

Species and Community Response to Above Normal Precipitation Following Prolonged Drought at Yucca Mountain, Nevada

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Abstract—EG&G Energy Measurements initiated a study in 1991 to determine how the perennial species component of vegetation associations and individual perennial plant species in the northern Mojave Desert responded to above-normal precipitation following a prolonged and severe drought. All vegetation associations had a large increase in both absolute and relative cover. Most perennial species increased in cover across all vegetation associations; however, several declined in cover in one or two associations. Plant populations did not show a similar increase in density. Only three species had a large relative or absolute increase in density, but their response was association specific.

Little information is available on how the perennial species component of desert plant communities responds to normal and above-normal precipitation following prolonged drought. Intuitively, one would expect total canopy cover to increase. Whether a concomitant increase in the density of perennial species also occurs is unknown. Even less is known about how individual species respond.

From 1987 through 1991 a prolonged drought occurred in much of the western United States, including the northern Mojave Desert at Yucca Mountain, Nevada. A 25-year precipitation record (1968-1993) from a weather station in Jackass Flats near Yucca Mountain indicates that the mean annual precipitation is 137 mm (5.38 in), and the October through March mean is 90 mm (3.53 in) (Table 1). The October through March period is important because soil-moisture recharge in the northern Mojave Desert frequently begins in October and usually continues through March. Plant growth begins by March, and soil moisture declines. During the drought the average precipitation from October through March was 58 mm (2.27 in), or 64% of the 25-year average. More important, from a vegetation perspective, were the back-to-back dry winters in 1988-1989 and 1989-1990. The respective October through March precipitation in both years was 13 and 19 mm (0.50 and 0.75 in), or less than 21% of normal. Schultz and Ostler (This proceedings)

have provided data that indicates that the vegetation associations at Yucca Mountain suffered substantial mortality during this drought.

In February and March 1991 Yucca Mountain received above-normal precipitation. The following two winters (October-March) also had above-normal precipitation (Table 1). Vegetation characterization studies supported by the U.S. Department of Energy (DOE) have provided data that can provide insights into how both vegetation associations and individual species respond to above-normal precipitation following a prolonged drought. Our specific study objectives were to determine: 1) if the collective perennial species component in each of four vegetation associations present at Yucca Mountain responded similarly to above-normal precipitation; 2) how individual perennial plant species responded to above-normal precipitation; and 3) if plant species that occurred in two or more vegetation associations responded similarly in each vegetation association.

Site Description

The Yucca Mountain Site Characterization Project (YMP) area occurs on the southwestern edge of the Nevada Test Site in Nye County, Nevada (Fig. 1), exclusively on land controlled by the Federal government. Ownership and control of the project area is divided among the DOE, which controls the eastern portion of the area through land withdrawn for use as the Nevada Test Site, the U.S. Air Force, which controls the northwestern section of the project area through land-use permits for the Nellis Air Force Range, and the Bureau of Land Management, which controls the southwestern portion of the site as public trust lands.

Yucca Mountain occurs near the northern edge of the Mojave Desert. This region has rugged linear (generally north-south) mountain ranges interspersed with broad valleys. Yucca Mountain is a long north-south volcanic ridge that has a maximum elevation of 1,494 m. A steep west slope (15-30°) tilts towards Crater Flat (about 1,175 m). A gradual east slope (5-10°), composed of a series of highly dissected ridges, tilts towards Jackass Flats (about 1,100 m) (EG&G/EM 1993).

Four primary vegetation associations occur in the Yucca Mountain Project area (Beatley 1976; O'Farrell and Collins 1984). They are: creosotebush/bursage (*Larrea tridentata*-*Ambrosia dumosa*), creosotebush/boxthorn/hopsage (*Larrea tridentata*-*Lycium andersonii*-*Grayia spinosa*), blackbrush (*Coleogyne ramosissima*), and boxthorn/hopsage (*Lycium andersonii*-*Grayia spinosa*). The blackbrush community

