

Effects of Prolonged Drought on Vegetation Associations in the Northern Mojave Desert

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Abstract—EG&G Energy Measurements initiated a study in 1991 to determine the effect a prolonged drought had on vegetation structure and composition at Yucca Mountain, Nevada. A substantial die-off apparently occurred in the low-elevation blackbrush (*Coleogyne ramosissima*) association; only 46% of the plant crowns present in 1991 were alive. The creosote/bursage (*Larrea tridentata*-*Ambrosia dumosa*) and creosotebush/boxthorn/hopsage (*Larrea tridentata*-*Lycium andersonii*-*Grayia spinosa*) associations, respectively, had 58% and 57%, of their plant crowns alive. The high-elevation blackbrush and the boxthorn/hopsage (*Lycium andersonii*-*Grayia spinosa*) associations had the most live plant crowns, 79% and 81%, respectively. Indian ricegrass (*Oryzopsis hymenoides*), desert needlegrass (*Stipa speciosa*), and shadscale (*Atriplex confertifolia*), were the species most affected by the drought; live plant crowns were 3%, 43% and 52%, respectively. Many other species had highly variable survival rates among the vegetation associations.

Desert vegetation associations contain many perennial plant species that are well adapted to arid environments; therefore, one would intuitively believe that perennial species in desert ecosystems readily survive drought conditions. Abundant research on plant-soil-water relationships in North American deserts has shown that many species can maintain water uptake and growth when soil-water potential is low (MacMahon and Schimph 1981). However, little research has focused on how both a prolonged and severe drought may affect either vegetation associations, or individual species present across vegetation associations.

From 1987 through 1991 a prolonged drought occurred in much of the western United States, including the Yucca Mountain area, in the northern Mojave Desert. The mean annual precipitation from a 25-year record (1968-1993) for a weather station near Yucca Mountain (Jackass Flats) 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 occurs

during these months. 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. During the 25-year precipitation record in Jackass Flats, there was only one other time when the winter precipitation was less than 25.4 mm (1.0 in). Also, there were no two consecutive years when the total precipitation from October through March was less than 38 mm (1.5 in). These precipitation data indicate that the vegetation at Yucca Mountain experienced a drought that was both more severe and prolonged than typically occurs in the northern Mojave Desert.

In February and March 1991, Yucca Mountain received above-normal precipitation. In 1992 and 1993 the October through March periods also had above-normal precipitation (Table 1). Vegetation characterization studies, initiated in 1990 by the U.S. Department of Energy (DOE) at Yucca Mountain, allowed EG&G Energy Measurements to collect data that inferred how both desert vegetation associations and individual perennial plant species were affected by a prolonged and severe drought. The specific objectives of this study were to determine how vegetation associations at Yucca Mountain, Nevada, respond to a prolonged drought, and to determine if plant species that occurred across two or more vegetation associations respond similarly.

Site Description

The Yucca Mountain Site Characterization Project (YMP) area occurs on the southwestern edge of the Nevada Test Site in Nye County, Nevada (Figure 1). The study area occurs exclusively on lands 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 site through land-use permits for the Nellis Air Force Range (NAFR); and the Bureau of Land Management, which controls the southwestern portion of the site as public trust lands.

Yucca Mountain occurs on the northern edge of the Mojave Desert, in a region that has rugged linear mountain ranges interspersed with broad valleys. Yucca Mountain is a long north-south volcanic ridge with a maximum elevation of 1,494 m, and a steep west slope (15-30°), that tilts

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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	97
1989	2	4	4	0	19	12	0	6	3	3	0	0	53	14
1990	11	4	1	7	8	1	39	10	19	t	7	1	108	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	263
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.

