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Secondary succession on disturber sites at Yucca Mountain, Nevada. Describes results of revegetation studies conducted on past disturbance site at Yucca Mountain (EGG 11265-1118) UC-702

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ADMINISTRATIVE RECORD

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

1994

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REVIEWED BY

W. Kent Ostler

W. K. Ostler, Director
Environmental Sciences Divison

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Classification Officer

DECEMBER 1994

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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:

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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)

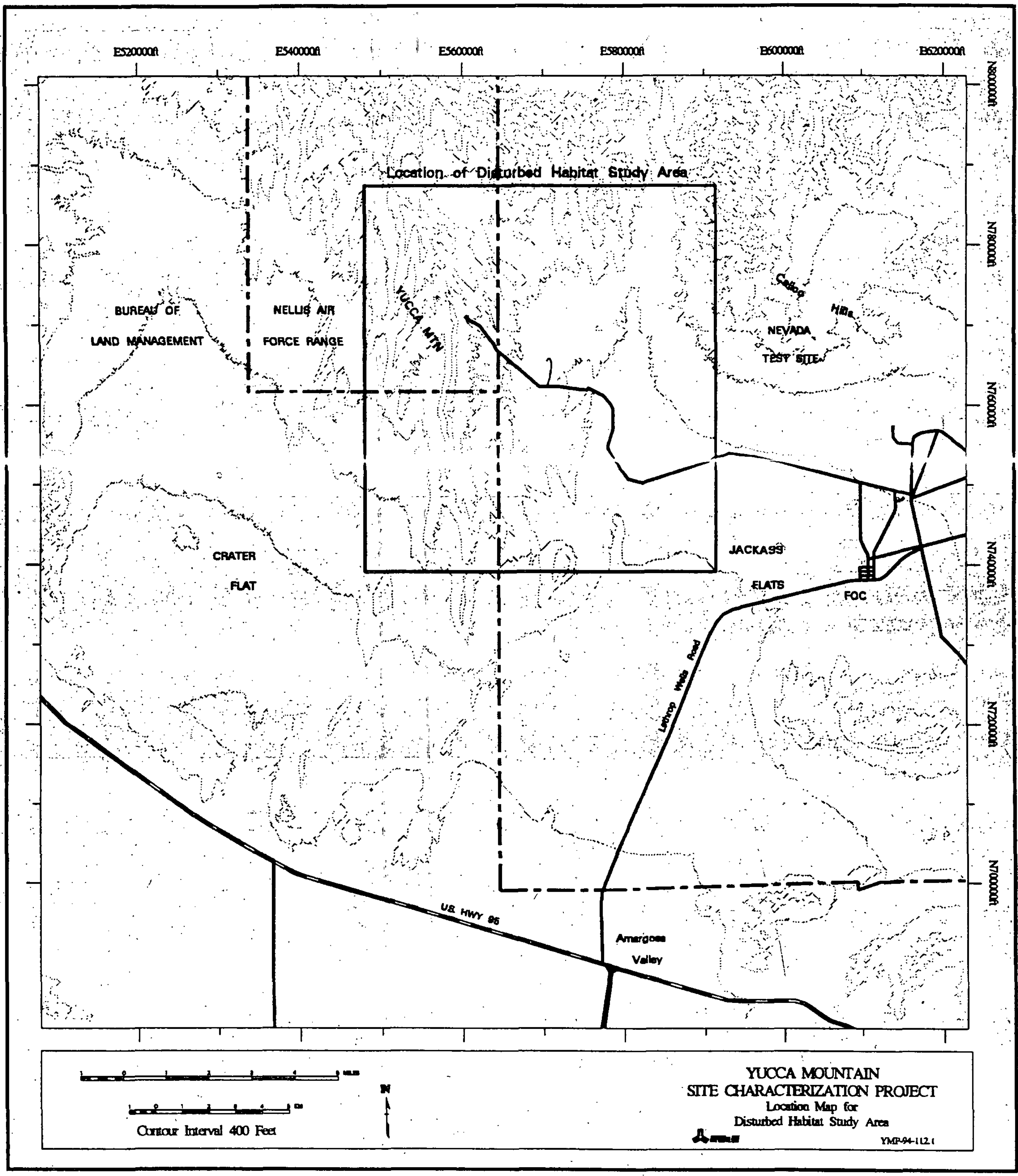
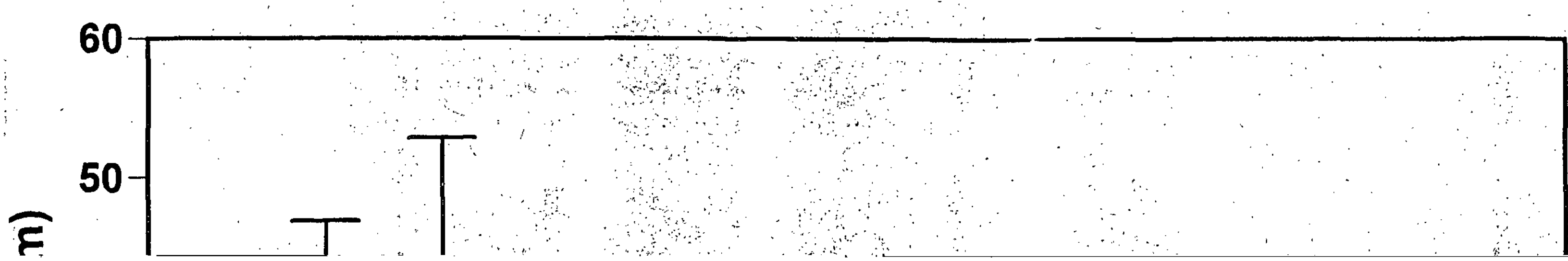
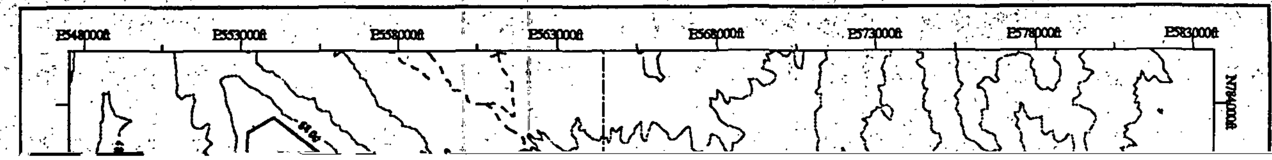


Figure 1. Location of Yucca Mountain, the disturbed habitat study area, and major topographical features.


