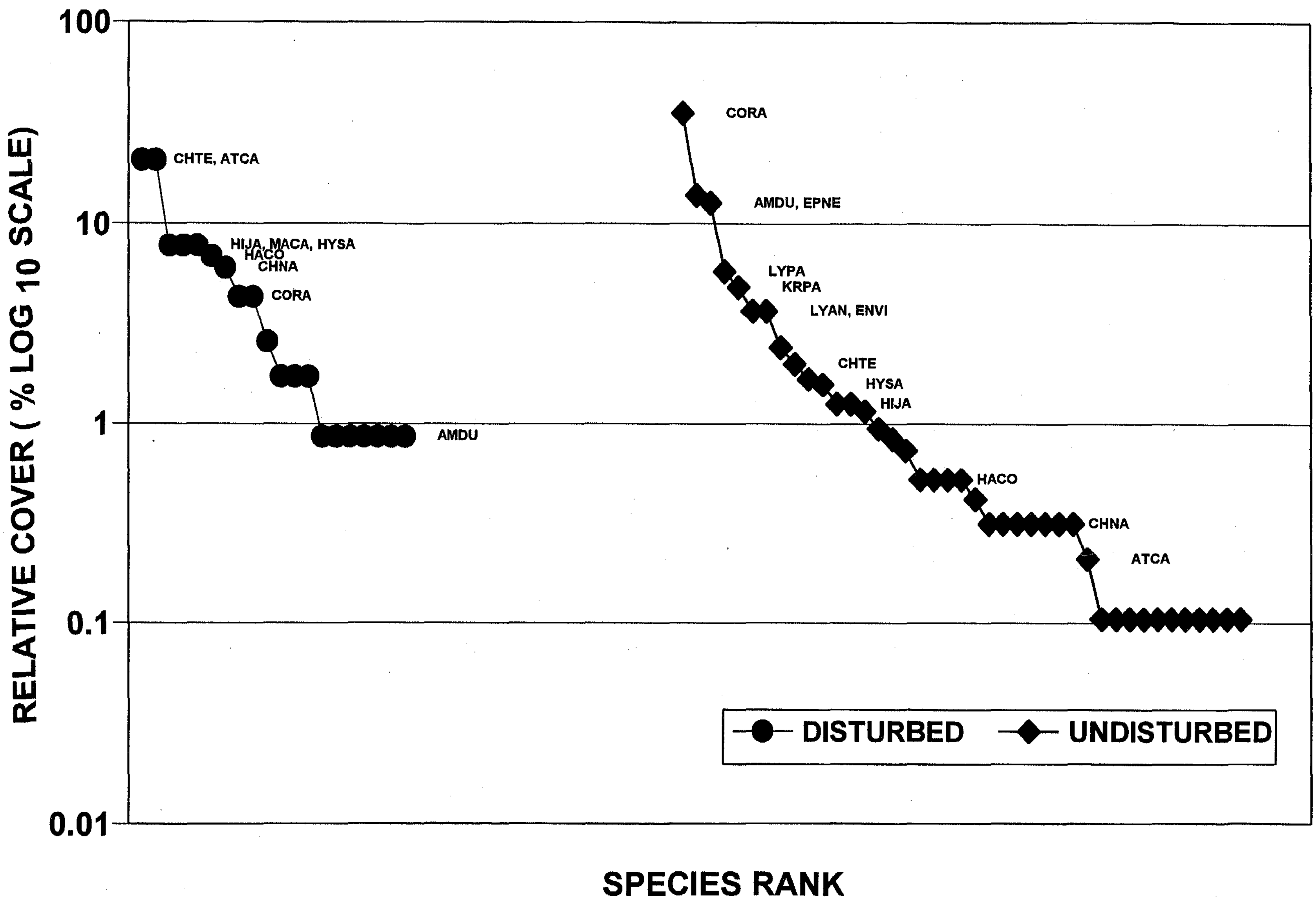


Figure 24. Dominance-diversity curves for relative cover (%) of perennial plant species in disturbed and undisturbed areas within the *Coleogyne* vegetation association at Yucca Mountain, NV. Species shown were the top seven dominant species in both disturbed and undisturbed areas. For explanation of species codes, see Appendix Table 1.

site cover values is low when compared to undisturbed COL sites. Estimated successional recovery time for the two undisturbed site dominants, *C. ramosissima* and *A. dumosa*, based on an average disturbed site age of 10.4 (± 0.3 SD) years, was 241 years and 471, respectively (Table 1). The absence of *L. pallidum, L. andersonii, K. parvifolia,* and especially *E. nevadensis* from the disturbed site cover may be an indication that the successional status of the disturbed COL sites will take more than 400 years to approach that of the undisturbed sites.

CCA ordination was conducted on the COL disturbed site perennial cover and environmental variables. Because of the low number of sites for this vegetation association, the analysis was not statistically significant. Therefore, no results will be presented.

5.3.4 *Larrea-Ambrosia* Vegetation Association

Four of the disturbed sites sampled for perennial cover occurred in the *Larrea-Ambrosia* (LA) vegetation association. These disturbed sites had average forb and grass cover that was comparable to the undisturbed sites (Figure 25). Gravel, rock, and cobble cover was substantially greater in the disturbed LA sites; however, bare ground cover was less than that in the undisturbed areas. As with the other vegetation associations, average shrub cover and plant litter cover were greater in the undisturbed areas.

Species richness in the LA disturbed sites was considerably less than that of undisturbed sites (Figure 9). Of the species in disturbed areas, *A. dumosa, S. pauciflora, L. tridentata, L. pallidum,* and *Chrysothamnus paniculatus*, had the highest mean cover (Figure 26). Of these species , *S. pauciflora* and *C. paniculatus* were minor components in the undisturbed sites whereas *A. dumosa, L. tridentata,* and *L. pallidum* were major components in the undisturbed areas. The other species having high mean cover values in the undisturbed areas were *M. spinescens, A. shockleyi* and *K. parvifolia*. These species had very low cover values or were not present in the disturbed sites sampled.

An examination of the dominance-diversity curves for disturbed and undisturbed sites provides an indication of the successional status of LA disturbed sites (Figure 27). *A. dumosa* was the dominant species in both the disturbed and undisturbed sites (Figure 27), and this species had an estimated recovery time of 16 years (Table 1). *L. tridentata, L. pallidum*, and *Acamptopappus shockleyi*, which had high cover rankings in the undisturbed LA sites (Figure 27) had recovery rates of 54 to 109 years (Table 1). However, *M. spinescens* and *E. nevadensis* did not contribute to the disturbed sites' cover (Figure 27), and this may be an indication that the successional status of these sites are quite different and may require recovery times greater than 110 years.

As with the *Coleogyne* vegetation association, the CCA ordination for LA sites and environmental variables was not statistically significant. Therefore, the influence of environmental variables within this vegetation association could not be determined.

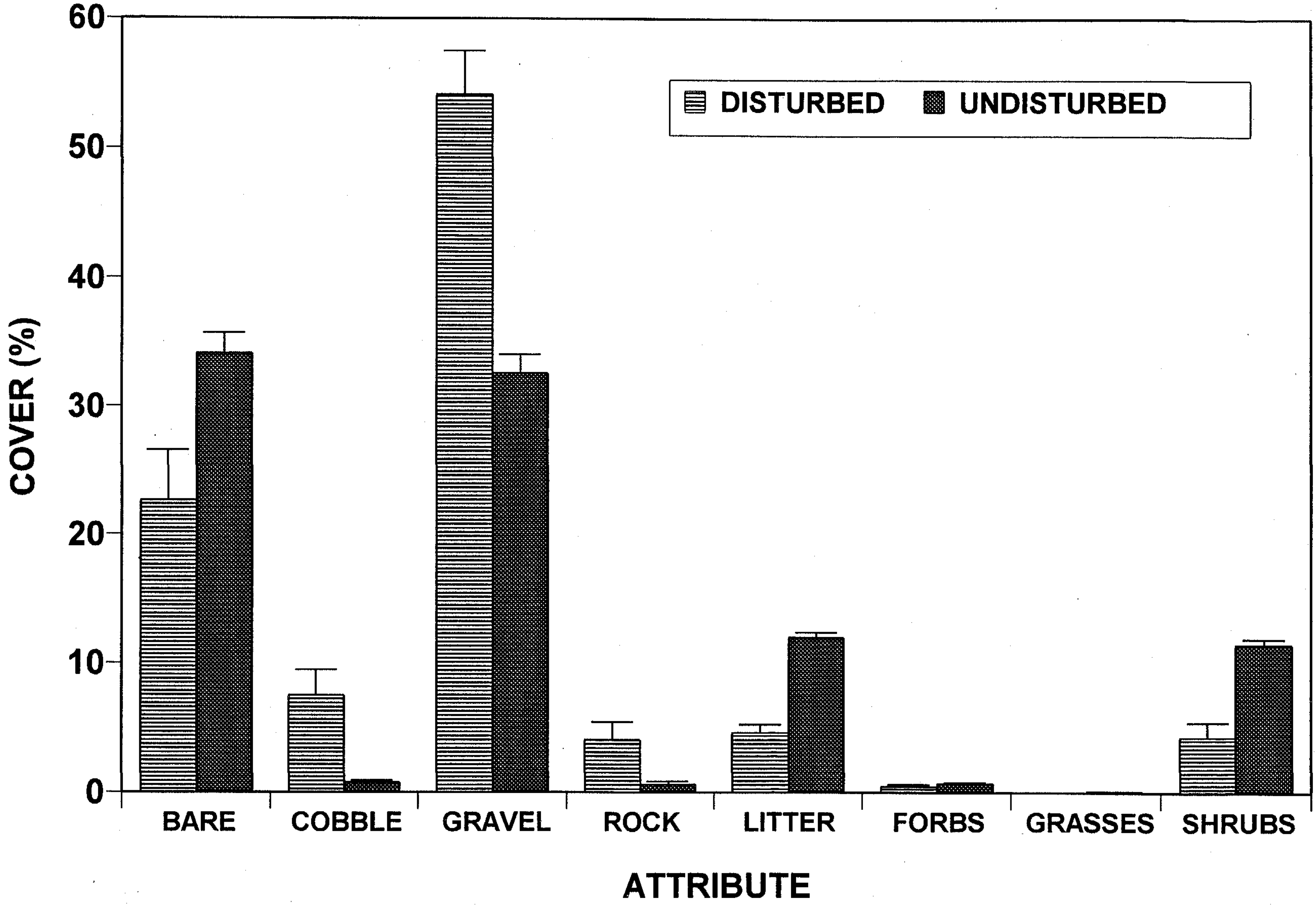


Figure 25. Mean cover attributes (±SE) for disturbed and undisturbed sites inventoried in the *Larrea-Ambrosia* vegetation association at Yucca Mountain, NV.