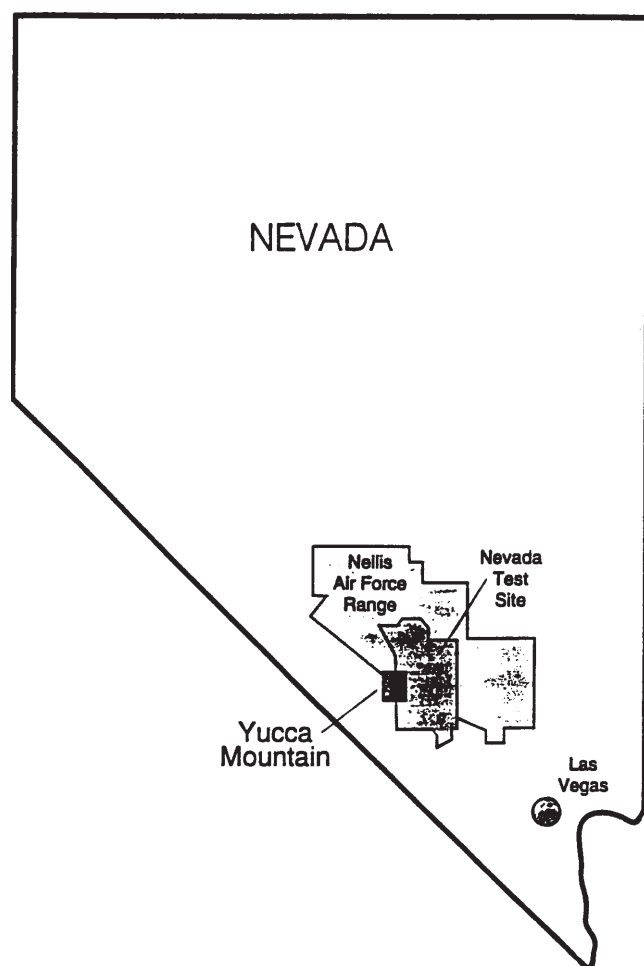


Figure 1—Location of the Yucca Mountain Site Characterization Project area.

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: the 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*) associations. The blackbrush association consists of both low and high-elevation phases (i.e., valley bottoms vs. mountain summits). For simplicity and continuity we refer to the low and high-elevation phases of the blackbrush association as the low and high-elevation blackbrush associations. Table 2 provides a relative description of each vegetation association, and the elevation and precipitation gradients that occur at Yucca Mountain.

Methods

Twelve, 200 x 200-m ecological study plots (ESPs) were randomly located in each vegetation association. The blackbrush association had eight ESPs in the low-elevation phase, and four ESPs in the high-elevation phase.

Plant density measurements occurred in eight or ten, 2 x 50-m belt transects, in each ESP. We further subdivided each belt transect into twenty-five, 2 x 2-m quadrats. We found that data collection from contiguous but discrete quadrats located inside each 2 x 50-m belt transect decreased both the frequency of data collectors missing plants, and the accidental inclusion or exclusion of plants from the belt transects. Live and dead perennial plants were counted by species in each 2 x 2-m quadrat. Only plants that had 50% or more of their root crown in a quadrat were counted. Seedlings from the current year were not included in the density measurements. Criteria used

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

Vegetation association	Elevation range (m)	Landform	Relative precipitation (1992 ave.)	Average soil depth (cm)¹
Creosotebush	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.

to identify seedlings were, plant size, leaf size and number, and stem hardness. Data collection occurred in 1991, the first year that precipitation was sufficient to allow an accurate assessment of live and dead plants.

The number of live and dead plants in each ESP was counted and the ratio of live to dead plants (L:D) for each species in each vegetation association was calculated. The L:D ratio was used as an index to assess how each species responded to drought. Species that had L:D ratios well below 1:1 were considered to have suffered substantial mortality from the drought. Species that had L:D ratios substantially above 1:1 are considered to have endured the drought well. We have assumed that among the vegetation associations the L:D ratios of the individual species, prior to the drought, were more or less equivalent, and that any differences in the L:D ratios of a species among vegetation associations in 1991 were the result of drought conditions.

To test the hypothesis that the drought affected each vegetation association similarly, we classified species that occurred in each vegetation association into two categories

(L:D >1:1 and <1:1), and performed a Chi-square test to assess if differences existed among vegetation associations.

Results

Vegetation Association Response

Table 3 shows the number of live and dead plant crowns in each vegetation association in 1991. The percentage of all live plant crowns, across all vegetation associations, after the drought was 63%. The low-elevation blackbrush association had the fewest live plant crowns (46%). The creosotebush/boxthorn/hopsage and the creosotebush/bursage associations had roughly the same percentage of live plant crowns, 57% and 58%, respectively. The high-elevation blackbrush and the boxthorn/hopsage associations had the highest percentage of live plant crowns, 79% and 81%, respectively.

A Chi-square analysis on the L:D ratios suggests that the drought did not affect each vegetation association at Yucca Mountain similarly ($X^2 = 28.0$, $p \leq 0.001$, $df = 4$, Table 4).