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Table 1—Average monthly and annual precipitation (mm) at station 4JA (elevation 3,422 m) in Jackass Flats, Nevada Test Site. Cumulative record is from 1968 through 1983. Values have been rounded to the nearest millimeter.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Oct-Mar total
1987	22	M	M	6	21	2	65	0	3	10	21	16	202	112
1988	38	12	0	39	4	0	10	19	6	0	3	1	132	98
1989	2	4	4	0	19	12	0	6	3	3	0	0	52	13
1990	11	4	1	7	8	1	39	10	19	t	7	1	109	19
1991	4	24	43	0	12	t	1	10	9	6	4	25	137	79
1992	30	73	75	0	1	0	t	0	0	19	0	56	225	213
1993	85	84	19	t	t	23							211	262
1987-91 Mean	15	11	12	10	13	3	23	9	7	4	7	8	126	58
1968-93 Mean	16	21	25	5	8	2	15	14	7	7	10	10	137	90
Percent Normal	95	54	47	215	159	133	152	63	111	52	76	87	92	64

M Monthly value is missing but yearly total is available from backup gauges.

t Value is less than 0.5 mm.

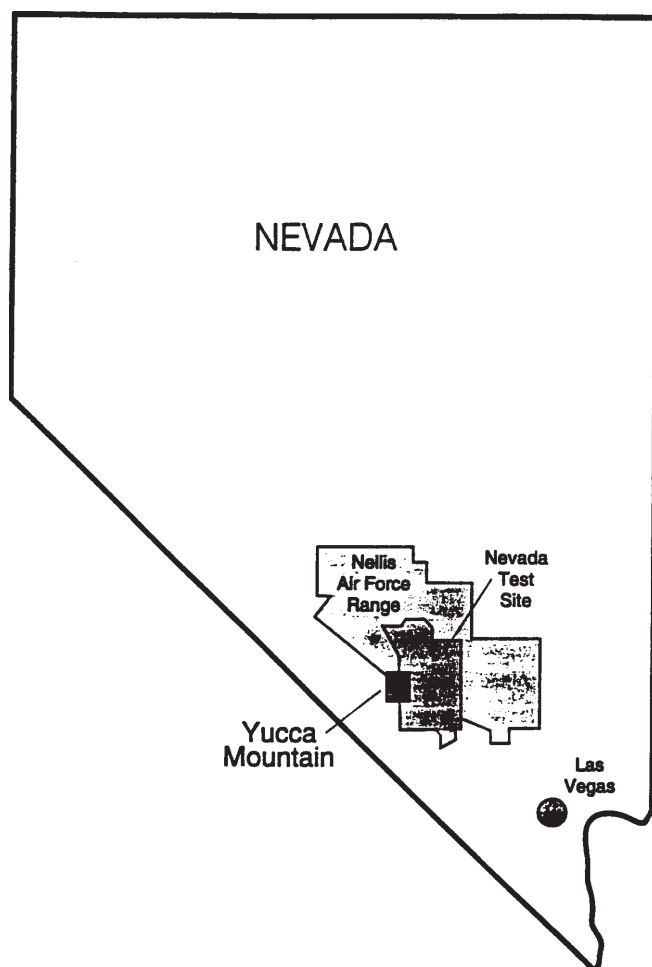


Figure 1—Location of the Yucca Mountain Project area.

consists of both low and high-elevation variations (i.e., valley bottoms versus mountain summits). For simplicity and continuity we refer to the upper and lower elevation phases of the blackbrush association as the low and high-elevation blackbrush associations. Table 2 provides a relative description of the biotic and abiotic conditions that occur in each vegetation association at Yucca Mountain. Table 3 gives the scientific name, common name, and four-letter codes for individual species.

Methods

We randomly located twelve, 200 x 200-m study plots in each vegetation association (48 total plots). The blackbrush association had eight study plots in the low-elevation phase and four study plots in the high-elevation phase (i.e., valley bottoms vs. mountain summits). We measured both the canopy cover and the density of established perennial plants to determine how both vegetation associations and individual species responded to above-normal precipitation, following a drought. Data collection for cover occurred in 1991, 1992, and 1993, and for density in 1991 and 1992.

Canopy cover measurements occurred with the point-intercept method (Bonham 1989) on eight or ten, 50-m line transects. We placed an ocular scope at 1-m intervals along each transect and recorded two point-intercepts, for a total of 100 points per transect (Buckner 1985). We calculated the mean absolute canopy cover of all perennial species, both collectively and individually, in each vegetation association for each year (1991-1993). We also calculated the absolute and relative change in canopy cover for each vegetation association and species, between 1991 and the subsequent year (1992 or 1993) that had the highest cover value.