60
50

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


E548000ft
E553000ft
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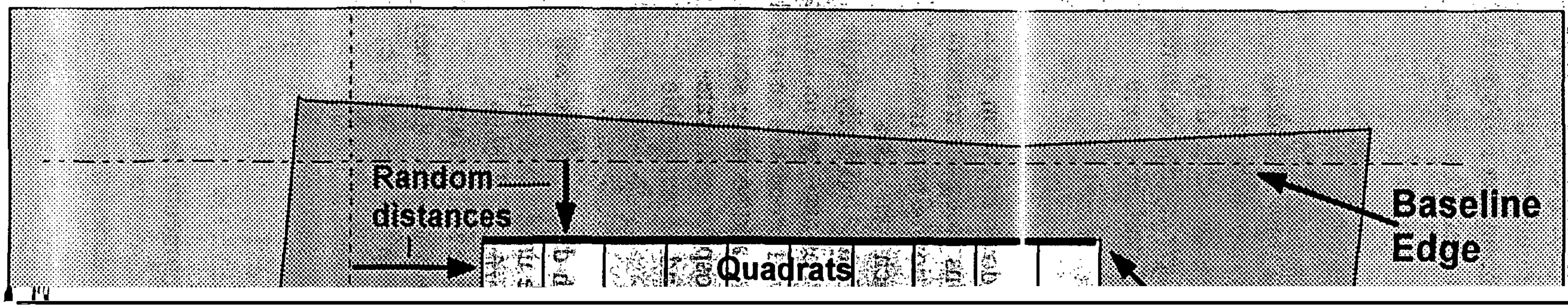
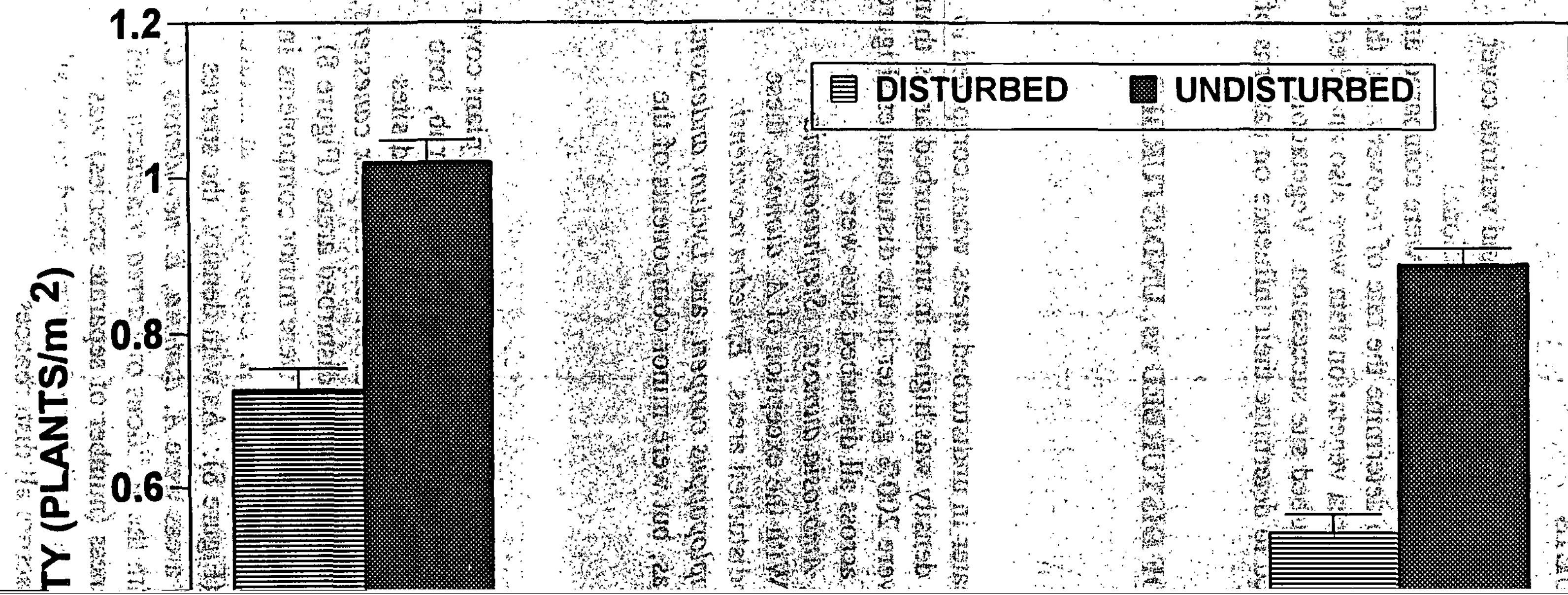
E563000ft
E568000ft
E573000ft
E578000ft
E583000ft
N784000ft

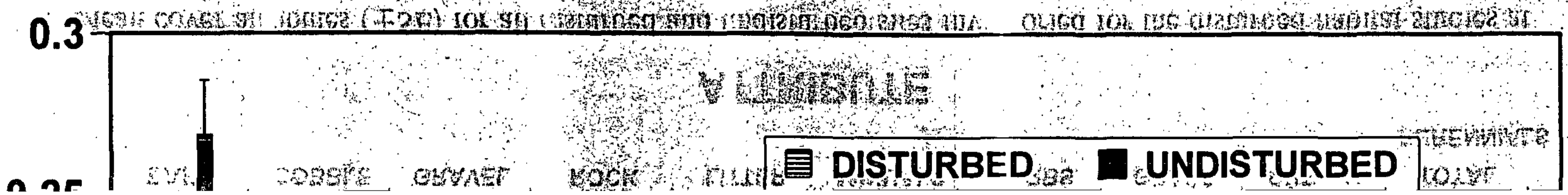

Random distances
Quadrats
Baseline Edge

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 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.

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


1.2
1
0.8
0.6
TY (PLANTS/m 2)
DISTURBED
UNDISTURBED


0.3
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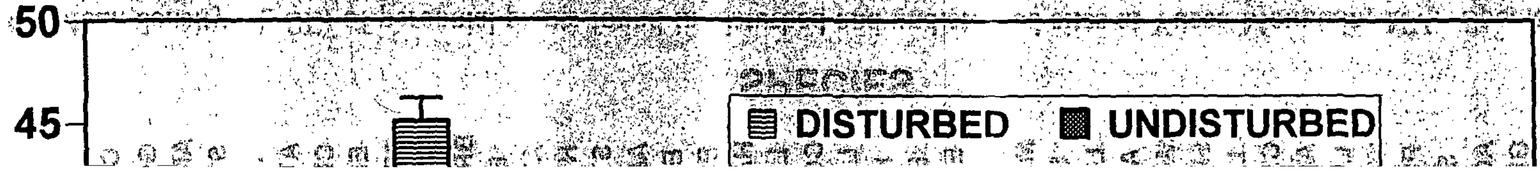
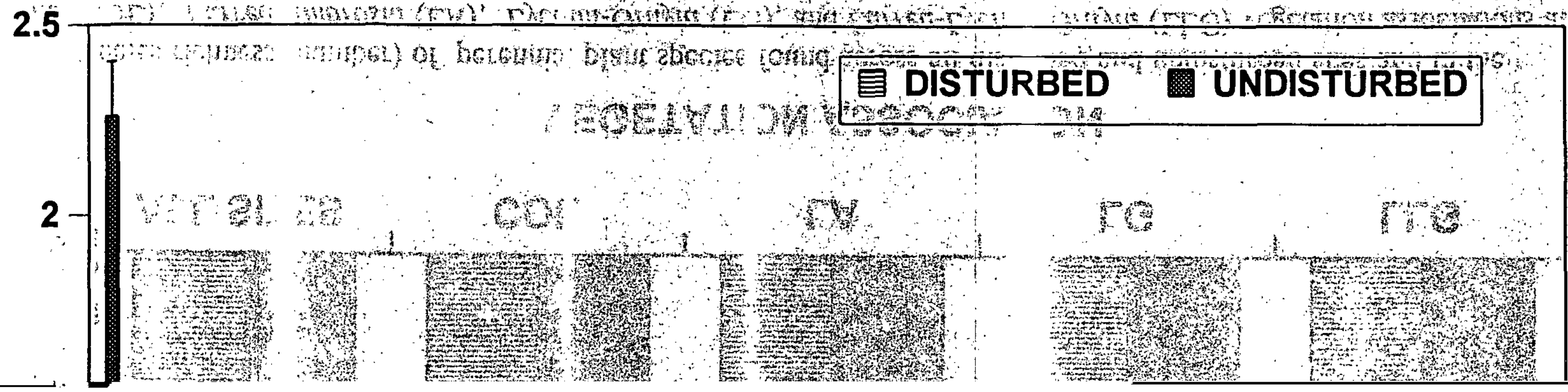