Table 3—Total live and dead plants recorded in the vegetation associations at Yucca Mountain in 1991.

	Vegetation association					Total
	Creosotebush/ bursage	Creosotebush/ boxthorn/ hopsage	Low- elevation blackbrush	High- elevation blackbrush	Boxthorn/ hopsage	
Live plants	13,497	5,938	4,920	2,512	14,324	41,191
Dead plants	9,759	4,478	5,685	662	3,298	23,882
Percent alive	58	57	46	79	81	63

Table 4—Chi-square analysis of live:dead ratios for the 30 most common perennial species in the vegetation associations at Yucca Mountain, Nevada, in 1991. $X^2 = 28.0$, $p \leq 0.001$, $df = 4$.

Live:Dead Ratio	Observations	Vegetation association					Total
		Creosotebush	Creosotebush/ boxthorn/ hopsage	Low-elevation blackbrush	High- elevation blackbrush	Boxthorn/ hopsage	
		----- <i>Number of species</i> -----					
≥ 1:1	Observed	17.0	11.0	11.0	18.0	30.0	87.0
	Expected	15.9	17.4	15.9	15.1	22.8	
< 1:1	Observed	4.0	12.0	10.0	2.0	0.0	28.0
	Expected	5.1	5.6	5.1	4.9	7.2	
Total		21.0	23.0	21.0	20.0	30.0	115.0

The creosotebush/bursage, high-elevation blackbrush, and the boxthorn/hopsage associations had more species than expected with L:D ratios greater than 1:1. The creosotebush/boxthorn/hopsage and low-elevation blackbrush had more species than expected with L:D ratios less than 1:1.

Species Response

Table 5 presents an analysis of how 30 species responded to the drought. The percentage of live plant crowns for each species, summed over all vegetation associations, ranged from a low of 3% for Indian ricegrass (*Oryzopsis hymenoides*), to a high of 98% for galletta grass (*Hilaria jamesii*) and rubber rabbitbrush (*Chrysothamnus nauseosus*). Only two species; Indian ricegrass and desert needlegrass (*Stipa speciosa*), had less than 50% of their plant crowns still alive in 1991. Shadscale (*Atriplex confertifolia*) fared slightly better; 52% of the shadscale crowns were alive in 1991. The median value for all species was 72%.

Twelve of the thirty species analyzed occurred across all vegetation associations. Another eight species occurred across the entire elevation and precipitation gradient (i.e., they occurred in either the high-elevation blackbrush or the boxthorn/hopsage association, but not both). Species

that occurred in most of the vegetation associations often did not have the same response in each vegetation association. Generally, species responses can be classified into three categories (Table 6). Category 1 species had L:D ratios >1:1 (i.e., >50% of the crowns present were alive) in every vegetation association in which they occurred. Category 2 species had L:D ratios ≤1:1 in the low-elevation blackbrush and/or the creosotebush/boxthorn/hopsage vegetation associations (i.e., middle elevation associations), and L:D ratios >1:1 in all other associations (i.e., high and low-elevation associations). Category 3 species had L:D ratios ≤1:1 in all but the boxthorn/hopsage association (i.e., highest elevation association).

Seventeen species (57%) had L:D ratios ≥1:1 in every vegetation association in which they occurred (Table 6). Figure 2 shows three species that had this type of response, and how their response varied by vegetation association. Ten species had L:D ratios ≥1:1 in both the lowest and highest elevation associations, and L:D ratios <1:1 in at least one of the two vegetation associations that occur at intermediate points on the elevation/precipitation gradient (Tables 6 and 2). Figure 3 shows two species that had this response, and their variation between associations.

Table 5—The total number of plants (alive and dead) identified by species in the study locations at Yucca Mountain in 1991.