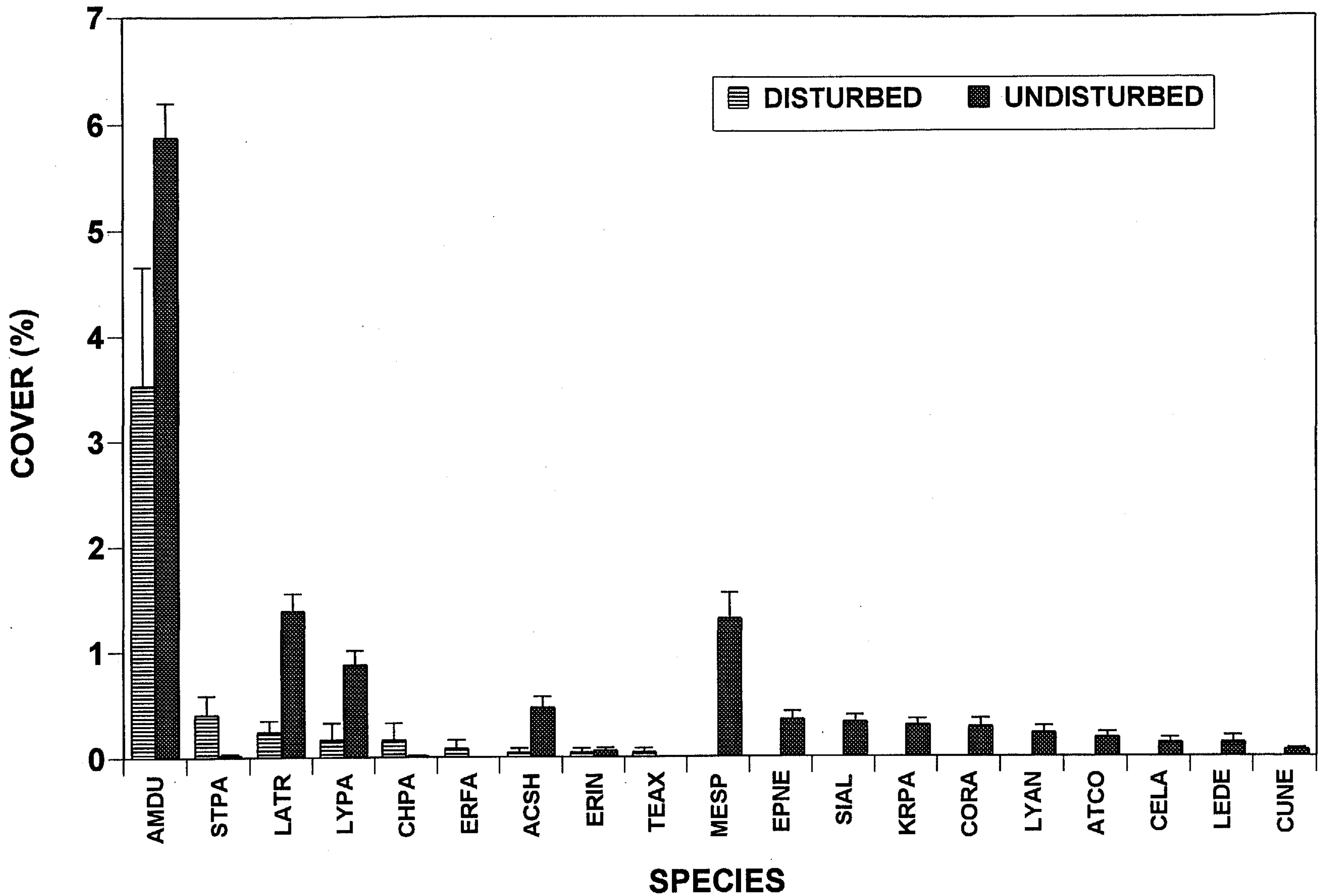


Figure 26. Mean cover (±SE) of perennial plant species found on disturbed and undisturbed sites inventoried within the *Larrea -Ambrosia* vegetation association at Yucca Mountain, NV. Eight species found on undisturbed sites with cover less than 0.05% are not shown. For explanation of species codes, see Appendix Table 1.

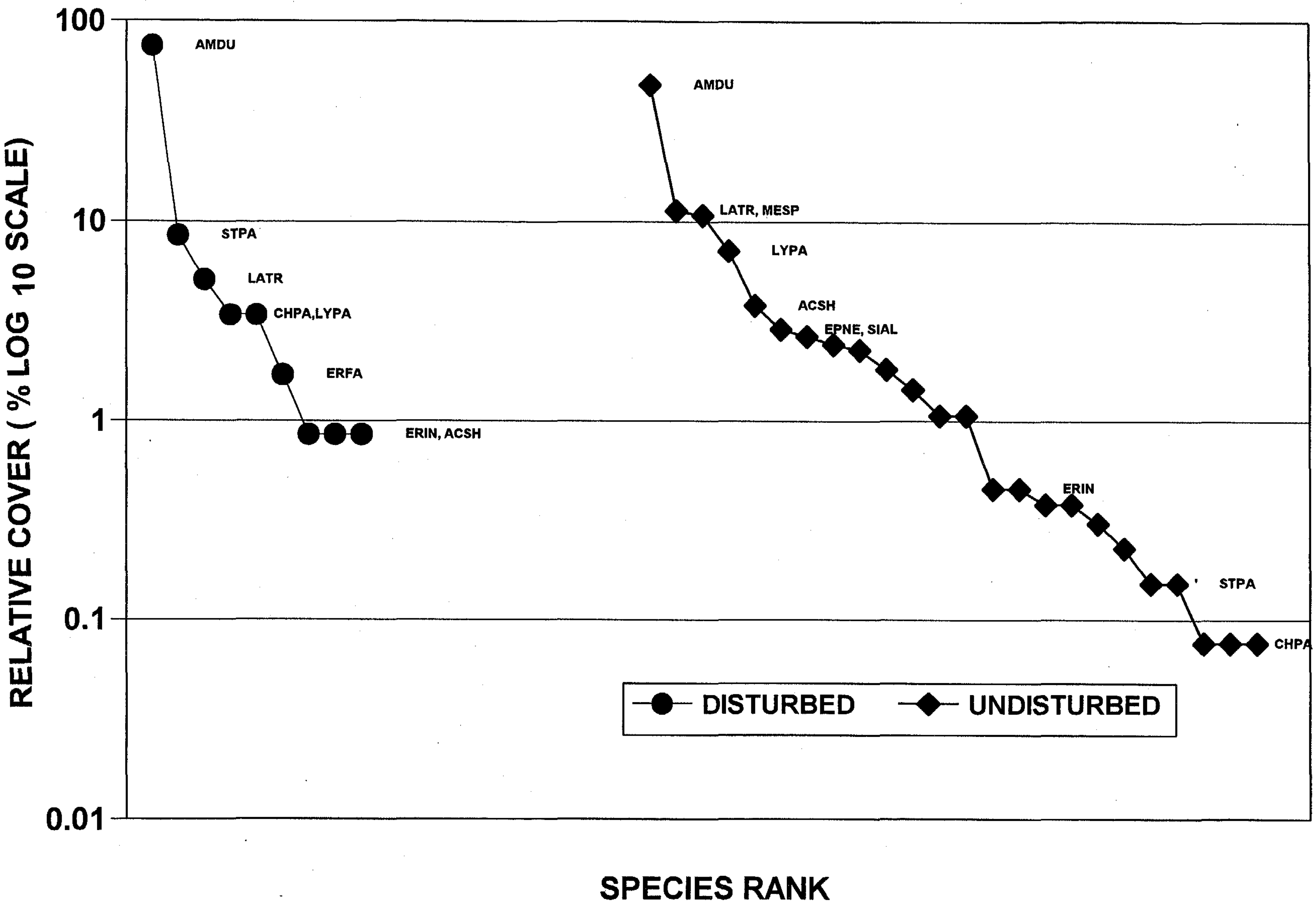


Figure 27. Dominance diversity curves for relative cover (%) of perennial plant species in disturbed and undisturbed areas within the *Larrea -Ambrosia* vegetation association at Yucca Mountain, NV. Species shown were the top eight dominant species in both disturbed and undisturbed areas. For explanation of species codes, see Appendix Table 1.

5.4 CHARACTERISTICS OF DISTURBANCE TYPES

The type of disturbance (i.e. borrow area, cutslope, drill pad, etc.) may be an important factor influencing the succession on a disturbed site. For example, succession on a borrow area may be quite different than that on a cutslope just because of the differences in slope. However, in this study, differences in plant succession on disturbance types are overridden by the influences of elevation. The influence of environmental variables on all disturbed sites categorized by disturbance type is presented in Figure 28. The high variability in the locations of the various disturbance types on the graph gives an indication that elevation had a stronger influence on species composition and cover of disturbed sites than did disturbance type alone. CCA ordinations conducted for each of the disturbance types generally had the same environmental variables with high correlations as those depicted in Figure 28. However, an examination of the characteristics of disturbance types may provide information about subtle differences in the disturbances types that can aid in the development of revegetation plans for disturbed sites.

Disturbed sites were categorized into the following disturbance type categories: 1) borrow areas (areas where topsoil and subsoil were removed and used for fill material as in Figure 29a); 2) cutslopes (areas were an exposed slope was created by the removal of soil material as in Figure 29b); 3) drill pads (an area cleared of vegetation frequently having fill material brought in for leveling as in Figure 30a); and 4) vegetation crushed (areas that have had light to moderate disturbance that crushes or breaks the vegetation as in Figure 30b). Of the disturbed sites sampled for perennial cover, there were 14 borrow areas, 15 cutslopes, 11 drill pads, and 5 crushed vegetation sites.

Forb and grass cover was not significantly different among disturbance types and was comparable to that of the undisturbed sites (mean of all undisturbed sites) (Figure 31). Sites with vegetation crushed had significantly greater shrub cover over other disturbance types and this was comparable to the undisturbed area. Drill pads had significantly greater annual plant cover when compared to the other disturbance types; however, this value was lower than that for annual cover on undisturbed areas. Gravel cover was not significantly different among sites but was considerably greater than that of undisturbed sites.

Of the disturbance types, borrow areas had the greatest species richness; however, these values were less than that for undisturbed areas (Figure 32). Species richness was the lowest for vegetation crushed sites. Dominance-diversity curves for the disturbance types and undisturbed areas indicate differences among the disturbance types in species composition and relative cover (Figure 33). In borrow areas, *A. canescens* and *C. teretifolius* were the dominant species. On cutslopes, *G. sarothrae* and *A. confertifolia* had the highest relative cover. *E. inflatum, G. sarothrae, A. canescens, S. altissimum, and C. teretifolius* were major component of cover on drill pads. On areas where vegetation was crushed, *A. dumosa* was dominant, followed by *C. teretifolius*. With the exception of *A. dumosa*, the above species were not major dominants in undisturbed sites.