50
45
DISTURBED
UNDISTURBED


2.5
2
DISTURBED
UNDISTURBED

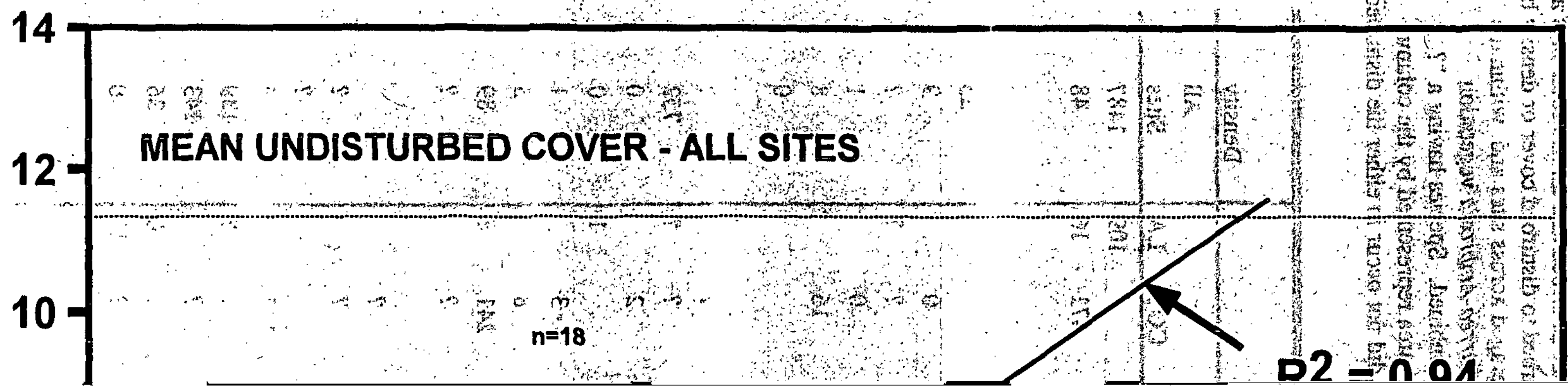

14
12
10
MEAN UNDISTURBED COVER - ALL SITES
n=18

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.

Scientific name	Species Code	Cover: All Sites	Cover: LG	Cover: LLG	Cover: COL	Cover: LA	Density: 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

Table 1. Continued

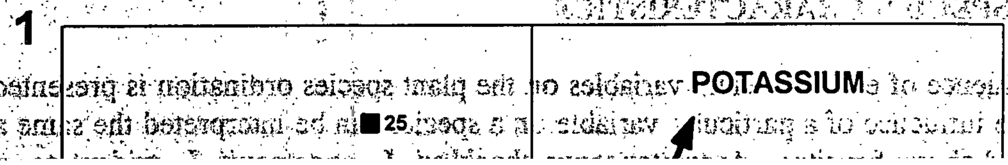
Scientific name	Species Code	Cover					Density
		All Sites	LG	LLG	COL	LA	All Sites
Gutierrezia sarothrae	GUSA	2	7		11		2

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

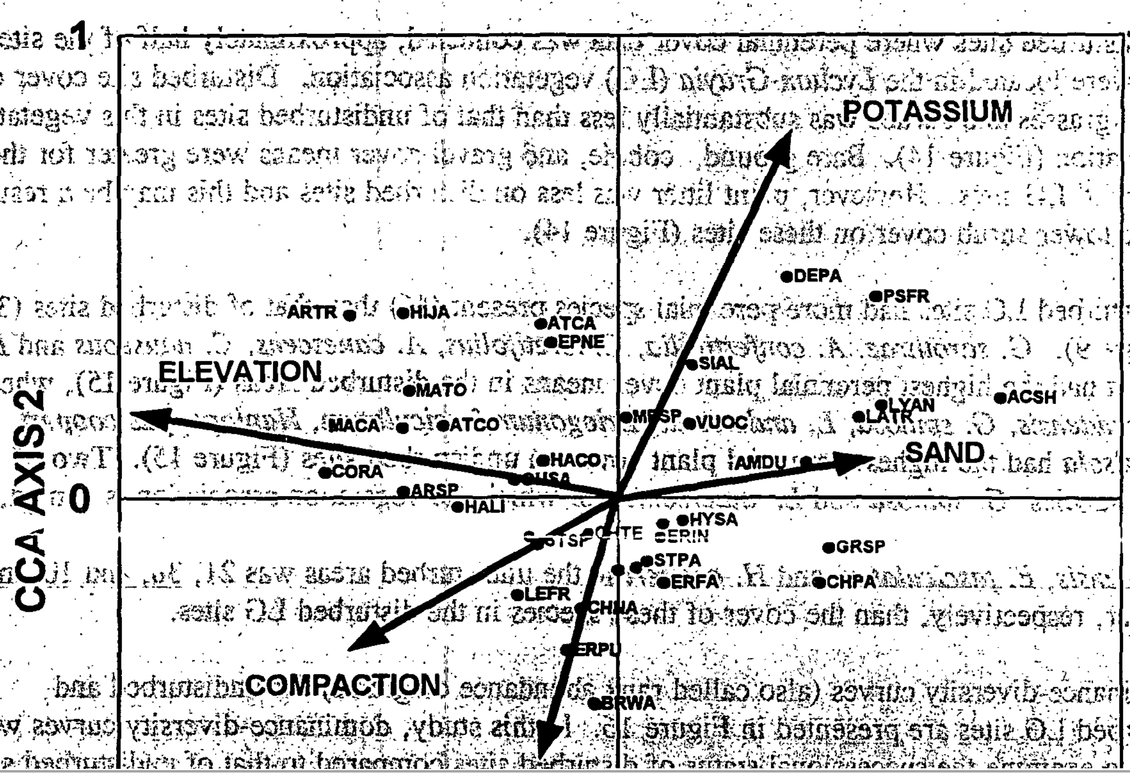
For determination of the influence of important environmental variables on disturbed site plant succession, perennial plant cover was chosen as the analysis variable. Perennial plant cover was chosen over density and total plant cover because it does not fluctuate widely from year to year. Total plant 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