Species	Total live	Total dead	Percent alive
Anderson boxthorn	1,538	388	80
Blackbrush	2,163	979	69
Bladdersage (<i>Salazaria mexicana</i>)	221	75	75
Broom snakeweed (<i>Gutierrezia sarothrae</i>)	401	143	74
Bursage*	10,477	4,803	69
Cheesebush (<i>Hymenoclea salsola</i>)	981	504	66
Coopers goldenweed (<i>Haplopappus cooperi</i>)	1,598	956	63
Creosotebush	1,261	49	96
Desert needlegrass	1,439	1,921	43
Desert globemallow (<i>Sphaeralcea ambigua</i>)	1,359	76	95
Douglas rabbitbrush (<i>Chrysothamnus viscidiflorus</i>)	183	42	81
Fourwing saltbush (<i>Atriplex canescens</i>)	60	13	82
Fluff grass (<i>Erioneuron pulchellum</i>)	1,338	399	77
Galletta grass	1,119	26	98
Green Ephedra (<i>Ephedra viridis</i>)	134	6	96
Goldenweed (<i>Haplopappus linearifolius</i>)	113	44	72
Hopsage	1,198	757	61
Indian ricegrass	80	2,288	3
Needleleaf rabbitbrush (<i>Chrysothamnus teretifolius</i>)	434	60	88
Nevada Ephedra (<i>Ephedra nevadensis</i>)	3,657	724	83
Pale boxthorn (<i>Lycium pallidum</i>)	947	112	89
Range ratany (<i>Krameria parvifolia</i>)	2,627	253	91
Rubber rabbitbrush	39	1	98
Shadscale	851	777	52
Shockley goldenrod* (<i>Acamplopappus shockleyi</i>)	2,099	482	81
Spiny Menodora (<i>Menodora spinescens</i>)	2,104	1,162	64
Virgin River Encelia (<i>Encelia virginensis</i>)	377	253	60
Winterfat (<i>Ceratoides lanata</i>)	1,023	337	75
Wire lettuce (<i>Stephanomeria pauciflora</i>)	62	13	83
Yellow buckwheat (<i>Eriogonum fasciculatum</i>)	1,304	848	61
Unknown	34	5,391	1
Total	41,191	23,882	72

* The actual percent alive values for these species should be slightly lower. Some dead specimens in the creosotebush/bursage association could not be separated between these two species. Only those that were positively identifiable were used in this analysis.

Table 6—Typical responses displayed by the 30 most common species analyzed for L:D ratios at Yucca Mountain, Nevada.

Response type	Species
1. Species that had L:D ratios $\geq 1:1$ in all of the vegetation associations in which they occurred.	Anderson's boxthorn Blackbrush Bladdersage Broom snakeweed ¹ Creosotebush Desert globemallow Douglas rabbitbrush ¹ Galletta grass ¹ Goldenweed ¹ Green Ephedra ¹ Needleleaf rabbitbrush ¹ Nevada Ephedra Pale boxthorn Range ratany Rubber rabbitbrush ¹ Virgin River Encelia Wire lettuce
2. Species that occurred across the entire elevation/precipitation gradient and had L:D ratios $\geq 1:1$ in vegetation associations at the lowest and highest elevations, and L:D ratios $< 1:1$ in vegetation associations at intermediate points on the elevation/precipitation gradient.	Bursage Cheesebush Cooper's goldenweed Fluff grass Four-wing saltbush Hopsage Shadscale Shockley goldenrod Spiny Menedora Winterfat
3. Species that had L:D ratios $< 1:1$ in all vegetation associations, except the boxthorn/hopsage (i.e., highest elevation).	Desert needlegrass Indian ricegrass Yellow buckwheat

¹Species that were present only in the high-elevation blackbrush and boxthorn/hopsage associations.