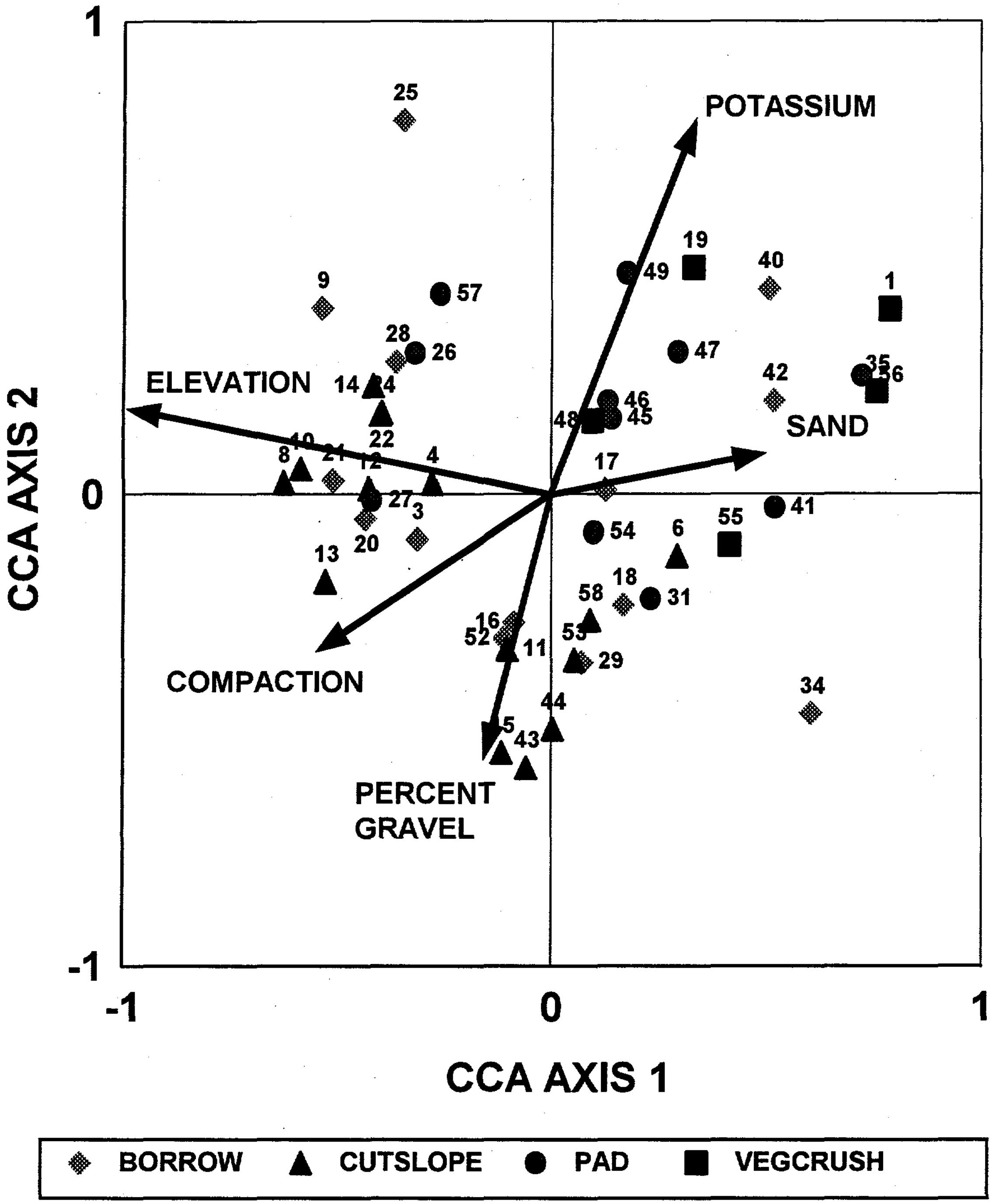
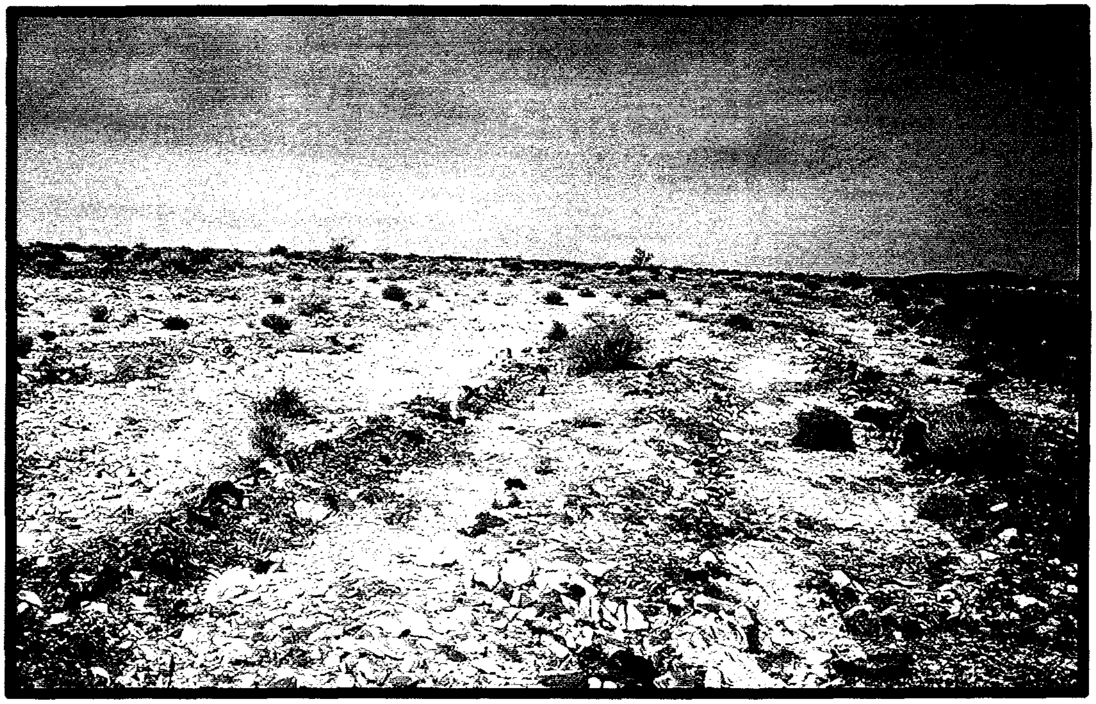


Figure 28. Canonical correspondence analysis (CCA) biplot for disturbed sites and significant environmental variables for Yucca Mountain, NV. Sites are classified by the following disturbance types: borrow areas (BORROW), cutslopes (CUTSLOPE), drill pads (PAD), and areas with crushed vegetation (VEGCRUSH). For location of the sites, see figure 3.

a.



b.

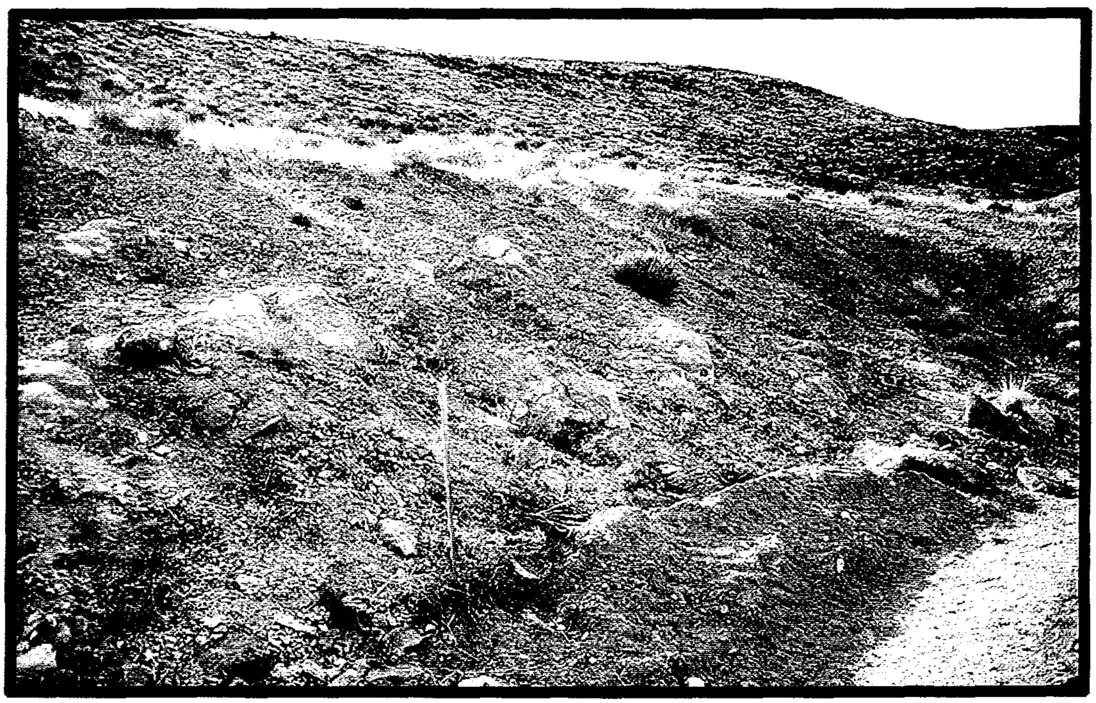


Figure 29. A borrow area (a) and cutslope (b) disturbance used for disturbed habitat studies at Yucca Mountain, NV.

a.

b.

Figure 30. A drill pad (a) and a crushed vegetation disturbance (b) used for disturbed habitat studies at Yucca Mountain, NV.