1
POTASSIUM
25

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*

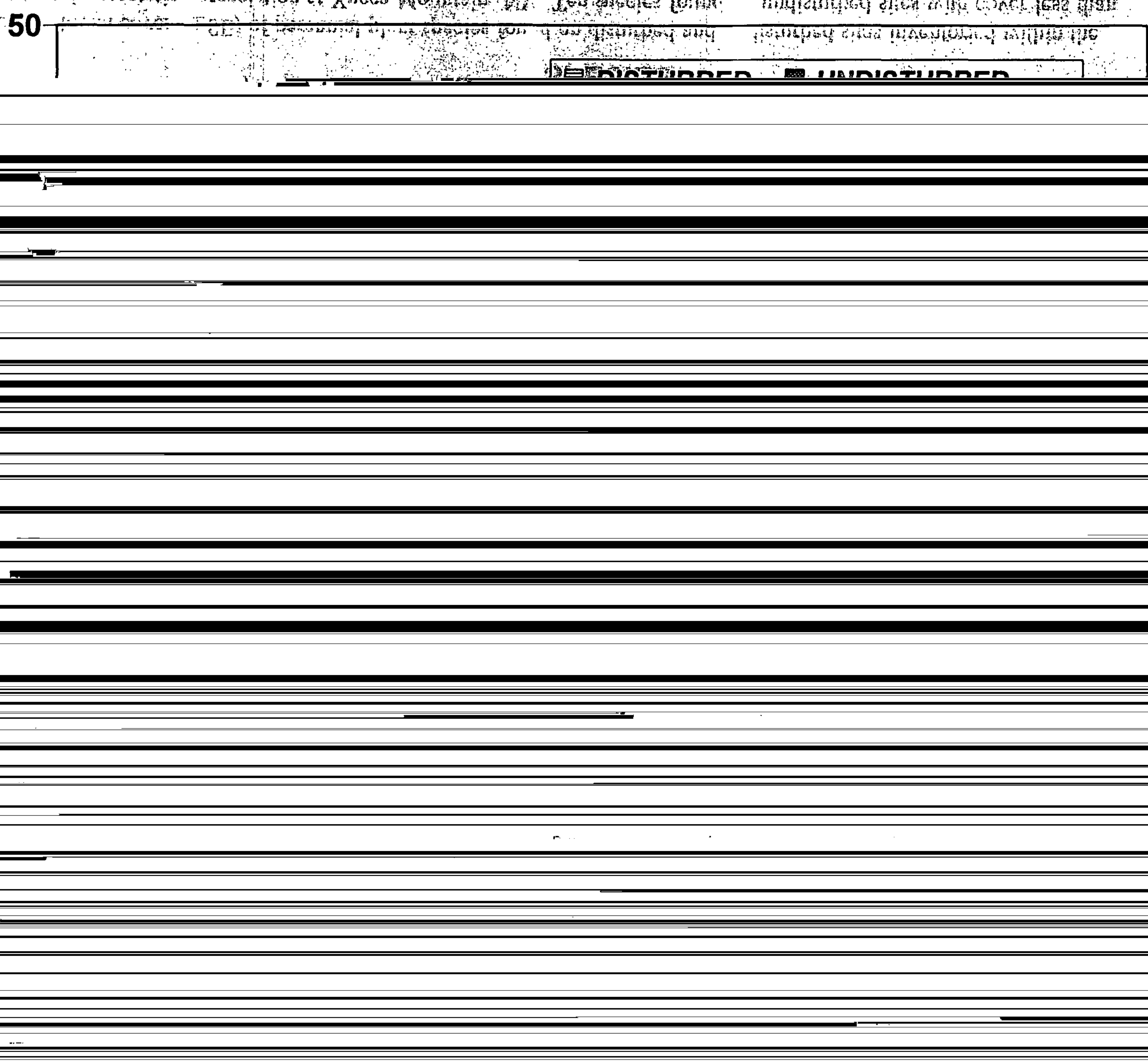


CCA AXIS 2
1
0
POTASSIUM
ELEVATION
SAND
COMPACTION
DEPA
PSFR
ARTR
HIJA
ATCA
EPNE
SIAL
MATO
ACSH
LYAN
LATR
MACA
ATCO
MESP
VUOC
AMDU
HACO
CORA
ARSP
HALI
HYSA
ERIN
GRSP
STPA
ERFA
CHPA
LEFR
CHNA
ERPU
BRWA

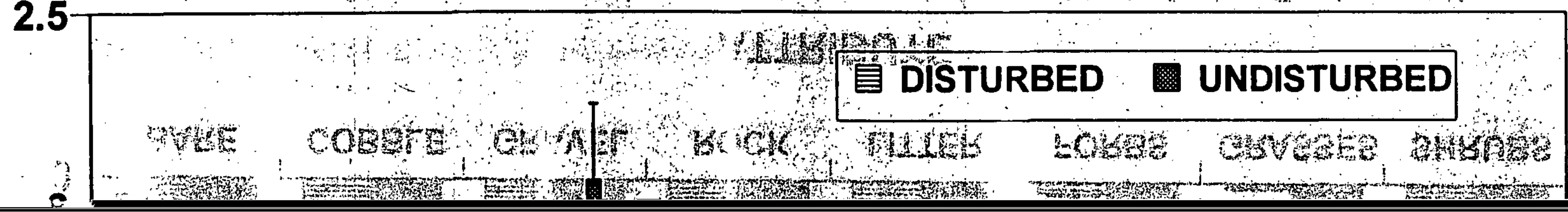
5.3.1 *Lycium-Grayia* Vegetation Association

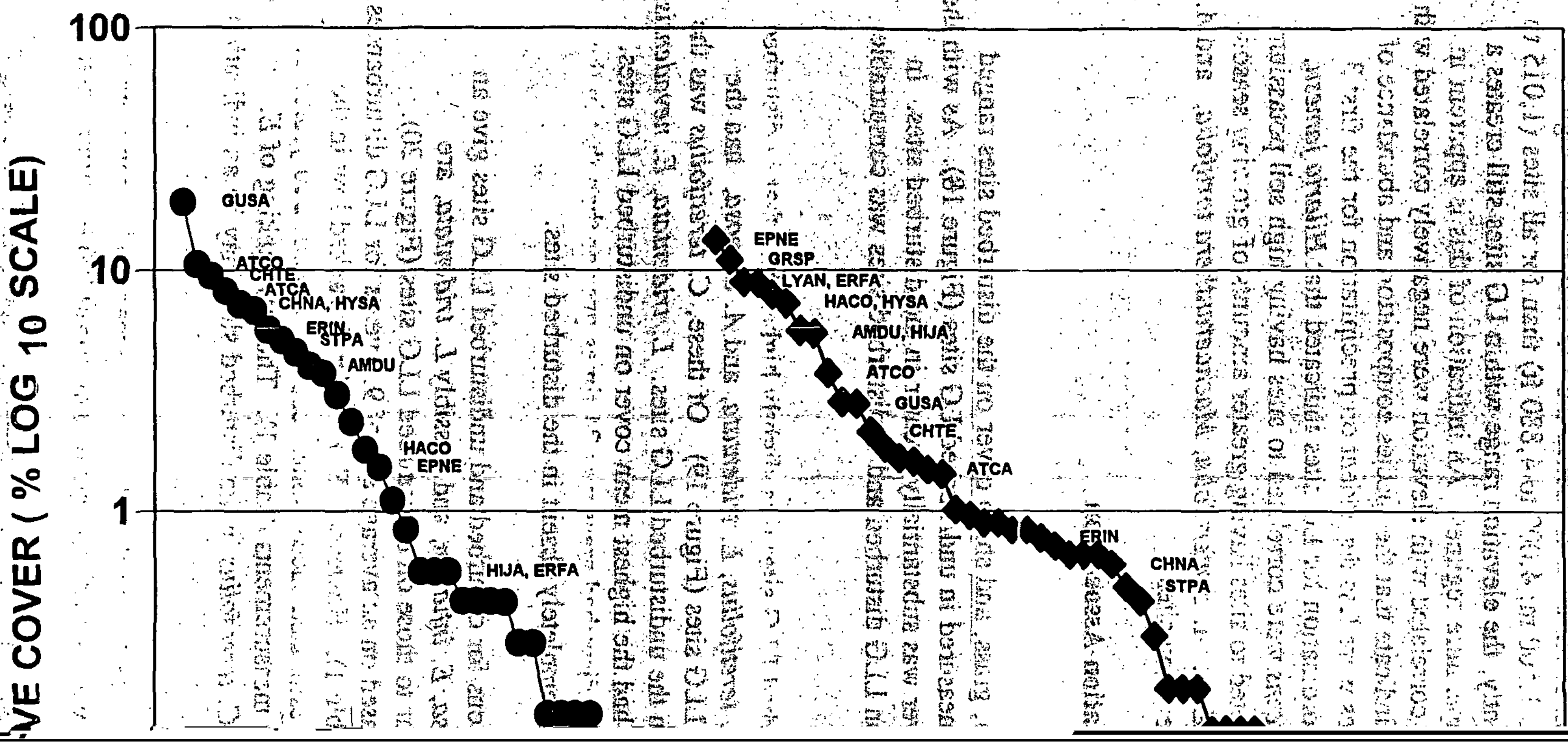
For disturbed sites where perennial cover data was collected, approximately half of the sites (25) were located in the *Lycium-Grayia* (LG) vegetation association. Disturbed site cover of forbs, grasses and shrubs was substantially less than that of undisturbed sites in this vegetation association (Figure 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