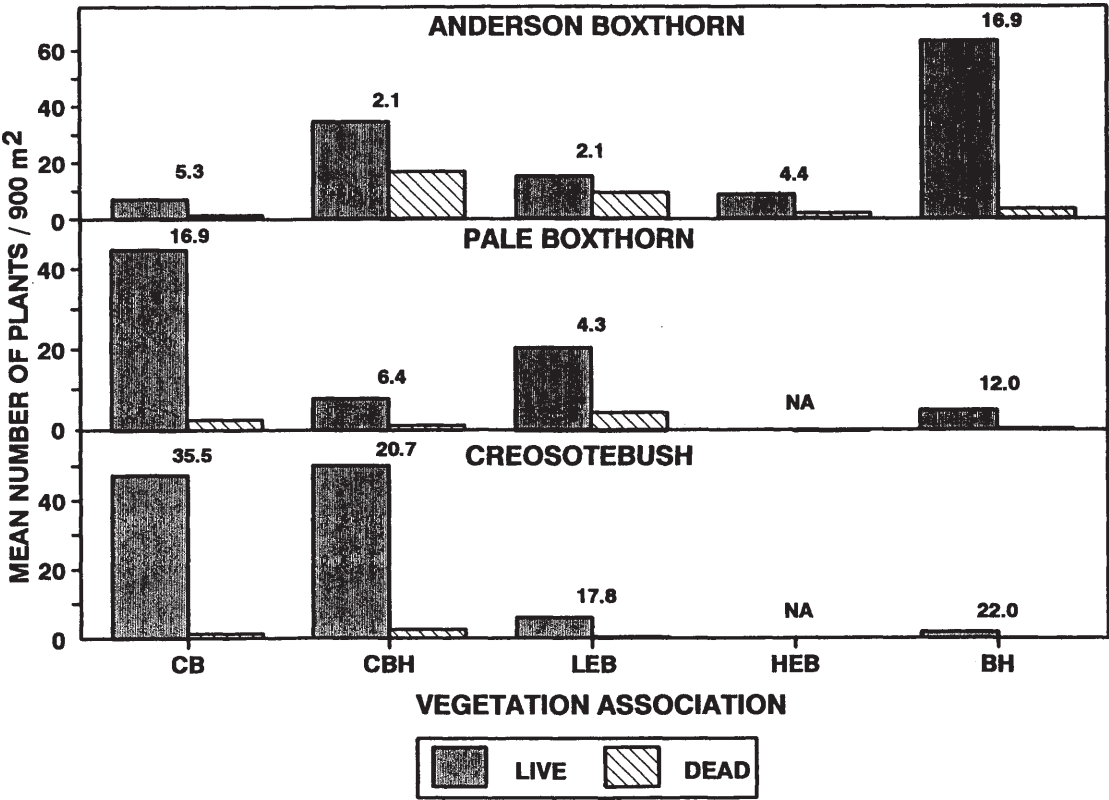


Figure 2—Three of the seventeen species that had L:D ratios $\geq 1:1$ in each of the vegetation associations in which they occurred, and the variation in species response between vegetation associations. Values above each set of bars are the L:D ratio for the species. Acronyms used to describe each vegetation association are as follows: CB = creosotebush/bursage; CBH = creosotebush/boxthorn/hopsage; LEB = low-elevation blackbrush; HEB = high-elevation blackbrush; BH = boxthorn/hopsage.