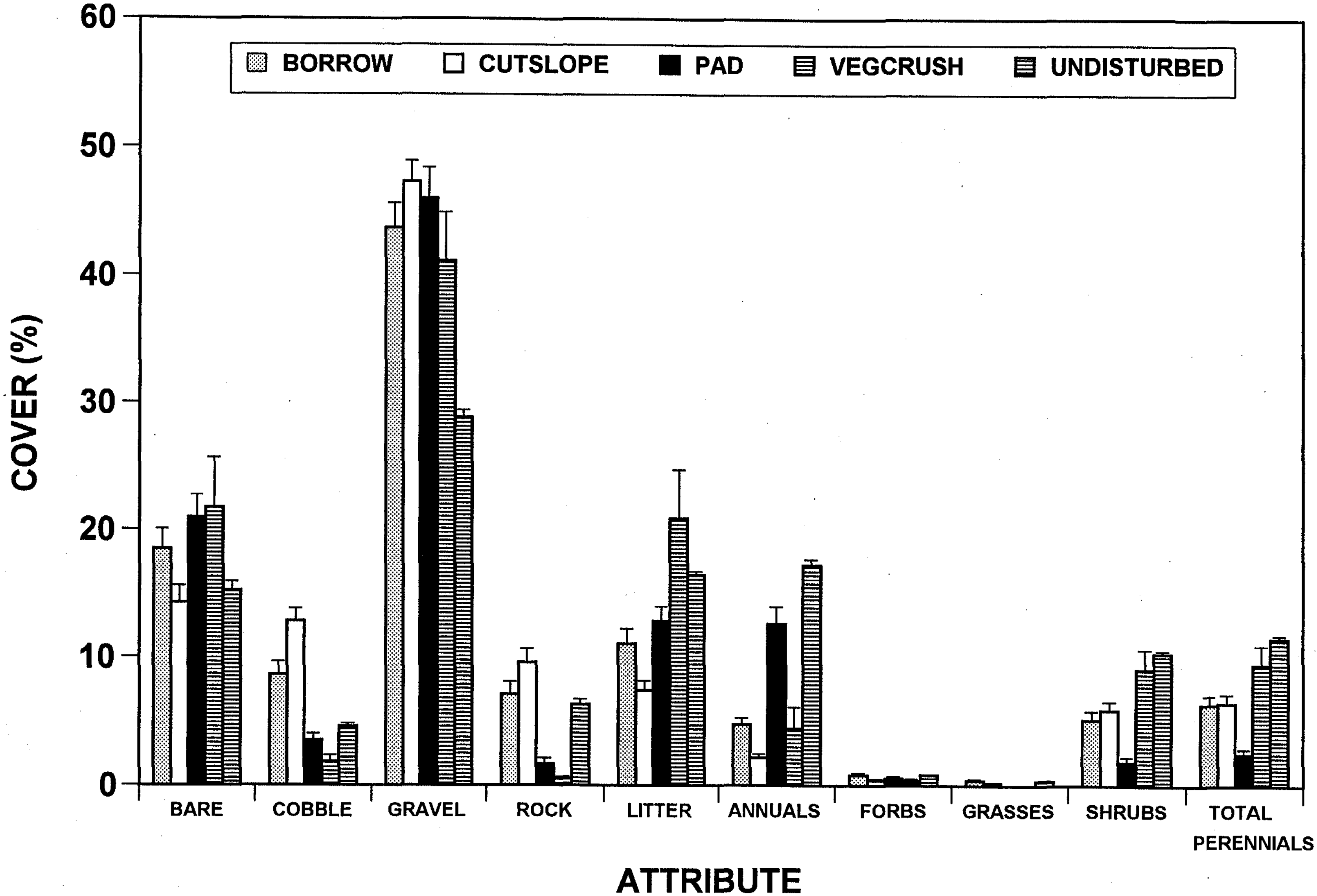


Figure 31. Mean cover attributes (±SE) for disturbance types and undisturbed sites inventoried for the disturbed habitat studies at Yucca Mountain, NV. The disturbance types were as follows: borrow areas (BORROW), cutslopes (CUTSLOPE), drill pads (PAD), and areas with crushed vegetations (VEGCRUSH).

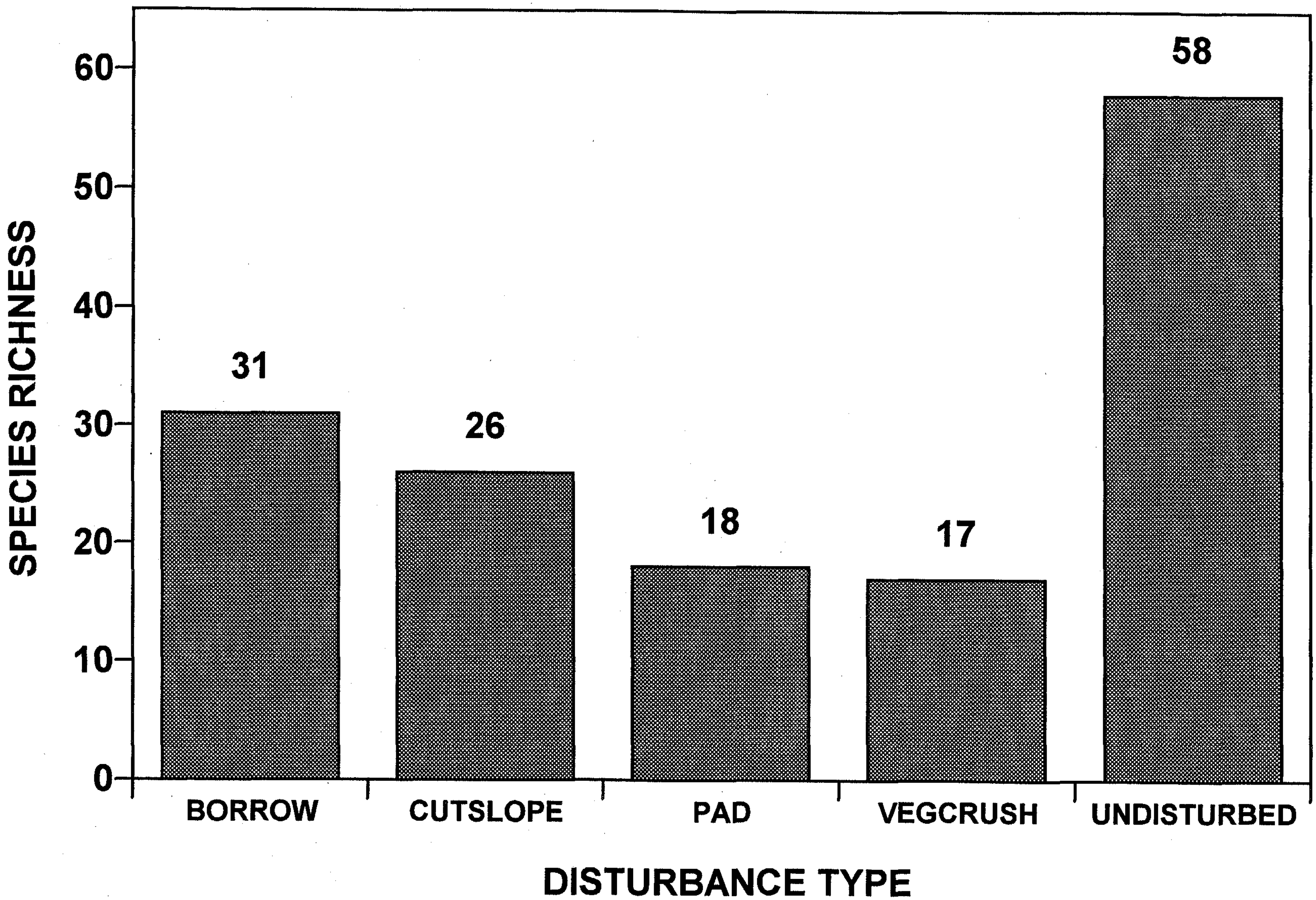


Figure 32. Species richness (number) of perennial plant species found in disturbance types and undisturbed sites at Yucca Mountain, NV. The disturbance types were as follows: borrow areas (BORROW), cutslopes (CUTSLOPE), drill pads (PAD), and areas with crushed vegetation (VEGCRUSH).

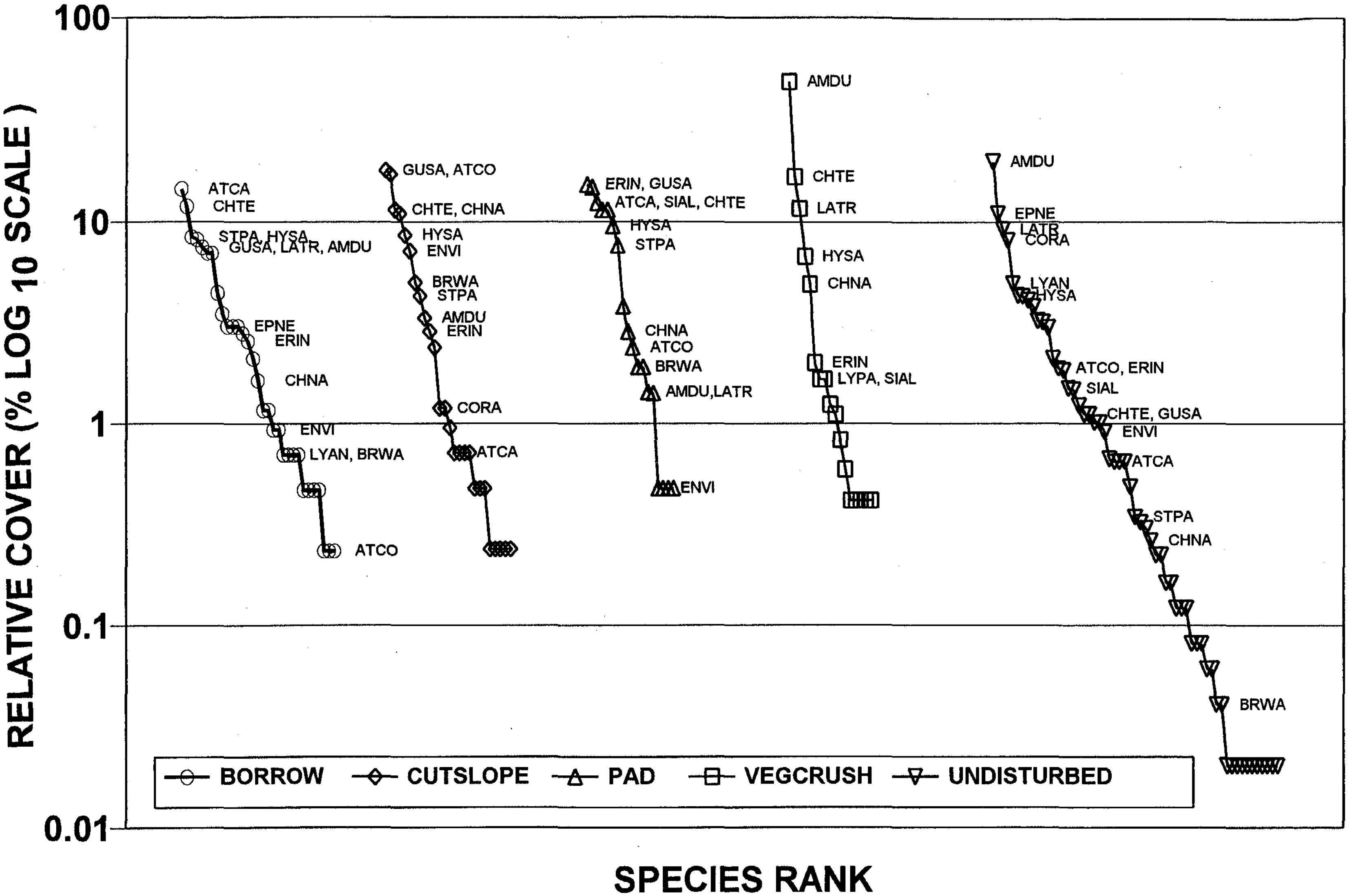


Figure 33. Dominance-diversity curves for relative cover (%) of perennial plant species for disturbance types and undisturbed areas Yucca Mountain, NV. The disturbance types were as follows: borrow areas (BORROW), cutslopes (CUTSLOPE), drill pads (PAD), and areas with crushed vegetation (VEGCRUSH). Species shown were the top seven dominant species in disturbance types and undisturbed areas. For explanation of species codes, see Appendix Table 1.