... of perennial plant species found on disturbed and ... disturbed sites inventoried within the ... vegetation association at Yucca Mountain, NV. Ten species found ... undisturbed sites with cover less than ... not shown. For explanation of species codes, see Appendix Table 1.

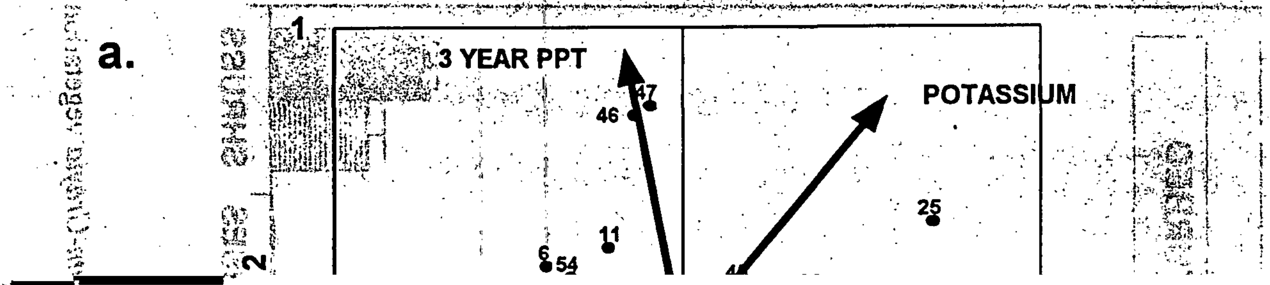

2.5
DISTURBED
UNDISTURBED

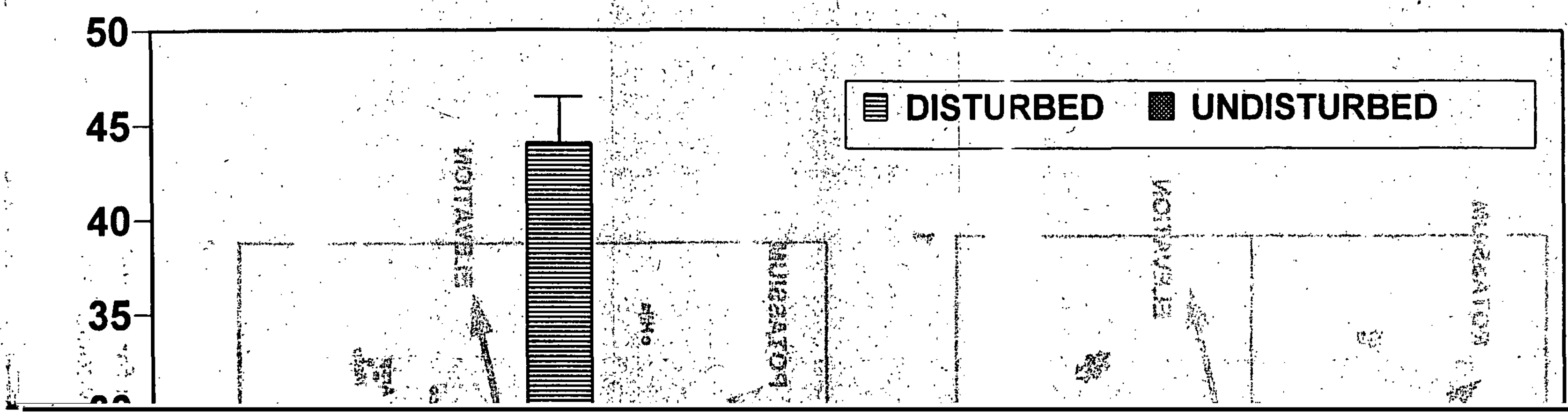


100
10
1
VE COVER (% LOG 10 SCALE)
GUSA
ATCO
CHTE
ATCA
CHNA, HYSA
ERIN
STPA
AMDU
HACO
EPNE
HIJA, ERFA
EPNE
GRSP
LYAN, ERFA
HACO, HYSA
AMDU, HIJA
ATCO
GUSA
CHTE
ATCA
ERIN
CHNA
STPA