Density measurements (plants/900 m²) of all established perennial plants occurred in eight or ten, 2 x 50-m belt transects in each ecological study plot. We further subdivided

Table 2—General physiographic and abiotic characteristics of the five primary vegetation associations at Yucca Mountain.

Vegetation association	Elevation range (m)	Landform	Relative precipitation (1992 ave.)	Average soil depth (cm) ¹
Creosotebush/bursage	900-1,050	Sandy alluvial plain	Lowest (166 mm)	80+
Creosote/boxthorn/hopsage	1,000-1,200	Young gravelly alluvial outwash	Intermediate (219 mm)	60-100
Low-elevation blackbrush	1,100-1,300	Old alluvial fans	Intermediate (212 mm)	15-45
High-elevation blackbrush	1,400-1,700	Flat mountain tops and mesas	Highest (260 mm)	30-45
Boxthorn/hopsage	1,150-1,500	Ridge tops and mountain sideslopes	Intermediate (220 mm)	30-45

¹Personal observation of the authors.

Table 3—Common and scientific names of species used in the text. Four-letter codes identify species in Figures 3 and 5.

Common name	Scientific name	Code
Anderson's boxthorn	<i>Lycium andersonii</i>	LYAN
Blackbrush	<i>Coleogyne ramosissima</i>	CORA
White bursage	<i>Ambrosia dumosa</i>	AMDU
Cheesebush	<i>Hymenoclea salsola</i>	HYSA
Cooper's goldenweed	<i>Haplopappus cooperi</i>	HACO
Creosotebush	<i>Larrea tridentata</i>	LATR
Green Ephedra	<i>Ephedra viridis</i>	EPVI
Hopsage	<i>Grayia spinosa</i>	GRSP
Indian ricegrass	<i>Oryzopsis hymenoides</i>	ORHY
Needleleaf rabbitbrush	<i>Chrysothamnus teretifolius</i>	CHTE
Nevada Ephedra	<i>Ephedra nevadensis</i>	EPNE
Pale boxthorn	<i>Lycium pallidum</i>	LYPA
Shadscale	<i>Atriplex confertifolia</i>	ATCO
Shockley goldenrod	<i>Acampopappus shockleyi</i>	ACSH
Spiny Menodora	<i>Menodora spinescens</i>	MESP
Virgin River Encelia	<i>Encelia virginensis</i>	ENVI
Yellow buckwheat	<i>Eriogonum fasciculatum</i>	ERFA

each belt transect into twenty-five, 2 x 2-m quadrats. We found that data collection from smaller quadrats inside each belt-transect decreased both the frequency of data collectors missing plants, and the accidental inclusion or exclusion of plants from the belt transects. Only plants that had 50% or more of their root crown located inside each belt transect were counted. We defined established plants as those individuals that were at least 1-year-old. Among very young or very small plants we used plant size, the number of leaves or leaf blades present, and stem hardness as indicators of plant age. For example, grass seedlings usually had one to three threadlike leaf blades that were less than 5 cm long. Yearling grass plants had substantially more and longer leaf blades, and each were several millimeters wide. Stems on shrub seedlings had not yet hardened. We calculated the collective mean density (plants/m²) of all perennial species in each vegetation association, and the percent change in the mean density of individual species (plants/900 m²), between 1991 and 1992. We report the mean density of each vegetation association as the plants/m², and the mean density of each species as plants/900 m². We selected these scales because species density values at the scale of plants/m² were often very small, and were difficult to visualize and interpret. For example, we report shadscale density as 36 plants/900 m², instead of 0.016 plants/m². Also, the collective size of our belt transects in each ESP averaged 900 m².

At the species level, we report the change in cover and density for the 17 most abundant species, across all four vegetation associations. We used a Chi-square test to determine if differences existed among vegetation associations.

Results

Cover

The mean absolute canopy cover (hereafter called cover) of all perennial species, across all study plots was 8.6% in 1991. Cover increased to 11.3% in 1992, and 12.7% in 1993. This represents a relative increase of 48% during the study period.

The collective cover of all perennial species in each vegetation association, except the boxthorn/hopsage association, increased each year (Fig. 2). Absolute cover in the boxthorn/hopsage association increased 4.5% from 1991 to 1992, but was similar in both 1992 and 1993.