6.0 DISCUSSION

6.1 ENVIRONMENTAL VARIABLES INFLUENCING DISTURBED SITE SUCCESSION

Disturbed site revegetation at Yucca Mountain was primarily influenced by site location and soil properties. The differences in sites, as displayed by their correlations with the location and soil environmental variables, indicate the site-specific nature of the environmental influences at Yucca Mountain. As seen in the canonical correspondence analysis biplots, individual sites and perennial plant species could be grouped according to their positive and negative correlations with the dominant environmental variables (Figures 12, 13, 17, and 21).

Elevation was the most highly correlated variable in the canonical correspondence analysis across sites. The correlation of elevation with species composition and abundance on disturbances was an indication of the soil and microclimate differences imposed by the change in elevation from the summit of Yucca Mountain down to Forty-Mile wash (Figure 3). Species compositional differences along this gradient were evident in the CCA biplot for perennial species (Figure 13). Species such as *C. ramosissima, A. tridentata,* and *H. jamesii* had the greatest cover at high elevations while *A. shockleyi* and *C. paniculatus* had the greatest cover at low elevations, indicating the habitat preferences for these species. When sites were categorized by vegetation associations, elevation continued to play a dominant role in species composition and abundance on the disturbed sites within the *Lycium-Grayia* and the *Larrea-Lycium-Grayia* vegetation associations (Figures 17 and 21).

Across sites, soils factors were the other dominating environmental variables. Degree of soil compaction, percent soil gravel, soil potassium, and percent sand influenced the species composition and abundance on the disturbed sites. As with elevation, certain perennial species were highly correlated with specific soil factors (Figure 13). The high degree of variability in sites was again an indication of the site-specific responses to disturbance.

For the purposes of reclamation planning, it is important to know the factors that will influence the success or failure of reclamation at a site. In this study, the determination of the environmental variables influencing disturbed site succession will aid in deciding how these variables can be used or manipulated to improve the success of reclamation. In the case of elevation, this is location specific, and cannot be manipulated. However, soil factors, in most cases, can be manipulated. Soil compaction could be alleviated by ripping or disking. Low amounts of potassium could be mitigated by adding fertilizer. In the case of the *Lycium-Grayia* vegetation association, the amount of precipitation for the first three years after disturbance was a dominant environmental variable, especially for sites in the low elevational range for this association. This could be mitigated by irrigating a site for the first three years after seeding the site.

The disturbance type also appeared to have an influence on the species composition and abundance on disturbances at Yucca Mountain. The specific environmental factors influencing each disturbance type could not be gleaned from the data since they were scattered across the elevational gradient; however, the individual disturbance types did differ in species composition and in relative amounts of forbs, grasses and shrubs (Figures 29 and 31). Some of the effects of disturbance type could be mitigated in reclamation. Borrow areas could have topsoil respread over the sites to improve the growth medium. Cutslopes, if lacking in sufficient soil, could have topsoil imported to them and respread. Drill pads, in many cases, were constructed with imported soil used to level the pad. These soils tended to be very compacted compared to other disturbance types. Compaction could be alleviated by ripping or disking.

Each disturbed site at Yucca Mountain differs by the disturbance type and the environmental variables influencing plant species composition and abundance. Because these influences vary by site, and as with elevation, some cannot be manipulated, reclamation plans should to be prepared on a site-specific basis.

6.2 DISTURBED SITE PLANT SPECIES

A. dumosa, C. teretifolius, H. salsola, G. sarothrae, A. confertifolia, A. canescens, and S. pauciflora were the most dominant plants across all disturbed sites at Yucca Mountain with subsets of these species being dominants in each of the vegetation associations (Figures 8, 15, 19, 23, 26) . These species generally have characteristics of being prolific seed producers and/or have windblown seeds. Rowlands et al. (1980) report that, in the Mojave Desert, the majority of species dominating sites after a disturbance tend to have wind disseminated seed. *C. teretifolius, G. sarothrae*, and *S. pauciflora* produce small seeds with tufts of hair that are easily dispersed by wind. *H. salsola, A. confertifolia, A. canescens,* and *A. confertifolia* produce winged seeds. *A. dumosa* is a prolific seeder (Vasek, 1983) that produces bur-type seeds that can be dispersed by wind or in the fur of passing animals.

Topsoil was removed from most of the disturbances inventoried in this study, thus removing most of the native seedbank. Recruitment of new plants into these disturbances appears to have been via windblown seed from the adjacent undisturbed areas. The low abundance or complete absence of species such as *E. nevadensis, L. andersonii,* and *M. spinescens* (Figure 7) may partially confirm this. *E. nevadensis* and *M. spinescens* have heavy seeds (when compared to the windblown seeds) that may depend on rodent caching or overland flow of water for dispersal. Otherwise, these species establish in close proximity to the mother plants. *L. andersonii* has small seed contained in a fleshy fruit. This species' dispersal may depend on rodent caching or by birds eating the fruit and later dispersing the seeds via their feces. The lack of vegetative cover on disturbances may reduce rodent caching because of increased chance of being preyed upon, and the lack of vertical structure provided by larger shrubs may reduce bird use of the sites, thus, reducing fecal deposition of seeds. Therefore, recruitment of *E. nevadensis, M. spinescens,* and *L. andersonii* from seed may be limited to the disturbed/undisturbed vegetation edge.

The species described above that have established readily on disturbed sites may or may not be suitable for use in reclamation at Yucca Mountain. Since many of these species on disturbances were not major components of the undisturbed sites (the exception was *A. dumosa)*, they may not be suitable if the long-term objective of reclamation at Yucca Mountain is to return disturbances to a form and productivity similar to that of the undisturbed site (as stated in the Draft Reclamation Plan for Yucca Mountain, DOE, 1989). An understanding of how species dominant in disturbed sites influence the long-term succession of sites is important in determining the suitability of a species for use in reclamation. Connell and Slatyer (1977) outlined three models of succession after disturbance: 1) facilitation, 2) tolerance and 3) inhibition. The facilitation model describes a process where early successional species facilitate the ingress and establishment of later successional species (Pickett et al., 1987). The tolerance model describes a process where species establishment is dependent on whether it can tolerate the initial conditions of the disturbed site (Pickett et al., 1987). The inhibition model describes a process where later successional species cannot establish in the presence of a healthy early successional plant community (Pickett et al., 1987). If species dominating disturbed sites at Yucca Mountain act as facilitators, then their use would be beneficial for reclaiming disturbances. However, if the species that readily establish on disturbed sites inhibit or at least increase the time for establishment of the species that dominated the site prior to disturbance, then they are not suitable for reclamation. Conditions at the disturbed sites could be so harsh that species dominating disturbances are the only species that can tolerate the conditions. Research needs to be conducted at Yucca Mountain to determine whether species dominating disturbances are facilitators, inhibitors, or tolerators. Results from these studies will aid in determining the use of these species for reclamation.

Species could also be selected based on their locations in the canonical correspondence analysis biplot for perennial species (Figure 13, 17, and 21). The cover of *L. andersonii, L. tridentata, A. dumosa,* and *G. spinosa* was correlated with the amount of sand in the soil, with greater cover of these species on site with sandy soils. *B. watsonii* cover was correlated with soil gravel amounts. This species may be suitable on sites where the amount of soil gravel cannot be changed via topsoil addition or some other means. A portion of the disturbed sites within the LLG vegetation association were correlated with exchangeable sodium in the soil (Figure 21). *A. canescens* and *P. fremontii* cover was highly correlated to exchangeable sodium giving an indication that these species may be suitable for use on this type of site.

6.3 NATURAL REVEGETATION SUCCESS

For the purposes of this study, the "success" of natural revegetation (secondary succession) will be defined as how similar disturbed plant community attributes (perennial cover, density and species richness) are to those of adjacent undisturbed areas. This is based on the criterion by which the success of revegetation by site reclamation will be measured at Yucca Mountain. The Draft Reclamation Program Plan for Site Characterization (DOE, 1989) states "the objective of the DOE reclamation program at Yucca Mountain is to return land disturbed by site characterization activities to a stable ecological state with a form and productivity similar to the predisturbance state". Using this criterion, plant communities on the disturbed sites at

Yucca Mountain appear to be quite different from the undisturbed sites in regard to their species richness, total density, and total cover of perennials (Figures 6, 8, 9).

Across all sites, the perennial plant species found on the disturbed sites were also found in the undisturbed sites; however, the dominant species on disturbed sites were generally quite different from the undisturbed areas. Disturbed areas were dominated by species that generally had low cover in the undisturbed areas. This trend has been documented in other studies of Mojave Desert disturbances (Wells, 1961; Webb and Wilshire, 1980; Vasek, 1983; Webb et al., 1983). Apparently, the factors described above regarding seed dissemination and establishment influence this trend.

The low cover values and complete absence of the undisturbed dominant species in the disturbed sites is another indication that natural revegetation has not been successful up to this point. The dominant species on undisturbed sites are a critical component in providing the original form and productivity of a site. Vasek (1983) states that species dominating undisturbed sites are usually long-lived perennials that respond strongly and negatively to disturbance, and require long periods of time to re-establish. However, once these species become established, they can persist for several hundred years. The re-establishment of many of the species dominating undisturbed sites onto disturbed sites at Yucca Mountain may be hampered by seed production and specific germination requirements of these species. For example, *C. ramosissima*, produces seed, on average, every five years, and requires at least a 14 day period of freezing temperatures for the majority of seeds to germinate (Pendelton et al., 1993). Sheps (1973) reported establishment of *Larrea tridentata* seedlings after a period of high temperatures and high rainfall in Death Valley (a rare combination of events in the Mojave desert); however, only 16% of the seedlings survived after one year. Barbour (1968) reported that the conditions for optimal germination (in the laboratory) of *L. tridentata* were: darkness, a temperature of 23 °C (73 °F), leaching mericarps with running water, exposure to cold temperatures prior to sowing, and maintaining the sowing medium at near-zero osmotic pressure and low in salts. The author stated that the combination of these events may be a rare occurrence in the natural environment of deserts. *G. spinosa*, a dominant in the *Lycium-Grayia* vegetation association, requires a cool, moist, seedbed throughout the late fall and winter months in order to have optimal germination in the spring (Shaw et al., 1994). The specific requirements and the narrow range of tolerance displayed by these species may hinder their establishment in most years.