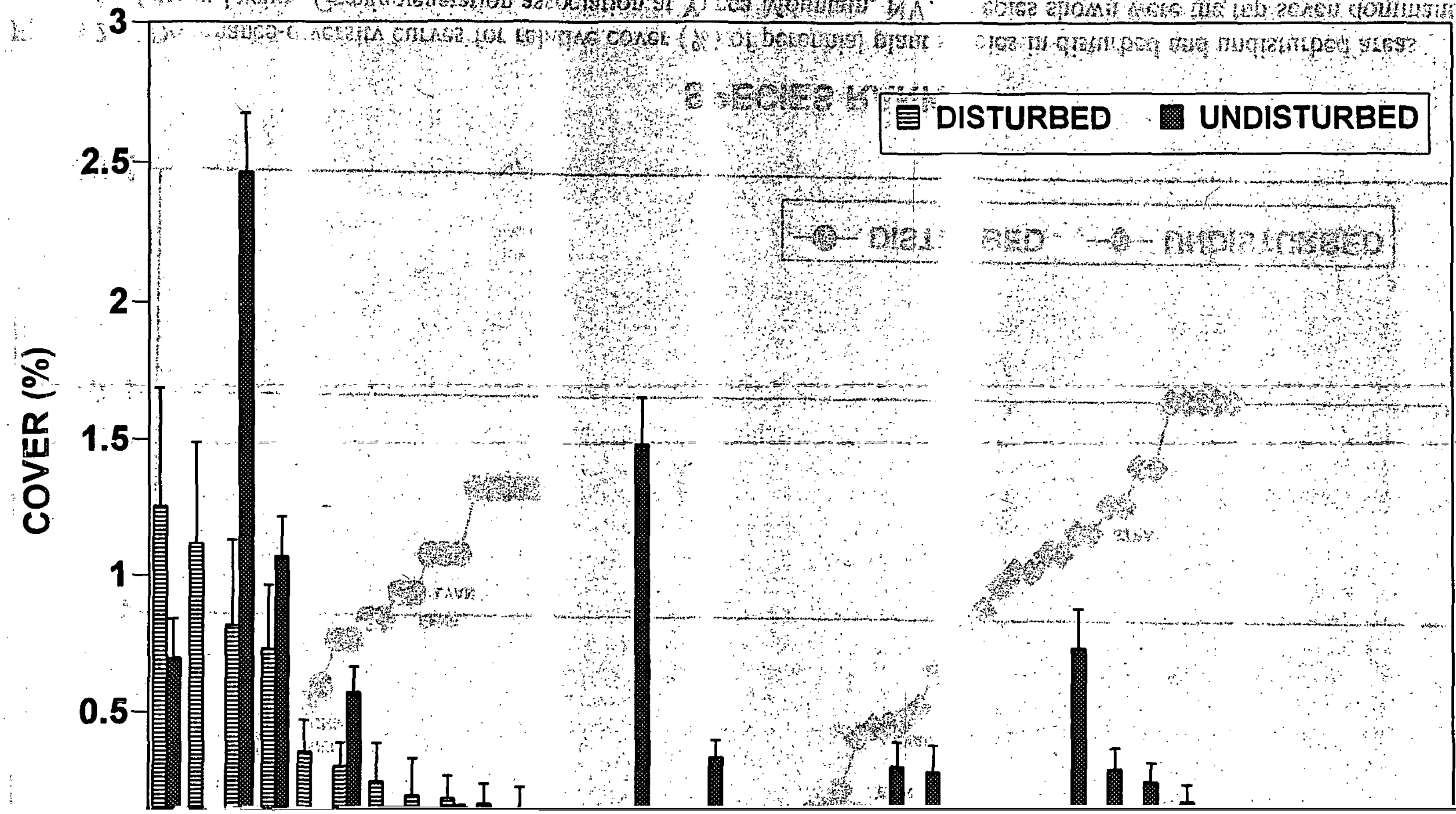
31

(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

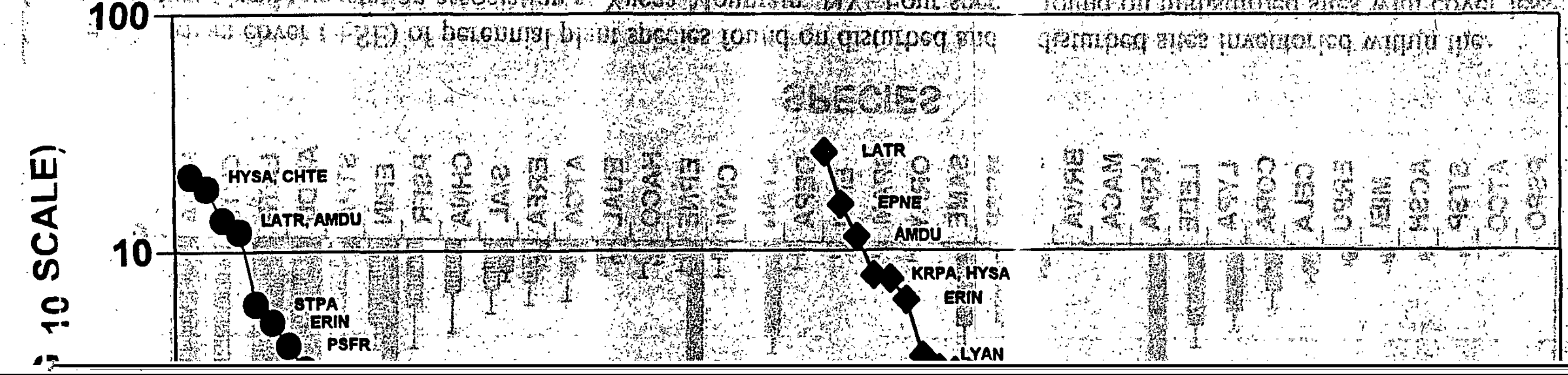

a.
1
2
3 YEAR PPT
POTASSIUM
47
46
11
6
54
25



50
45
40
35
DISTURBED
UNDISTURBED



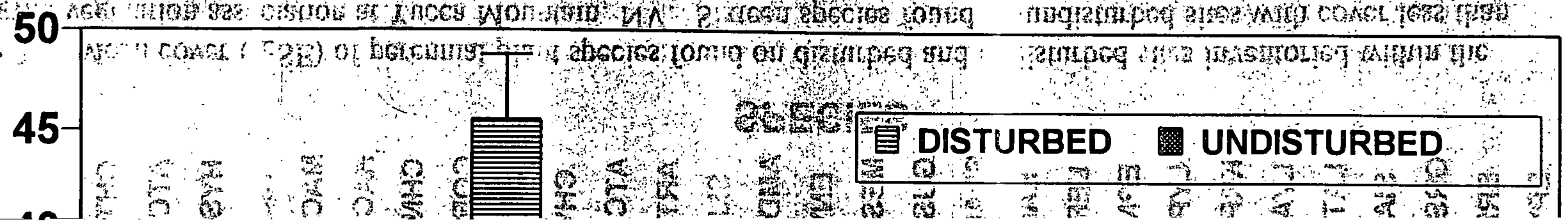
COVER (%)
3
2.5
2
1.5
1
0.5
DISTURBED
UNDISTURBED



10 SCALE)
100
10
HYSA, CHTE
LATR, AMDU
STPA
ERIN
PSFR
LATR
EPNE
AMDU
KRPA, HYSA
ERIN
LYAN

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



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45
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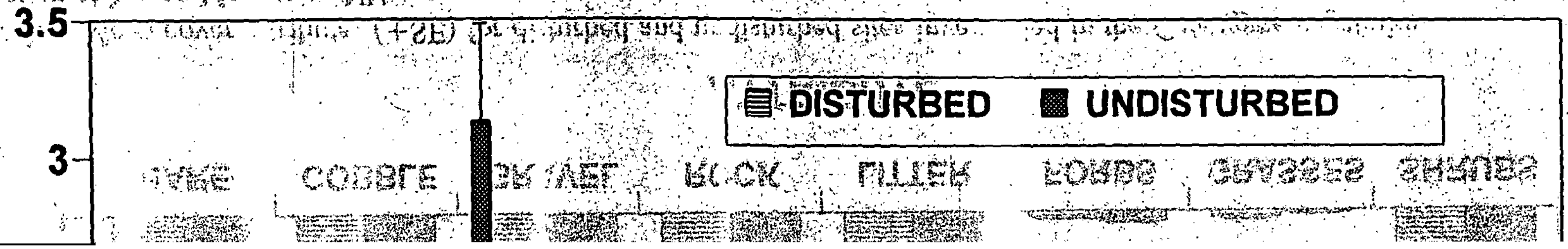
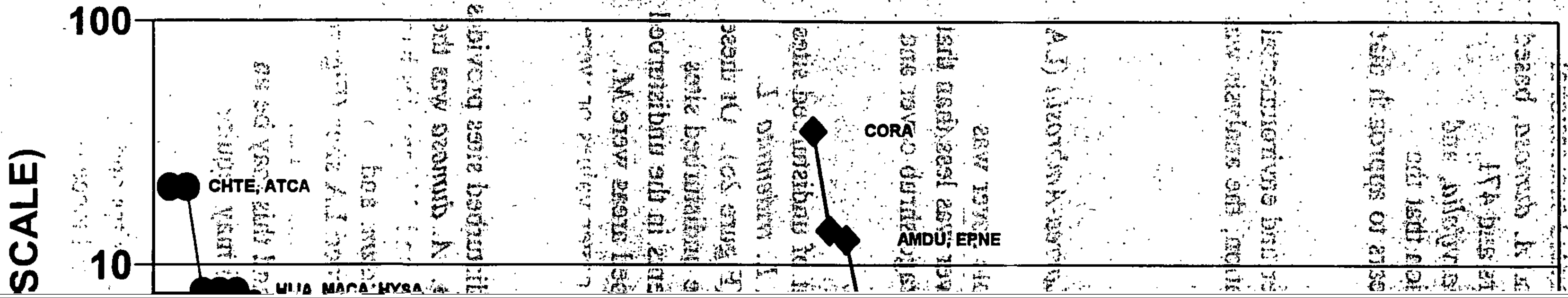

3.5
3
DISTURBED
UNDISTURBED


SCALE)
100
10
CHTE, ATCA
CORA
AMDU, EPNE

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.