Between 1991 and 1993 the absolute cover of the perennial species component in each vegetation association increased at least 3.3%, and the relative cover increased at least 37%. The creosotebush/bursage association had the largest increase in both absolute and relative cover, 5.3% and 62%, respectively (Fig. 2). The boxthorn/hopsage association had the second highest increase in absolute cover (4.5%), but this represented the smallest increase in relative cover (37%). The creosotebush/boxthorn/hopsage and blackbrush associations had the smallest increases in absolute cover, 3.4% and 3.3%, respectively (Fig. 2).

The absolute cover of most species increased between 1991 and 1993 (Figs. 3a-3d). Bursage, Nevada Mormon tea (*Ephedra nevadensis*), hopsage, creosotebush, Anderson's boxthorn, and pale boxthorn (*Lycium pallidum*) were the only species whose absolute cover increased 0.5% or more (e.g., from 2.5% to 3.1%). This level of increase, however, did not occur in each vegetation association. Bursage and creosotebush increased their absolute cover 0.5% or more only in the creosotebush/bursage, creosotebush/boxthorn/hopsage, and low-elevation blackbrush associations. Hopsage, Nevada Mormon tea, and Anderson's boxthorn increased their absolute cover 0.5% or more only in the boxthorn/hopsage community. Pale boxthorn only had a large increase in absolute cover in the creosotebush/bursage association.

Hopsage, Indian ricegrass, and shadscale (*Atriplex confertifolia*) had the greatest relative increase in cover among years (Figs. 3a-3d). The large increase in relative cover, however, was association specific. For hopsage and Indian