The lack of natural revegetation "success" on disturbed sites at Yucca Mountain may also be the result of the type and condition of the disturbance. Webb et al. (1983) state that conditions of the disturbed site may be so different from the undisturbed community (e.g. degree of compaction, amount of topsoil, etc) that the resulting plant community may have a species composition and abundance that is strikingly different from the undisturbed site. If these conditions persist, the site may never be similar to the predisturbance plant community. Since the majority of the disturbances at Yucca Mountain have had topsoil removed, bedrock exposed, or are compacted, the conditions may be so harsh that the successional trend may be toward a plant community different from the undisturbed sites. Because this is a point in time study and these disturbances are relatively young, future visits to these disturbances will be required to determine a more accurate description of the successional trend.

6.4 SUCCESSION RATES

Average perennial density and cover on disturbed sites was 30 to 37% less than that of undisturbed sites after an average of 10 years. The estimated succession rate, based on the "optimistic" linear extrapolation, indicated that perennial plant cover (without consideration to the species composition and abundance comprising the cover) would reach that of the undisturbed areas after 20 years (Figure 11). The succession rates estimated using the logarithmic extrapolation can be viewed as a more probable rate of recovery because this function more closely represents plant community growth rates. Vasek et al. (1975b) stated that secondary succession in the Mojave desert would be expected to have "slow initial regeneration, rapid intermediate development during an exponential phase, and then slow and very slow development during senescence or during an asymptotic approach to final conditions". Succession rates estimated with the logarithmic extrapolation indicated rapid increases in cover during the first five years with the increase in cover increasing very slowly thereafter. An estimated 845 years would be required for cover on disturbances to reach that of undisturbed areas with this extrapolation.

The above described succession rates for perennial plant cover do not take into consideration the species composition and abundances that comprise the cover. As seen in Figure 7, the species comprising the total plant cover on disturbances were quite different from the undisturbed sites. If disturbed sites are compared to undisturbed sites with regard to the undisturbed site species composition and abundance, individual recovery rates for the ten undisturbed dominant species (based on cover and the linear relationship) ranged from 31 years (*A. dumosa)* to 1,100 years (*G. spinosa)* (Table 1). If the end product of secondary succession on these disturbed sites is to have a plant community similar to that of the undisturbed sites, then the time required for this to occur is probably much greater than that estimated above for the "optimistic" linear extrapolation and the "more probable" logarithmic extrapolation.

The succession rates described above for cover are slightly different, but fall within the range of those reported elsewhere in the literature for Mojave Desert disturbances. Webb and Wilshire (1983) reported a rate of approximately 40 years for cover (regardless of species composition and abundance) to be replenished on disturbances at the Wahmonie townsite in Area 25. These authors estimated that total recovery, based on the undisturbed site cover, density, and species richness, would take 200 to 1,000 years. Lathrop (1983) reported rates of 45 to 112 years for cover and 76 to 212 years for density to recover on areas disturbed by military maneuvers. The author attributed the ranges in recovery times to the differences in soil compaction at the sites. Vasek (1983) reported that total recovery of disturbed sites in the Mojave desert would require several centuries to several thousand years depending on the degree of disturbance at the site.

An understanding of the rate and success of secondary succession at Yucca Mountain is very important for determining the cost/benefit of reclamation. A benefit of using reclamation is that it will speed the successional process with the use of appropriate site preparation techniques and plant materials. Reclamation is a feasible alternative to natural revegetation at Yucca Mountain, not only because it reduces the time required for the disturbed site to return to its original form and productivity, but it is also beneficial for controlling erosion on disturbed sites and reducing the visual impacts caused by the disturbance. Reclamation studies being conducted now and in the future at Yucca Mountain will aid in determining how successful reclamation is compared to the rate and success of natural revegetation.

7.0 CONCLUSIONS

1. Secondary succession on disturbed sites at Yucca Mountain was highly variable with respect to environmental parameters measured. Elevation was the most important variable influencing the composition and abundance of perennial plant species across disturbances. Soil compaction, soil potassium, soil gravel and amount of sand in the soil were other important environmental parameters.

2. *A. dumosa, C. teretifolius, H. salsola, G. sarothrae, A.confertifolia, A. canescens,* and *S. pauciflora* were the most dominant plants across all disturbed sites at Yucca Mountain with subsets of these species being dominants in each of the vegetation associations.

3. With the exception of *A. dumosa,* species that dominated disturbed sites were generally minor components of the undisturbed areas.

4. The form and productivity of disturbed sites is markedly different from that of undisturbed sites. Using the criterion set forth in the Draft Reclamation Program Plan, natural revegetation on disturbances at Yucca Mountain, after an average of 10 years, has not met the reclamation goal.

5. The time required for cover to be similar to that of undisturbed areas was estimated to be 20 years for an optimistic recovery rate and 845 years for the more probable recovery rate. However, the time required for the species composition and abundance in disturbances to approach that of undisturbed areas may require even more time than the above estimates.

8.0 RECOMMENDATIONS

1. Site-specific reclamation plans developed for disturbed sites should include considerations for elevation, vegetation association, species composition and abundances in adjacent undisturbed areas, soil properties, and the type of disturbance. Reclamation trials should be implemented to investigate ways to mitigate, manipulate, or benefit from the site-specific circumstances imposed by disturbed site location, soil properties, and disturbance type.

2. Reclamation studies should be conducted to determine whether the use of pioneer species (i.e. those species dominating disturbed sites) will enhance the successional process and meet the objectives of the reclamation program at Yucca Mountain.

3. Studies should be conducted to assess why dominant species in the undisturbed areas are minor components on disturbed sites, and how to enhance the establishment of these species on disturbed sites. Information from these studies will aid in the development of mitigation procedures for site-specific reclamation.

4. A portion of these disturbed sites should be selected along the elevational gradient and monitored every five years to determine if the successional trend is toward that of the original species composition and abundance, or if these disturbances continue to have a plant community is different from the adjacent undisturbed areas.

5. Results from reclamation studies should be compared to this study and future disturbed site succession studies to verify that the rate and success of reclamation is sufficiently greater than that of natural revegetation of disturbed sites.

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10.0 APPENDIX

Appendix Table 1. Codes, scientific names, common names, life cycle and growthform of plant species found in undisturbed and disturbed areas at Yucca Mountain, NV. Common names follow those used by Beatley (1976), Munz (1979) and Hickman (1993).

Code	Scientific Name	Common Name	Life Cycle[1]	Growth Form[2]
ACSH	*Acamptopappus shockleyi*	Goldenhead	P	S
AMDU	*Ambrosia dumosa*	Bursage	P	S
AMTE	*Amsinckia tessellata*	Bristly fiddleneck	AW	F
ARFE	*Aristida fendleriana*		P	G
ARPU	*Aristida pupurea*	Purple threeawn	p	G
ARSP	*Artemesia spinescens*	Budsage	P	S
ARTR	*Artemesia tridentata var. tridentata*	Big sagebrush	P	S
ASAC	*Astragalus acutirostris*	Locoweed	AW	F
ASLA	*Astragalus layneae*	Layne's locoweed	P	F
ATCA	*Atriplex canescens var. canescens*	Fourwing saltbush	P	S
ATCO	*Atriplex confertifolia*	Shadscale	P	S
BRRU	*Bromus rubens*	Red brome	AW	F
BRTE	*Bromus tectorum*	Cheat grass	AW	F
BRWA	*Brickellia watsonii*	Brickellbush	P	S
CACH	*Castilleja chromosa*	Indian paintbrush	P	F
CAFL	*Calochortus flexuosus*	Desert lilly	P	F
CAHE	*Camissonia heterochroma*	Shockley's evening primrose	A	F
CAMSPP	*Camissonia species*		A	F
CELA	*Ceratoides lanata*	Winterfat	P	S
CHBR	*Chorizanthe brevicornu var. brevicornu*	Brittle spineflower	AW	F
CHNA	*Chrysothamnus nauseosus ssp. leiospermus*	Rubber rabbitbrush	P	S
CHPA	*Chrysothamnus paniculatus*	Black-stem rabbitrush	P	S
CHRI	*Chorizanthe rigida*	Devil's spiny herb	AW	F
CHSPP	*Chaenactis species*		AW	F
CHST	*Chaenactis stevioides*	Steves duskymaiden	AW	F
CHTE	*Chrysothamnus teretifolius*	Needle leaf rabbitbrush	P	S
CHTH	*Chorizanthe thurberi*	Spineflower	AW	F
CHVI	*Chrysothamnus viscidiflorus ssp. stenophyllus*	Yellow rabbitbrush	P	S
CORA	*Coleogyne ramosissima*	Blackbrush	P	S
CRCI	*Cryptantha circumscissa*	Matted Cryptantha	AW	F

Appendix Table 1. Continued.

Code	Scientific Name	Common Name	Life Cycle[1]	Growth Form[2]
CRMI	*Cryptantha micrantha*	Cryptantha	AW	F
CRNE	*Cryptantha nevadensis var. nevadensis*	Cryptantha	AW	F
CRPT	*Cryptantha pterocarya*	Winged Cryptantha	AW	F
CRSPP	*Cryptantha species*		AW	F
DEPA	*Delphinium parishii var. parishii*	Desert larkspur	P	F
DEPI	*Descurainia pinnata ssp. glabra*	Pinnate tansymustard	AW	F
DESO	*Descurainia sophia*	Tansy-mustard	AW	F
DIPU	*Dichelostemma pulchellum*	Bluedick	P	F
ECEN	*Echinocereus engelmanii var. engelmannii*	Hedgehog cactus	P	C
ECPO	*Echinocactus polycephalus*	Cottontop barrelcactus	P	C
ENVI	*Encelia virginensis ssp. virginensis*	Brittlebush	P	S
EPNE	*Ephedra nevadensis*	Nevada Mormon tea	P	S
EPVI	*Ephedra viridis*	Green Ephedra	P	S
ERCI	*Erodium cicutarium*	Storksbill	AW	F
ERDE	*Eriogonum deflexum var. nevadense*	Skeletonweed	AW	F
ERER	*Eriastrum eremicum*	Eriastrum	AW	F
ERFA	*Eriogonum fasciculatum var. polifolium*	California buckwheat	P	S
ERIN	*Eriogonum inflatum*	Desert trumpet	P	F
ERMA	*Eriogonum maculatum*	Rose/white	AW	F
ERMI	*Eriogonum microthecum var. foliosum*	Buckwheat	P	S
ERNI	*Eriogonum nidularium*	Buckwheat	AW	F
ERPR	*Eriophyllum pringlei*	Pringle's wooly leaf	AW	F
ERPU	*Erioneuron pulchellum*	Fluff grass	P	G
ERSP	*Eriastrum sparsiflorum*	Eriastrum	A	F
ERUM	*Eriogonum umbellatum*	Sulfur flower	P	F
ESMI	*Eschscholzia minutiflora*	Pygmy poppy	AW	F
EUAL	*Euphorbia albamarginata*	Rattlesnake weed	P	F
EUMI	*Euphorbia micromera*	Leafy spurge	AS	F
GIFL	*Gilia flavocincta*	Gilia	AW	F
GISPP	*Gilia species*		AW	F
GRSP	*Grayia spinosa*	Spiny hopsage	P	S
GUSA	*Gutierrezia sarothrae*	Matchweed	P	S

Appendix Table 1. Continued.