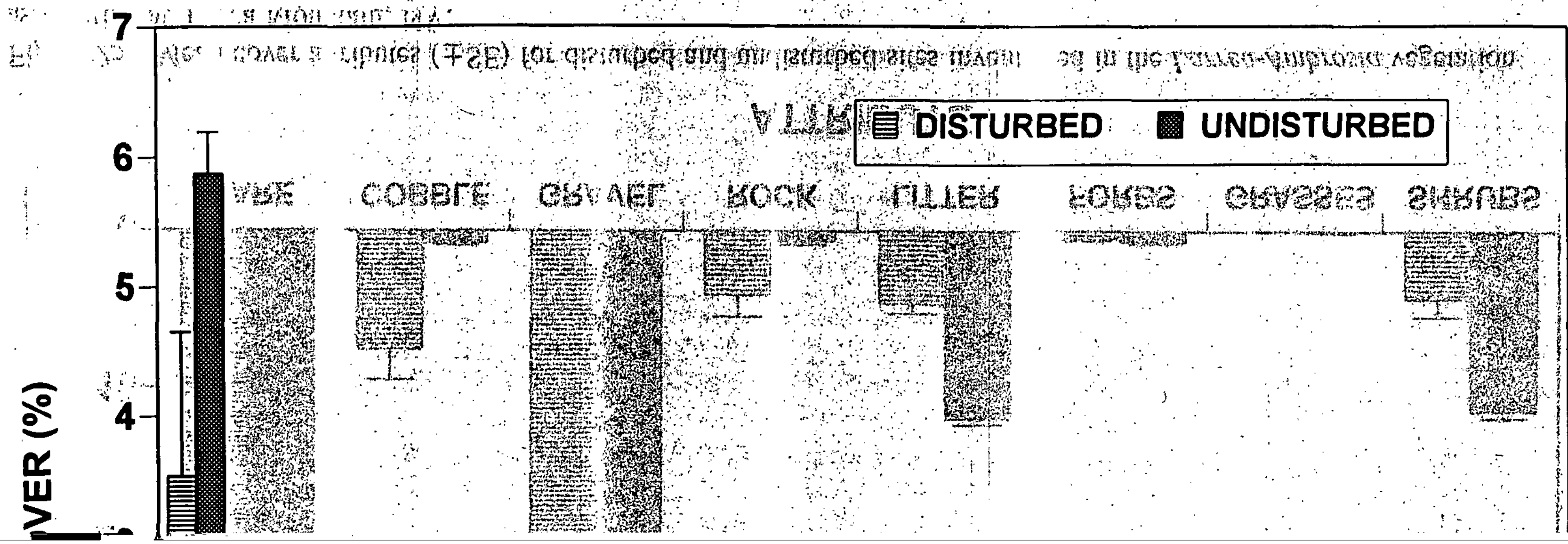
5.3.4 *Larrea-Ambrosia* Vegetation Association

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

… cover (±SE) of perennial plant species found on disturbed and undisturbed sites inventoried within the Larrea … association at Yucca Mountain, NV … species found on … disturbed sites with cover less than 0.05% … explanation of species codes see Appendix Table 1.


DISTURBED
UNDISTURBED
VER (%)
7
6
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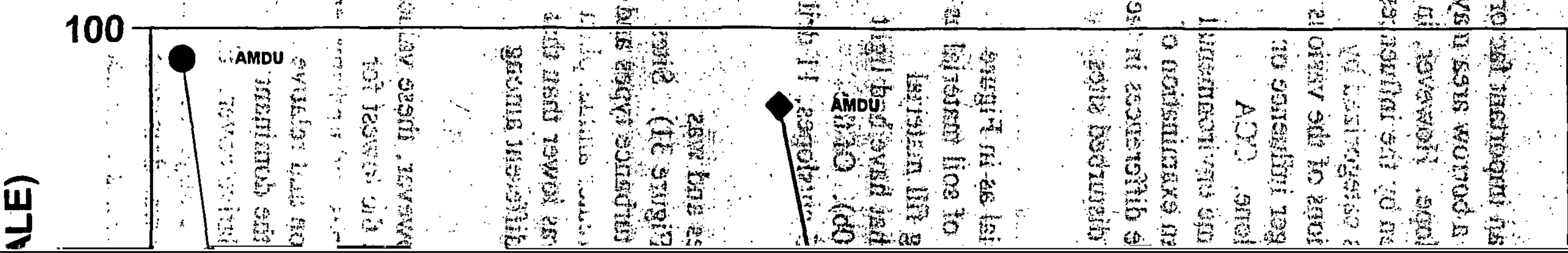
4



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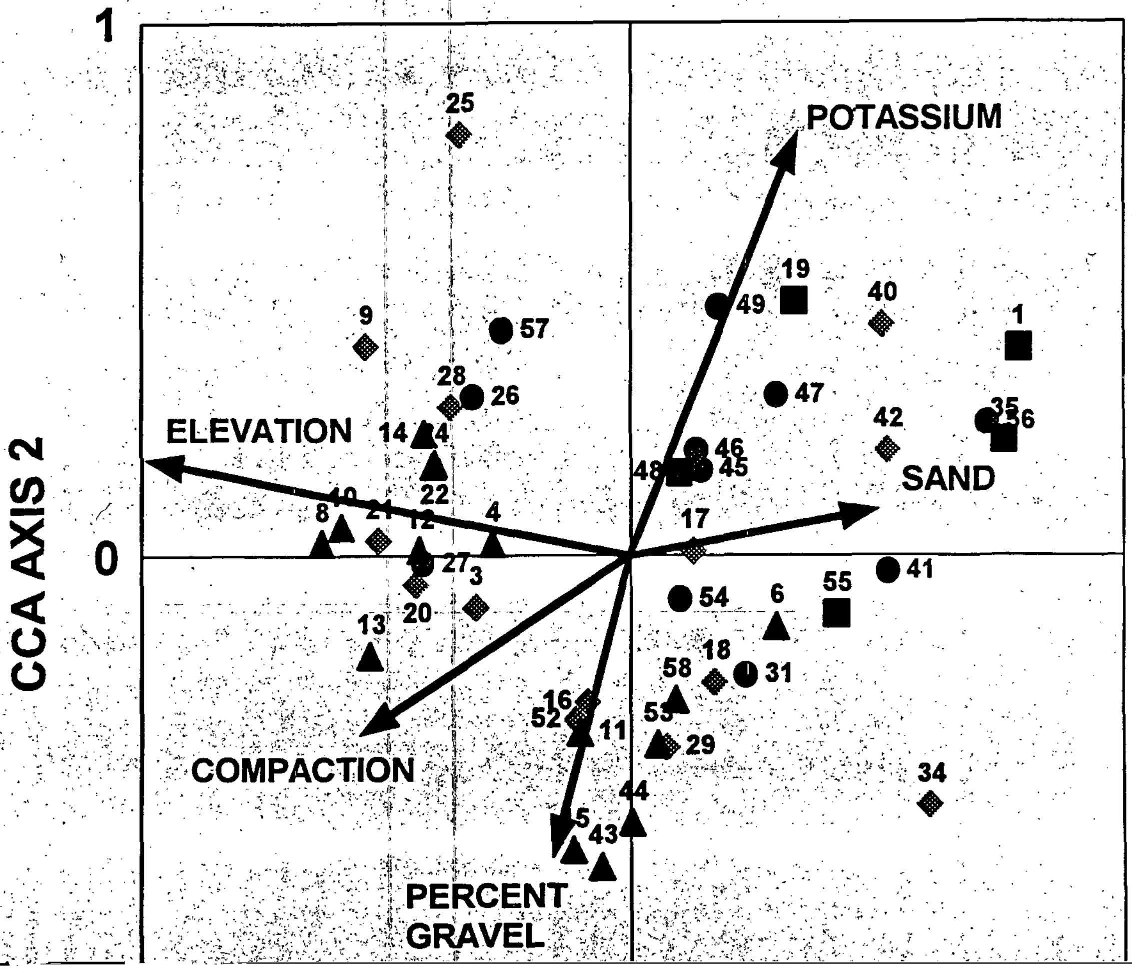