VEGETATION COVER BY VEGETATION ASSOCIATION AND YEAR

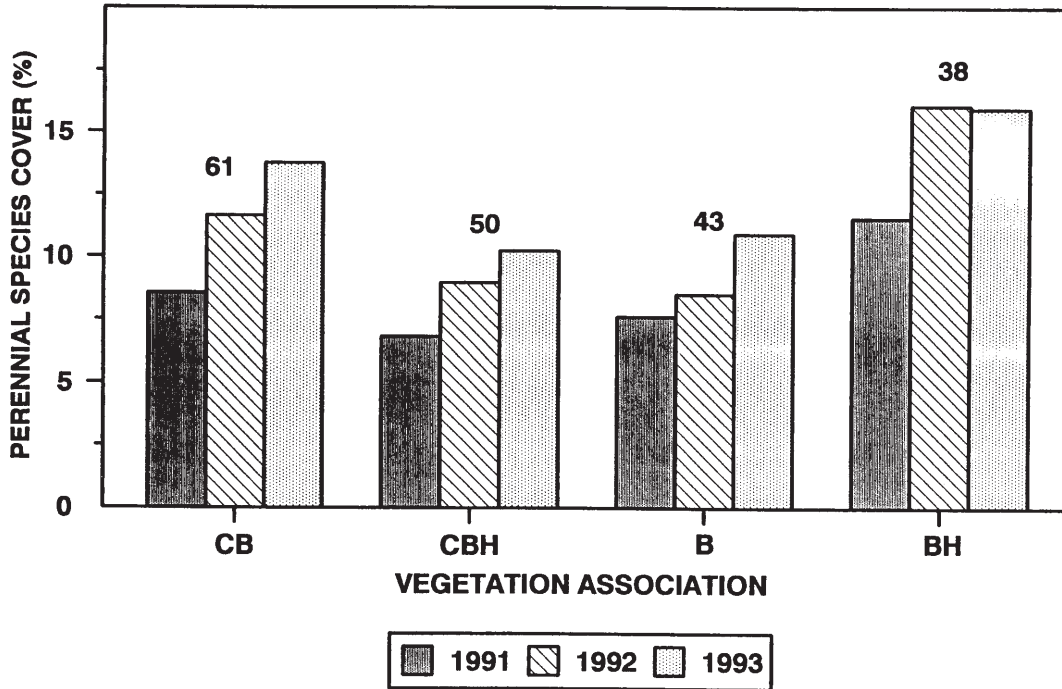
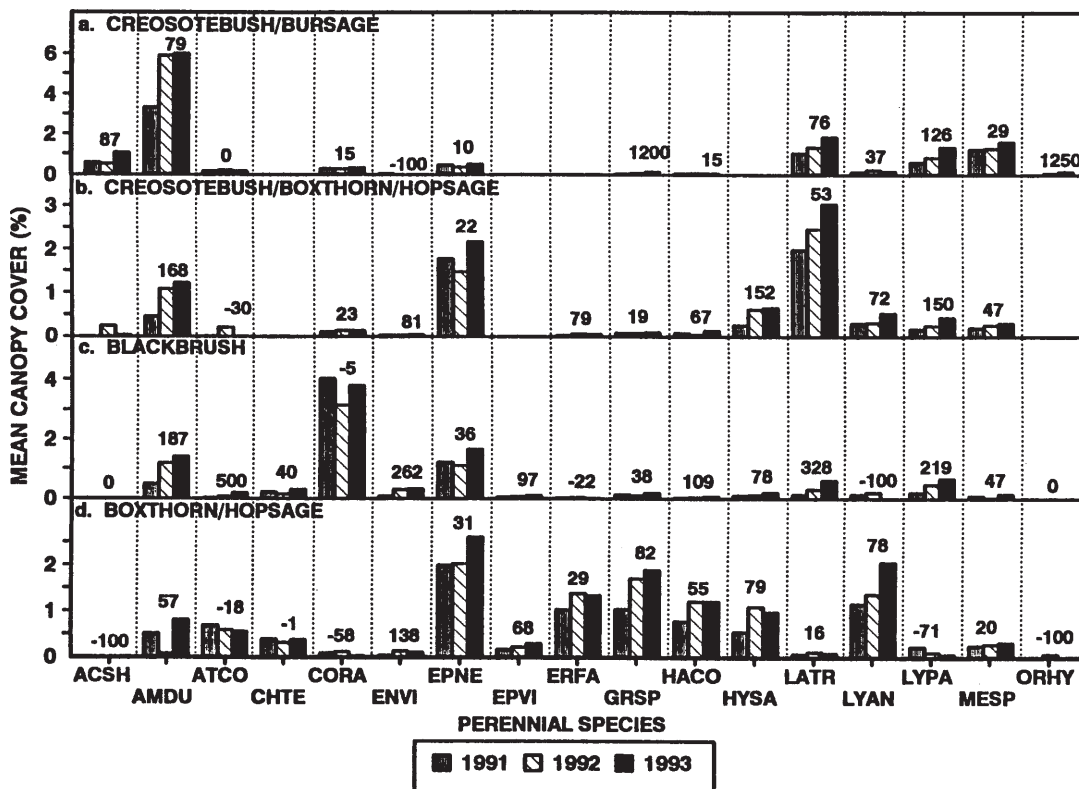


Figure 2—The mean absolute canopy cover of all perennial species in 1991, 1992, and 1993 in the four vegetation associations at Yucca Mountain, Nevada. Values above each bar are the percent change in relative cover between the years that had the lowest and highest absolute cover. Acronyms used to describe each vegetation association are as follows: CB = creosotebush/bursage; CBH = creosotebush/boxthorn/hopsage; B = blackbrush; BH = boxthorn/hopsage.



Figures 3a-3d—The mean canopy cover, in each of three years, of the 17 most common perennial plant species in the four vegetation associations at Yucca Mountain, Nevada. The value above each group of bars is the percent change in total cover between 1991 and 1993. See Table 3 for a description of the species codes.

ricegrass, the increase occurred only in the creosotebush-bursage vegetation association. For shadscale, the increase occurred only in the blackbrush association (primarily the low-elevation study plots). Despite the large increase in the relative cover of hopsage, Indian ricegrass, and shadscale, their increase in absolute cover was small (<0.2%). Other species had a larger change in absolute cover, but their relative increase in cover was comparatively small (Figs. 3a-3d).

Eight species increased their absolute cover across all four vegetation associations (Figs. 3a-3d). Seven additional species had an increase in cover in all but one vegetation association. Two species, shadscale and blackbrush, had a decline in absolute cover in two vegetation associations. None of the seventeen major species present had a consistent decline in cover across all four vegetation associations. The Chi-square test showed that there was no consistent difference in a species increase or decrease in cover among the vegetation associations ($X^2 = 5.3$ with 3 df, $p > .1$).