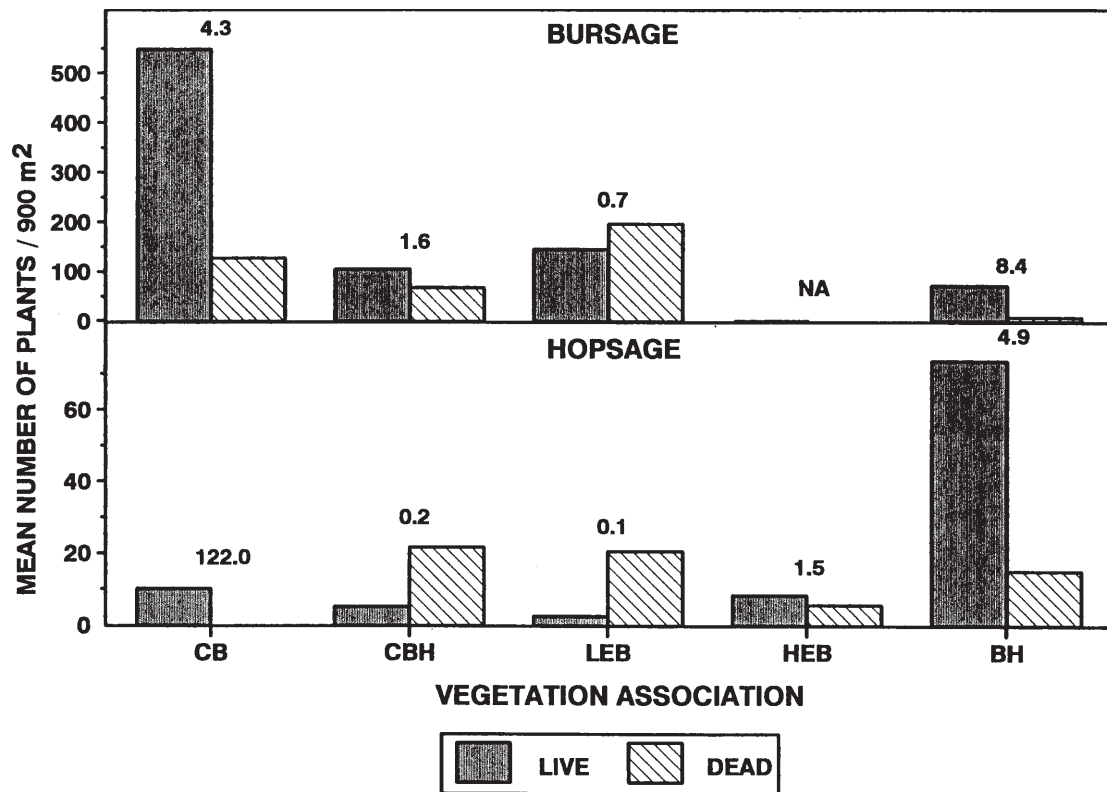


Figure 3—Two of the ten species that had L:D ratios $\geq 1:1$ in the vegetation associations at the lowest and highest elevations, and L:D ratios $\leq 1:1$ in one or both of the vegetation associations that occurred at intermediate points on the elevation/precipitation gradient. Values above each set of bars are the L:D ratio for the species. Acronyms used to describe each vegetation association are as follows: CB = creosotebush/bursage; CBH = creosotebush/boxthorn/hopsage; LEB = low-elevation blackbrush; HEB = high-elevation blackbrush; BH = boxthorn/hopsage.

Three species had L:D ratios $\geq 1:1$ in only the boxthorn/hopsage vegetation association, and L:D ratios $< 1:1$ in all other vegetation associations (Table 6). The two most common bunch grasses in the project area, Indian ricegrass and desert needlegrass had this response to the drought (Fig. 4).

Discussion and Conclusions

The data from Yucca Mountain, Nevada, indicate that neither vegetation associations nor individual species in the northern Mojave Desert respond similarly to a prolonged and severe drought. One vegetation association had less than 50% of its plant crowns alive in 1991, while another association had over 80% of the plant crowns alive (Table 3). At the species level some species had L:D ratios that were much higher than 1:1 in every vegetation association (Fig. 2), but other species had L:D ratios well above 1:1 in one association and well under 1:1 in another association (Table 6; Figs. 3 and 4).

Precipitation probably explains part of, but not all of, the vegetation response to drought. The four vegetation associations studied occur along an elevation gradient

that influences total precipitation levels. As storm systems move over the higher ridges, orographic uplift increases the precipitation. This may explain why the three low-elevation vegetation associations each had more dead plant crowns, a higher percentage of dead plant crowns, and more species with L:D ratios less than 1:1 than did the upper-elevation vegetation associations (Tables 2, 3, and 4). Differences in precipitation, however, do not explain the large difference in the percentage of live plant crowns among the three low-elevation vegetation associations (Table 3), or why the creosotebush/bursage association had substantially fewer species with L:D ratios less than 1:1 (Table 4). The creosotebush/bursage association occurs at the lowest elevations and receives the least precipitation of any vegetation association at Yucca Mountain; however, among the three low-elevation vegetation associations, the creosotebush/bursage association had the highest percentage of live plant crowns, and few species with L:D ratios less than 1:1. If precipitation alone influenced vegetation response to the drought, the creosotebush/bursage association should have had substantially more dead plant crowns than the low-elevation blackbrush association.

When the L:D ratios of each species are grouped by vegetation association (Table 4) there is inferential evidence