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a.

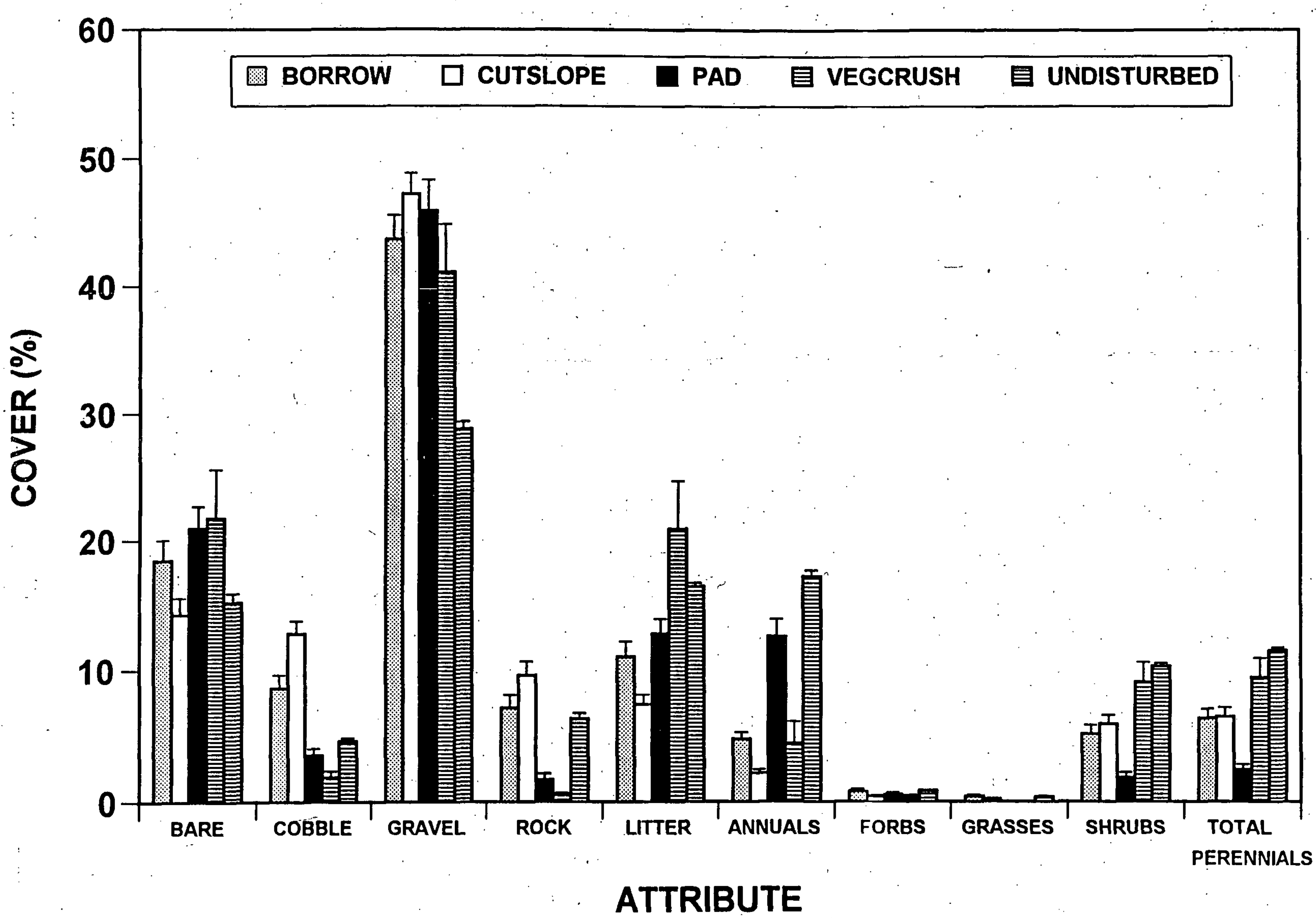
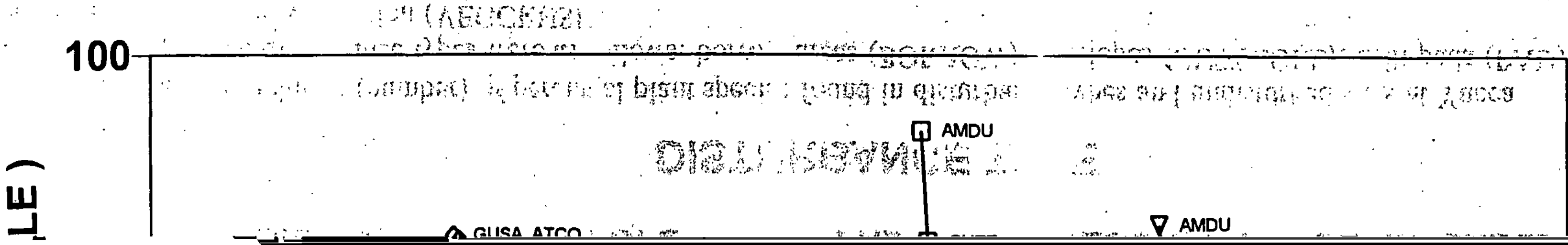


Figure 31. Mean cover attributes (±SE) for disturbance types and undisturbed sites inventoried for the disturbed habitat studies at Yucca Mountain, NV. The disturbance types were as follows: borrow areas (BORROW), cutslopes (CUTSLOPE), drill pads (PAD), and areas with crushed vegetations (VEGCRUSH).

60

58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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).

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,

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 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.

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.

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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	*Castilleia chromosa*	Indian paintbrush	P	F

Appendix Table 1. Continued.

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

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

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

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

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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