Code	Scientific Name	Common Name	Life Cycle[1]	Growth Form[2]
HACO	*Haplopappus cooperi*	Goldenbush	P	S
HAGL	*Halogeton glomeratus*	Halogeton	A	F
HALI	*Haplopappus linearifolius*	Interior goldenbush	P	S
HIJA	*Hilaria jamesii*	Galleta	P	G
HYSA	*Hymenoclea salsola*	Burrobrush	P	S
JUOS	*Juniperus osteosperma*	Dwarf Juniper	P	T
KRPA	*Krameria parvifolia*	Ratany	P	S
LASC	*Langloisia schottii*	Shott's calico	AW	F
LATR	*Larrea tridentata*	Creosote bush	P	S
LEDE	*Lepidium densiflorum*	Prairie pepperweed	P	F
LEFR	*Lepidium fremontii*	Desert pepperweed	P	F
LELA	*Lepidium lasiocarpum*		AW	F
LEPU	*Leptodactylon pungens ssp. hallii*	Prickly gila	P	S
LOHU	*Lotus humistratus*	Foothill deervetch	AW	F
LUCO	*Lupinus concinnus var. orcuttii*	Bajada Lupine	AW	F
LUFL	*Lupinus flavoculatus*	Lupine	AW	F
LUPIN	*Lupinus species*		A	F
LUSP	*Lupinus sparsiflorus*	Coulter's Lupine	A	F
LYAN	*Lycium andersonii*	Box thorn	P	S
LYPA	*Lycium pallidum var. obligospermum*	Wolfberry	P	S
MACA	*Machaeranthera canescens var. canescens*		P	F
MAGL	*Malacothrix glabrata*	Smooth tooth dandelion	AW	F
MATO	*Machaeranthera tortifolia var. tortifolia*	Desert-aster	P	F
MEOB	*Mentzelia obscura*	Silverstems	AW	F
MESP	*Menodora spinescens*	Menodora	P	S
MIBI	*Mirabilis bigelovii*	Desert wishbone bush	P	F
MOBE	*Monoptilon bellidiforme*	Desert star	AW	F
MUPO	*Muhlenbergia porteri*	Bush muhly	P	G
NADE	*Nama demissum var. demissum*		AW	F
OPBA	*Opuntia basilaris var. basilaris*	Beavertail pricklypear	P	C
OPEC	*Opuntia echinocarpa var. echinocarpa*	Strawtop pricklypear	P	C
ORHY	*Oryzopsis hymenoides*	Indian ricegrass	P	G

Appendix Table 1. Continued.

Code	Scientific Name	Common Name	Life Cycle[1]	Growth Form[2]
OXPE	*Oxytheca perfoliata*	Roundleaf spineflower	AW	F
PEPL	*Pectocarya platycarpa*	Pectocarya	AW	F
PESE	*Pectocarya setosa*		AW	F
PHFR	*Phacelia fremontii*	Freemont's Pacelia	AW	F
PHRO	*Phacelia rotundifolia*		A	F
PHSPP	*Phacelia species*		AW	F
PSAN	*Psathyrotes annua*	Turtleback	A	F
PSFR	*Psorothamnus fremontii var. fremontii*	Indigo bush	P	S
RANE	*Rafinesquia neomexicana*	New Mexico plumseed	AW	F
SAIB	*Salsola iberica*	Russian thistle	A	F
SAME	*Salazaria mexicana*	Bladdersage	P	S
SCAR	*Schismus arabicus*	Arabian Scismus	AW	G
SCPO	*Sclerocactus polyancistrus*		P	C
SIAL	*Sisymbrium altissimum*	Tumblemustard	PB	F
SIHY	*Sitanion hystrix*	Squirreltail	P	G
SIJU	*Sitanion jubatum*		P	G
SPAM	*Sphaeralcea ambigua ssp. ambigua*	Globemallow	P	F
SPCR	*Sporobolus cryptandrus*	Sand dropseed	P	G
STEX	*Stephanomeria exigua ssp. exigua*	Small wirelettuce	AW	F
STPA	*Stephanomeria pauciflora*	Wire-lettuce	P	F
STSP	*Stipa speciosa*	Desert needlegrass	P	G
SYFR	*Syntrichopappus fremontii*	Syntrichopappus	AW	F
TEAX	*Tetradymia axillaris var. axillaris*	Longspine horsebush	P	S
TEGL	*Tetradymia glabrata*	Littleleaf horsebush	P	S
VUOC	*Vulpia octoflora*	Sixweeks fescue	AW	G
YUBR	*Yucca brevifolia*	Joshua tree	P	T

[1] A = Annual, AW = Annual, Winter growing season, B = Biennial, P = Perennial

[2] C = Cactus, F = Forb, G = Grass, S = Shrub, T = Tree

Appendix Table 2. Pearson's correlation coefficients (r) for environmental variables used to test for their influence on species composition and abundance in disturbance areas. For long name of the environmental variable, see Appendix Table 3.

Environmental Variable	Age	Slope	Elev-ation	Aspect	Dist. Area	Grow-ppt	Gppt-sum	Gppt-3yr	Gppt-5yr	Depth	Cone-pen
Age	1.00	-0.19	0.08	-0.10	-0.11	0.24	0.99	0.90	0.64	-0.12	-0.03
Slope	-0.19	1.00	0.24	0.23	0.03	-0.22	-0.22	-0.16	-0.27	0.32	0.27
Elevation	0.08	0.24	1.00	-0.09	-0.08	-0.47	0.02	0.17	-0.26	-0.03	0.35
Aspect	-0.10	0.23	-0.09	1.00	-0.12	0.11	-0.11	-0.22	0.01	0.29	-0.09
Dist. Area	-0.11	0.03	-0.08	-0.12	1.00	-0.20	-0.10	0.01	-0.08	-0.14	0.06
Growppt	0.24	-0.22	-0.47	0.11	-0.20	1.00	0.32	0.14	0.45	-0.24	-0.08
Gpptsum	0.99	-0.22	0.02	-0.11	-0.10	0.32	1.00	0.90	0.70	-0.16	-0.04
Gppt3yr	0.90	-0.16	0.17	-0.22	0.01	0.14	0.90	1.00	0.38	-0.20	-0.01
Gppt5yr	0.64	-0.27	-0.26	0.01	-0.08	0.45	0.70	0.38	1.00	-0.11	-0.07
Depth	-0.12	0.32	-0.03	0.29	-0.14	-0.24	-0.16	-0.20	-0.11	1.00	-0.38
Conepen	-0.03	0.27	0.35	-0.09	0.06	-0.08	-0.04	-0.01	-0.07	-0.38	1.00
PerGrav	0.17	-0.08	0.17	-0.13	-0.02	0.13	0.21	0.29	0.13	-0.37	0.13
Satpercent	0.14	0.32	0.64	-0.02	0.03	-0.26	0.11	0.22	-0.10	0.13	0.23
pH	-0.10	-0.15	-0.22	-0.01	0.07	-0.04	-0.13	-0.07	-0.30	-0.04	-0.12
EC	-0.20	0.06	0.20	-0.22	0.21	-0.23	-0.19	-0.11	-0.13	-0.08	-0.08
CaH2O	-0.13	0.02	0.19	-0.24	0.10	-0.19	-0.12	-0.05	-0.09	-0.12	-0.09
MgH2O	-0.07	-0.05	0.18	-0.26	0.04	-0.15	-0.06	-0.00	-0.05	-0.14	-0.10
NAH2O	-0.24	0.09	0.20	-0.19	0.25	-0.24	-0.23	-0.15	-0.17	-0.04	-0.07
SAR	-0.22	0.01	0.25	-0.21	0.29	-0.28	-0.23	-0.12	-0.24	-0.10	-0.08
CaNH4	-0.03	-0.14	-0.06	-0.18	-0.07	0.10	-0.02	-0.00	-0.05	-0.12	0.33
MgNH4	-0.01	-0.16	-0.09	-0.17	-0.08	0.12	0.00	0.01	-0.02	0.18	0.23
NaNH4	-0.03	-0.16	-0.10	-0.17	-0.08	0.16	-0.02	-0.02	-0.01	-0.06	-0.09
P	0.29	-0.02	0.16	-0.08	-0.13	0.12	0.31	0.24	0.36	-0.16	0.09
K	0.27	-0.49	-0.35	-0.11	-0.08	0.32	0.30	0.16	0.37	-0.15	-0.21
NO3_N	0.03	-0.02	0.33	-0.26	0.03	-0.24	0.02	0.08	0.01	-0.31	0.20
OM	0.17	0.17	0.32	0.05	-0.06	-0.09	0.16	0.15	0.14	-0.19	0.44
CEC	0.02	0.38	0.69	-0.05	0.03	-0.33	-0.04	0.11	-0.33	0.14	0.29
Sand	-0.14	-0.32	-0.63	0.03	-0.06	0.22	-0.11	-0.24	0.14	0.19	-0.36
Silt	0.19	0.14	0.37	-0.01	0.09	-0.06	0.19	0.23	0.08	-0.35	0.25
Clay	0.03	0.38	0.67	-0.04	0.01	-0.29	-0.01	0.16	-0.31	0.05	0.34
Exch. Ca	-0.11	-0.08	-0.05	-0.19	-0.05	0.03	-0.11	-0.06	-0.15	-0.34	0.17
Exch. Mg	-0.01	-0.17	-0.11	-0.17	-0.08	0.13	0.00	0.00	-0.01	0.06	-0.13
Exch. Na	-0.02	-0.17	-0.10	-0.17	-0.08	0.12	-0.00	0.00	-0.02	-0.16	-0.14

Appendix Table 2 continued.