Density

Except for the blackbrush association there was little change in the mean density in each vegetation association (Fig. 4). Only three species, bursage, Indian ricegrass, and shadscale had a substantial increase in absolute density (Figs. 5a-5d). Bursage and shadscale increased their density in the blackbrush association, particularly in the low-elevation study plots. Indian ricegrass increased in density

only in the creosotebush/bursage association. The remaining species typically had a small change in density. A Chi-square analysis showed no differences in species density increases or decreases among the four vegetation associations ($X^2 = 7.56$, $df=6$, $p > .2$).

Discussion

The primary response of the perennial species component of four vegetation associations at Yucca Mountain, when exposed to above-normal precipitation following a prolonged drought, was an increase in absolute cover (Figs. 2 and 4). Each vegetation association had a substantial increase in absolute canopy cover, and except for the blackbrush association no change in density. This result indicates that the existing individuals in these vegetation associations can respond rapidly, with an increase in leaf area, when growing conditions improve (Figs. 3a-3d). Populations of most species, however, increase their numbers at a much slower rate (Figs. 5a-5d).

At the vegetation association level the magnitude of the increase in cover varied widely. The largest increase in both absolute and relative canopy cover occurred in the creosotebush/bursage association, and the smallest increase in the blackbrush association (Fig. 2). The increase in the absolute cover of each vegetation association did not follow the elevation and precipitation gradient present at Yucca

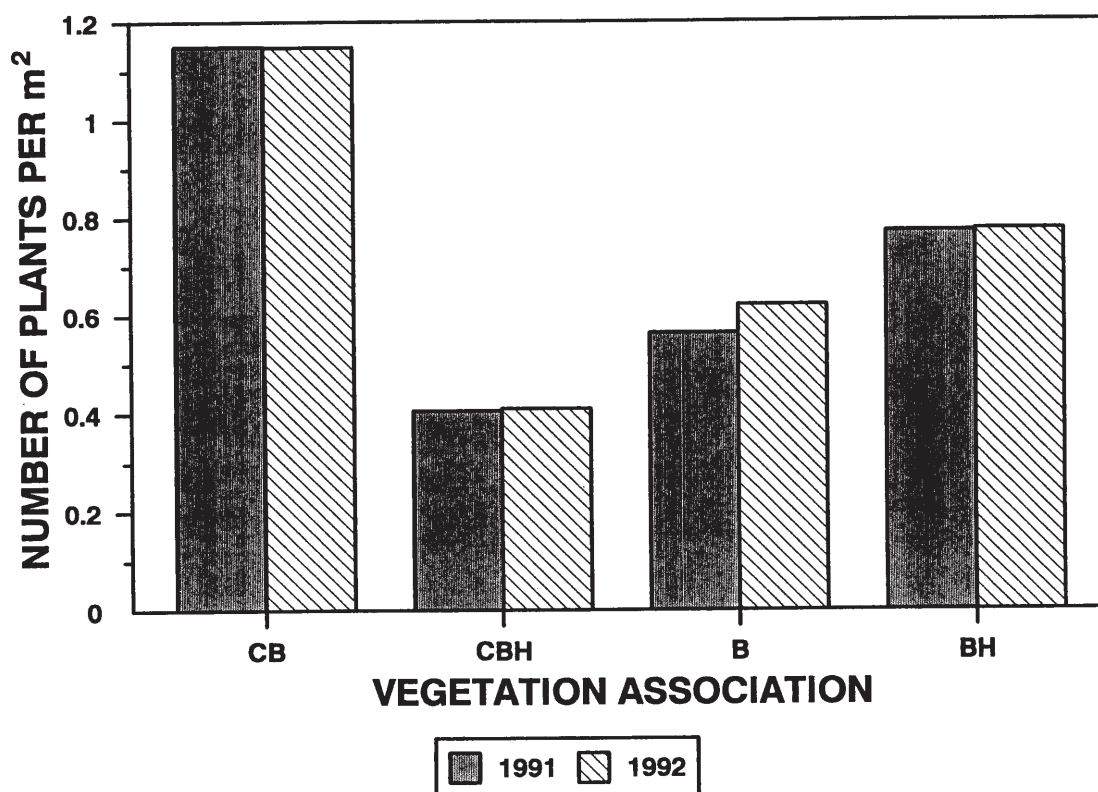
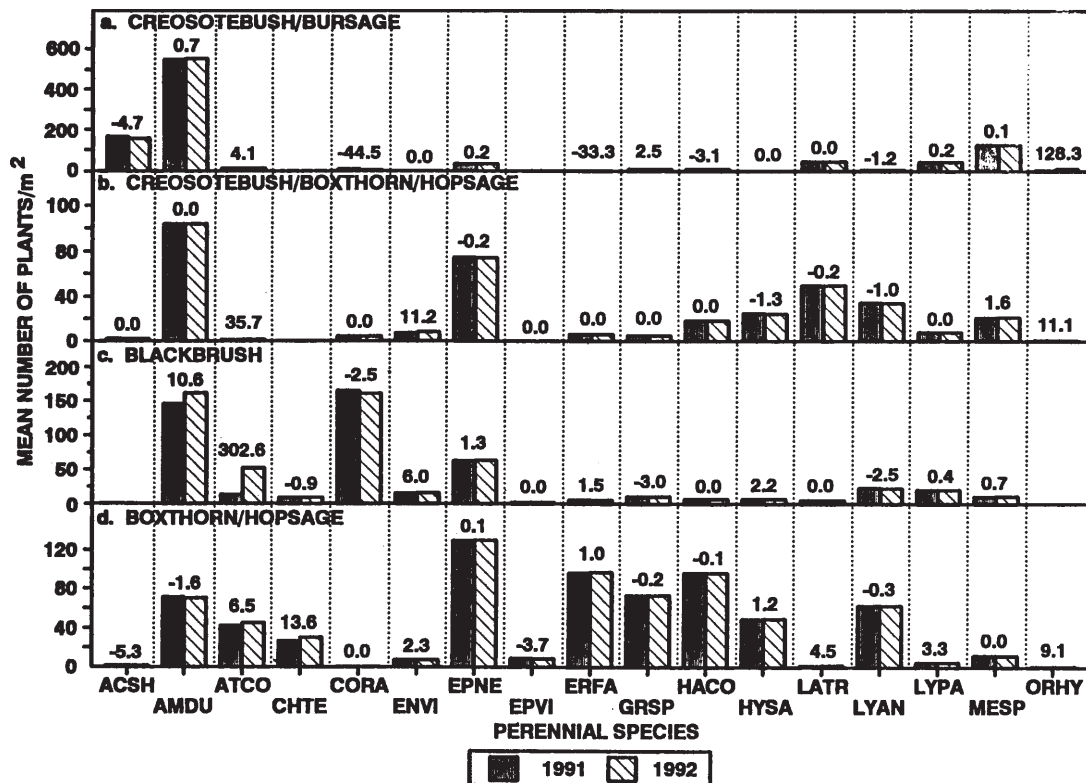