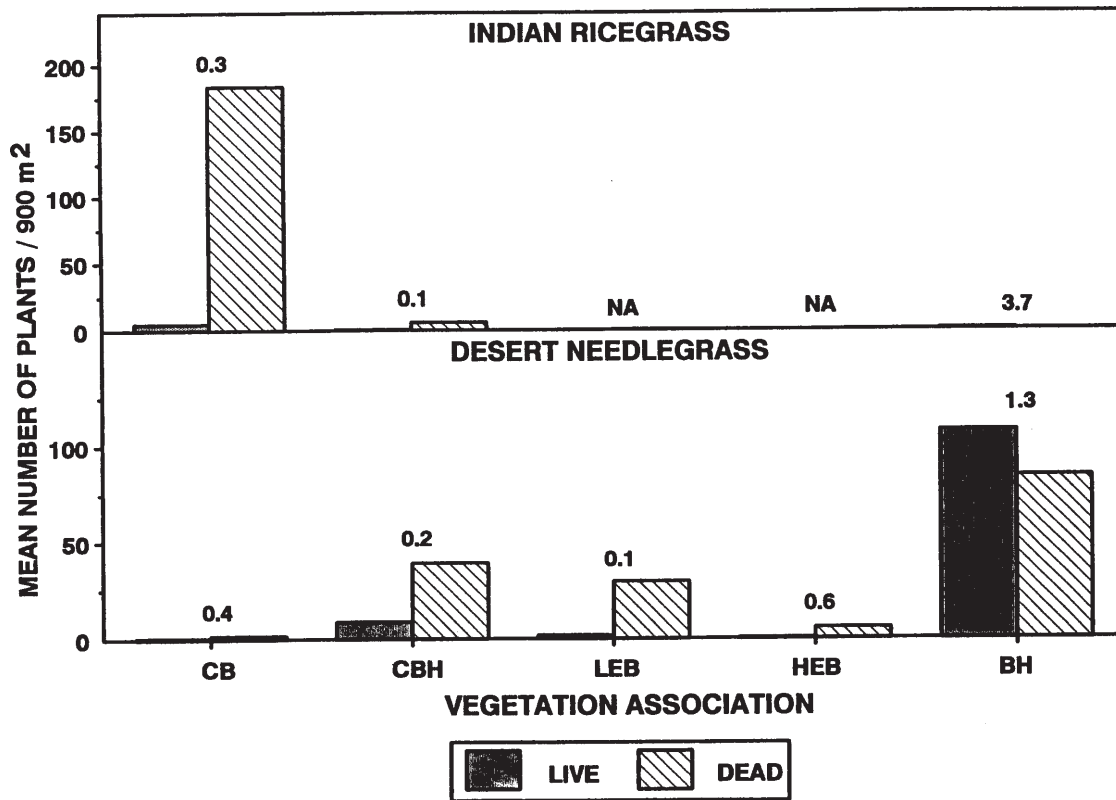


Figure 4—Two of the three species that had L:D ratios $\geq 1:1$ in only the boxthorn/hopsage vegetation association. Values above each set of bars are the L:D ratio for the species. Acronyms used to describe each vegetation association are as follows: CB = creosotebush/bursage; CBH = creosotebush/boxthorn/hopsage; LEB = low-elevation blackbrush; HEB = high-elevation blackbrush; BH = boxthorn/hopsage.

that at least one factor besides precipitation influenced both the vegetation association and species response to the drought. The vegetation associations at both the lower and upper ends of the elevation/precipitation gradient had more plant species with L:D ratios $\geq 1:1$ than vegetation associations at intermediate points on the elevation and precipitation gradient (i.e., creosotebush/boxthorn/hopsage and low-elevation blackbrush). Additional evidence that some factor(s) other than precipitation influenced the vegetation's response to drought comes from species that occurred across all five vegetation associations, and particularly, those species that had L:D ratios well above 1:1 in both the driest and wettest vegetation associations, and L:D ratios well under 1:1 in those vegetation associations at intermediate points on the elevation/precipitation gradient (Table 6 and Fig. 3). Bursage and hopsage are two species that illustrate this point (Fig. 3). If only the lack of precipitation influenced their response to the drought, these species should have had L:D ratios near or below 1:1 in the creosotebush/bursage association instead of L:D ratios of 4 and 122:1, respectively.

We believe that one or more soil factors influenced how drought affected both the vegetation associations and individual species at Yucca Mountain. Two soil characteristics that varied among each vegetation association were soil

depth and texture (B. Schultz, personal observation), both of which can influence the availability of soil moisture. Most likely soil structure, pH, and the abundance of carbonates and other salts differed among the vegetation associations, and influenced the availability of soil moisture for plant growth. If soil characteristics among the vegetation associations were different enough to influence the availability of soil moisture to plants, then the annual precipitation and available soil moisture may not follow a one-to-one relationship. Vegetation associations or plant communities that receive more total precipitation, but which grow in a soil that has different chemical and physical properties may have less effective moisture available for plant growth. Precisely how soil chemistry and soil physics affect soil moisture availability in Mojave Desert vegetation associations requires additional research.

Additional research on plant-soil relationships, and how drought can affect species mortality, is necessary before more definitive conclusions can be drawn. Additional research on how the L:D ratios change as moisture conditions return towards the long-term average will help determine the population dynamics of perennial species in the northern Mojave Desert.

Acknowledgments

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