Environmental Variable	Per-Grav	Sat-percent	pH	EC	CaH2O	MgH2O	NAH2O	SAR	CaNH4	MgNH4	NaNH4
Age	0.17	0.14	-0.10	-0.20	-0.13	-0.07	-0.24	-0.22	-0.03	-0.01	-0.03
Slope	-0.08	0.32	-0.15	0.06	0.02	-0.05	0.09	0.01	-0.14	-0.16	-0.16
Elevation	0.17	0.64	-0.22	0.20	0.19	0.18	0.20	0.25	-0.06	-0.09	-0.10
Aspect	-0.13	-0.02	-0.01	-0.22	-0.24	-0.26	-0.19	-0.21	-0.18	-0.17	-0.17
Dist. Area	-0.02	0.03	0.07	0.21	0.10	0.04	0.25	0.29	-0.07	-0.08	-0.08
Growppt	0.13	-0.26	-0.04	-0.23	-0.19	-0.15	-0.24	-0.28	0.10	0.12	0.16
Gpptsum	0.21	0.11	-0.13	-0.19	-0.12	-0.06	-0.23	-0.23	-0.02	0.00	-0.02
Gppt3yr	0.29	0.22	-0.07	-0.11	-0.05	-0.00	-0.15	-0.12	-0.00	0.01	-0.02
Gppt5yr	0.13	-0.10	-0.30	-0.13	-0.09	-0.05	-0.17	-0.24	-0.05	-0.02	-0.01
Depth	-0.37	0.13	-0.04	-0.08	-0.12	-0.14	-0.04	-0.10	-0.12	0.18	-0.06
Conepen	0.13	0.23	-0.12	-0.08	-0.09	-0.10	-0.07	-0.08	0.33	0.23	-0.09
PerGrav	1.00	0.07	-0.03	-0.08	-0.07	-0.06	-0.08	-0.01	-0.01	-0.01	-0.01
Satpercent	0.07	1.00	-0.39	0.16	0.14	0.10	0.16	0.16	-0.13	-0.15	-0.16
pH	-0.03	-0.39	1.00	-0.15	-0.29	-0.31	-0.06	0.20	0.38	0.37	0.35
EC	-0.08	0.16	-0.15	1.00	0.91	0.84	0.98	0.82	-0.00	-0.02	-0.00
CaH2O	-0.07	0.14	-0.29	0.91	1.00	0.98	0.80	0.59	-0.03	-0.04	-0.03
MgH2O	-0.06	0.10	-0.31	0.84	0.98	1.00	0.70	0.51	-0.01	-0.02	-0.01
NAH2O	-0.08	0.16	-0.06	0.98	0.80	0.70	1.00	0.89	0.01	-0.00	0.01
SAR	-0.01	0.16	0.20	0.82	0.59	0.51	0.89	1.00	0.08	0.06	0.07
CaNH4	-0.01	-0.13	0.38	-0.00	-0.03	-0.01	0.01	0.08	1.00	1.00	0.97
MgNH4	-0.01	-0.15	0.37	-0.02	-0.04	-0.02	-0.00	0.06	1.00	1.00	0.97
NaNH4	-0.01	-0.16	0.35	-0.00	-0.03	-0.01	0.01	0.07	0.97	0.97	1.00
P	0.16	0.17	-0.58	-0.13	-0.02	0.03	-0.20	-0.33	-0.21	-0.20	-0.21
K	-0.20	-0.32	0.16	-0.10	0.00	0.08	-0.15	-0.14	0.52	0.54	0.56
NO3_N	0.05	0.23	-0.06	0.62	0.57	0.56	0.59	0.61	0.27	0.25	0.17
OM	-0.07	0.30	-0.36	0.06	0.12	0.13	0.02	-0.08	-0.22	-0.24	-0.24
CEC	-0.06	0.78	-0.13	0.21	0.14	0.10	0.25	0.30	0.07	0.04	0.04
Sand	-0.10	-0.63	0.34	-0.15	-0.19	-0.21	-0.12	-0.15	0.15	0.17	0.20
Silt	0.20	0.24	-0.26	0.11	0.18	0.24	0.06	0.10	-0.02	-0.03	-0.07
Clay	-0.05	0.79	-0.30	0.13	0.13	0.11	0.14	0.15	-0.22	-0.24	-0.26
Exch. Ca	0.04	-0.15	0.46	0.00	-0.00	0.01	0.01	0.12	0.95	0.94	0.91
Exch. Mg	-0.01	-0.18	0.38	-0.02	-0.04	-0.02	-0.01	0.05	1.00	1.00	0.97
Exch. Na	-0.01	-0.17	0.38	-0.01	-0.03	-0.01	0.01	0.07	1.00	1.00	0.97

Appendix Table 2 continued.

Environmental Variable	P	K	NO3_N	OM	CEC	Sand	Silt	Clay	Exch. Ca	Exch. Mg	Exch. Na
Age	0.29	0.27	0.03	0.17	0.02	-0.14	0.19	0.03	-0.11	-0.01	-0.02
Slope	-0.02	-0.49	-0.02	0.17	0.38	-0.32	0.14	0.38	-0.08	-0.17	-0.17
Elevation	0.16	-0.35	0.33	0.32	0.69	-0.63	0.37	0.67	-0.05	-0.11	-0.10
Aspect	-0.08	-0.11	-0.26	0.05	-0.05	0.03	-0.01	-0.04	-0.19	-0.17	-0.17
Dist. Area	-0.13	-0.08	0.03	-0.06	0.03	-0.06	0.09	0.01	-0.05	-0.08	-0.08
Growppt	0.12	0.32	-0.24	-0.09	-0.33	0.22	-0.06	-0.29	0.03	0.13	0.12
Gpptsum	0.31	0.30	0.02	0.16	-0.04	-0.11	0.19	-0.01	-0.11	0.00	-0.00
Gppt3yr	0.24	0.16	0.08	0.15	0.11	-0.24	0.23	0.16	-0.06	0.00	0.00
Gppt5yr	0.36	0.37	0.01	0.14	-0.33	0.14	0.08	-0.31	-0.15	-0.01	-0.02
Depth	-0.16	-0.15	-0.31	-0.19	0.14	0.19	-0.35	0.05	-0.34	0.06	-0.16
Conepen	0.09	-0.21	0.20	0.44	0.29	-0.36	0.25	0.34	0.17	-0.13	-0.14
PerGrav	0.16	-0.20	0.05	-0.07	-0.06	-0.10	0.20	-0.05	0.04	-0.01	-0.01
Satpercent	0.17	-0.32	0.23	0.30	0.78	-0.63	0.24	0.79	-0.15	-0.18	-0.17
pH	-0.58	0.16	-0.06	-0.36	-0.13	0.34	-0.26	-0.30	0.46	0.38	0.38
EC	-0.13	-0.10	0.62	0.06	0.21	-0.15	0.11	0.13	0.00	-0.02	-0.01
CaH2O	-0.02	0.00	0.57	0.12	0.14	-0.19	0.18	0.13	-0.00	-0.04	-0.03
MgH2O	0.03	0.08	0.56	0.13	0.10	-0.21	0.24	0.11	0.01	-0.02	-0.01
NAH2O	-0.20	-0.15	0.59	0.02	0.25	-0.12	0.06	0.14	0.01	-0.01	0.01
SAR	-0.33	-0.14	0.61	-0.08	0.30	-0.15	0.10	0.15	0.12	0.05	0.07
CaNH4	-0.21	0.52	0.27	-0.22	0.07	0.15	-0.02	-0.22	0.95	1.00	1.00
MgNH4	-0.20	0.54	0.25	-0.24	0.04	0.17	-0.03	-0.24	0.94	1.00	1.00
NaNH4	-0.21	0.56	0.17	-0.24	0.04	0.20	-0.07	-0.26	0.91	0.97	0.97
P	1.00	0.18	0.19	0.62	-0.01	-0.33	0.40	0.14	-0.28	-0.21	-0.21
K	0.18	1.00	0.13	0.11	-0.27	0.15	0.11	-0.36	0.43	0.54	0.54
NO3_N	0.19	0.13	1.00	0.32	0.26	-0.32	0.34	0.18	0.27	0.24	0.25
OM	0.62	0.11	0.32	1.00	0.22	-0.47	0.45	0.32	-0.22	-0.24	-0.24
CEC	-0.01	-0.27	0.26	0.22	1.00	-0.73	0.31	0.87	0.01	0.02	0.02
Sand	-0.33	0.15	-0.32	-0.47	-0.73	1.00	-0.82	-0.82	0.17	0.19	0.19
Silt	0.40	0.11	0.34	0.45	0.31	-0.82	1.00	0.34	-0.03	-0.04	-0.04
Clay	0.14	-0.36	0.18	0.32	0.87	-0.82	0.34	1.00	-0.25	-0.26	-0.26
Exch. Ca	-0.28	0.43	0.27	-0.22	0.01	0.17	-0.03	-0.25	1.00	0.94	0.94
Exch. Mg	-0.21	0.54	0.24	-0.24	0.02	0.19	-0.04	-0.26	0.94	1.00	1.00
Exch. Na	-0.21	0.54	0.25	-0.24	0.02	0.19	-0.04	-0.26	0.94	1.00	1.00

Appendix Table 3. Code names and explanations for environmental variables used to determine their influence on species composition and abundance of plants on disturbed areas at Yucca Mountain, NV.

Environmental Variable Code	Environmental Variable and Units
Age	Years since initial disturbance
Slope	Slope (%)
Elevation	Elevation (ft)
Aspect	Aspect (degrees)
Dist. Area	Disturbance Area (ha)
Growppt	Growing Season Precipitation (mm) - First year after initial disturbance
Gpptsum	Growing Season Precipitation (mm) - Sum of all years after initial disturbance
Gppt3yr	Growing Season Precipitation (mm) - Sum of first 3 years after initial disturbance
Gppt5yr	Growing Season Precipitation (mm) - Sum of first 5 years after initial disturbance
Depth	Depth Penetrometer reading (cm)
Conepen	Cone Penetrometer reading (kg/cm2)
PerGrav	Percent Gravel >2 mm in the soil
Satpercent	Soil Saturation Percentage
pH	Soil pH
EC	Soil Electrical Conductivity
CaH2O	Water soluable Calcium (meq/L of soil solution)
MgH2O	Water soluable Magnesium (meq/L of soil solution)
NAH2O	Water soluable Sodium (meq/L soil solution)
SAR	Sodium Absorption Ratio
CaNH4	NH4 Extractable Calcium (meq/100 g of soil)
MgNH4	NH4 Extractable Magnesium (meq/100 g soil)
NaNH4	NH4 Extractable Sodium (meq/100 g soil)
P	Phosphorus (mg/kg of soil)
K	Potassium (mg/kg of soil)

Appendix Table 3. continued

Environmental Variable Code	Environmental Variable and Units
NO3_N	Nitrate Nitrogen (mg/kg of soil)
OM	Soil Organic Matter (percent)
CEC	Cation Exchange Capacity (meq/100 g of soil
SAND	Sand (% by hydrometer)
SILT	Silt (% by hydrometer)
CLAY	Clay (% by hydrometer)
Exch. Ca	Exchangeable Calcium (%)
Exch. Mg	Exchangeable Magnesium (%)
Exch. Na	Exchangeable Sodium (%)

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