Figure 4—The mean density of the perennial species component of the four primary vegetation associations at Yucca Mountain. Acronyms used to describe each vegetation association are as follows: CB = creosotebush/bursage; CBH = creosotebush/boxthorn/hopsage; B = blackbrush; BH = boxthorn/hopsage.



Figures 5a-5d—The mean density, in 1991 and 1992, of the 17 most common perennial species in four vegetation associations at Yucca Mountain, Nevada. The value above each group of bars is the percent change in density from 1991 to 1992. See Table 3 for a description of the species codes.

Mountain. The creosotebush/bursage association occurs at the lowest elevation, and receives the least precipitation (Table 2); yet this association had the greatest increase in absolute canopy cover (Fig. 2). This may indicate that the creosotebush/bursage association suffered a greater die-back of leaf-producing stems during the drought, and once environmental conditions improved had the greatest potential for community response. An alternative explanation is that bursage, creosotebush, and pale boxthorn, the three species that had the greatest increase in absolute cover in the creosotebush/bursage association, have evolved to increase their leaf area rapidly when growing conditions are optimal. A rapid and comparatively large increase in the leaf area of an individual plant should improve its ability to exploit available resources during brief periods of resource abundance.

Because the increase in absolute cover exhibited by both vegetation associations and individual species did not follow the elevation and precipitation gradient present, and because species performance was not consistent across vegetation associations, factors other than precipitation probably play an important role in how both vegetation associations and individual species respond to above normal precipitation following drought. Two observed differences among each vegetation association were soil depth and texture, both of which influence available soil moisture. Soil structure, pH, and the abundance of carbonates and other salts probably differed among the vegetation associations, and may have affected soil moisture availability for plant growth.

If different soil characteristics exist among the vegetation associations, and these soil conditions control the amount of soil moisture available to plants, then the amount of soil moisture available to plants may not follow a one to one relationship with precipitation. Vegetation associations or plant communities that have a greater total precipitation, but which grow in a soil that has a different chemical and physical composition may have less effective moisture available for plant growth. Precisely, how soil chemistry and soil physics affect the availability of soil moisture in Mojave Desert vegetation associations requires additional research.

The change in canopy cover of an individual species does not always follow the general response of the vegetation association in which the species occurs. For example, the absolute cover in all vegetation associations increased (Fig. 2), but several species had a decrease in absolute cover from 1991 to 1993 (Figs. 3a-3d). Without a detailed statistical analysis we can not say for sure if the observed declines in the cover of some species are significant; however, we feel the differential response exhibited by the vegetation associations and some species provides additional evidence that biotic and or abiotic factors other than precipitation influenced the vegetation associations at Yucca Mountain during and after the drought.

Indian ricegrass, shadscale, and bursage were the only species that had a substantial increase in both cover and density (Figs. 3a-3d and 5a-5d). Their respective increase in cover and density only occurred in the creosotebush/bursage

and low-elevation blackbrush vegetation associations, and may reflect their initial stage of recovery from the high mortality they suffered during the drought (Schultz and Ostler, this proceedings). Other research at Yucca Mountain (Hall and others, this proceedings) found that only Indian ricegrass had good seedling survival (43%) from 1992 to 1993. The large increase in the mean density of shadscale in the blackbrush association, between 1991 and 1992, indicates that shadscale probably had relatively good seedling survival in this association. We noted that Indian ricegrass seedlings often occurred in interspaces between shrubs, but that shadscale seedlings were most frequent under the skeletons of dead shrubs, most of which had been shadscale plants.

Several implications and conclusions can be drawn from these observations. Indian ricegrass appears to be well adapted to the creosotebush/bursage vegetation association, and can rapidly increase in density when climatic conditions are good. Indian ricegrass had good seed germination and seedling survival in the interspaces between shrubs, an area considered inhospitable to plant growth in arid environments. Indian ricegrass, at least in the creosotebush/bursage vegetation association, is a climatic opportunist. In the other vegetation associations, all of which receive higher annual precipitation, the density of Indian ricegrass appears to be limited by other factors. These may include interspecific competition, soil characteristics, or a lack of safe-sites for either seed germination or seedling survival. Hall and others (This proceedings) provide evidence that interspecific competition with annuals may limit the presence of Indian ricegrass in the other vegetation associations.

Shadscale is well adapted to the low-elevation blackbrush association, but appears to require a die-off of existing plants before a large number of seedlings will survive. The low number of shadscale seedlings in interspaces, the high number of seedlings under living shrubs, and the higher abundance of yearling shadscale plants under dead shrubs (Brad Schultz, personal observation) indicates that shadscale has different and probably narrower micro-habitat requirements than Indian ricegrass. The best micro-habitat for seed germination does not appear to be the best habitat for seedling survival. Either intra- or interspecific competition appears to limit seedling survival, primarily to locations under dead shrubs.

Conclusions

The perennial species component of each vegetation association responded similarly to above-normal precipitation

following drought. Each association expressed a large increase in absolute cover; however, the magnitude of the increase varied among the vegetation associations. None of the vegetation associations had a comparatively large change in mean density.

Individual species did not always respond similarly across vegetation associations. Some species (e.g., bursage) increased their absolute cover in every vegetation association in which they occurred. Other species (e.g., shadscale) had an increase in cover in one association, and a decrease in cover in another association. Only two species saw a large increase in absolute density.

Individual plants appear to respond rapidly to improved growing conditions, and sharply increase their canopy cover. Plant populations respond at a much slower rate, and each species appears to have a specific set of biotic or abiotic conditions that must be present before density can increase. Factors other than just precipitation appear to control how both vegetation associations and plant populations respond to above-normal precipitation following a drought.

Acknowledgments

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