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Elevational Shifts of *Coleogyne ramossissima* in the Mojave Desert during the Little Ice Age

KIMBERLY L. HUNTER
Department of Biological Sciences, University of Nevada, Las Vegas, Las Vegas, Nevada 89154

AND

JOSEPH R. MCAULIFFE
Desert Botanical Garden, 1201 North Galvin Parkway, Phoenix, Arizona 85008

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Plant macrofossils from woodrat (*Neotoma*) middens collected in the Mojave Desert of southern Nevada were used to reconstruct the timing and magnitude of vegetation change during the past 1000 yr. Although vegetation at the site now is dominated by the shrub *Coleogyne ramossissima*, this species does not occur in fossil middens prior to 600 ± 50 yr B.P. The appearance and persistence of *C. ramosissima* in middens was coincident with the Little Ice Age (ca. 1250 to 1850 A.D.) and was probably related to an increase in precipitation. ©1994 University of Washington.

INTRODUCTION

There has been rapid growth of information from various sources providing evidence for climatic change during the Holocene (e.g., Cole, 1981; Spaulding, 1985; Van Devender and Spaulding, 1979). These records indicate the late Holocene has undergone significant climatic variability. A recent time period that has received considerable interest is the Little Ice Age (Matthes, 1939). The Little Ice Age culminated around 1550–1825 A.D. in Europe, but apparently had a total range from the 14th to the late 19th century (Lamb, 1966, 1982; Grove, 1985). Much of the information on the Little Ice Age originally came from studies conducted in Europe (Lamb, 1966; Grove, 1988). However, a growing body of research involving many disciplines indicates a synchronous, global change during the Little Ice Age (Thompson *et al.*, 1986).

In the Mojave Desert of the American Southwest evidence of a cooler and possibly wetter climate during the Little Ice Age comes from two sources. Changes in levels of ephemeral Silver Lake, the terminus of the Mojave River draining the western part of this desert region, indicates a period of increased winter precipitation from Pacific frontal storms (Enzel *et al.*, 1989). At a site in the northwestern Mojave Desert near Death Valley National Monument, Cole and Webb (1985) presented evidence from fossil woodrat middens for a downward elevational shift of 50–100 m in the distribution of the shrub *Coleogyne ramossissima* (blackbrush), indicating a lessening of aridic conditions.

The Mojave Desert, located primarily in southern California and Nevada, is only about 300–350 km wide from its eastern to western limits. However, this relatively small desert region exhibits a sharp gradient from east to west in the amounts of summer versus winter precipitation. Summer precipitation (July–September) associated with the southwestern branch of the American Monsoon (Reyes and Cadet, 1988) is a substantial component of total annual precipitation only in eastern parts of the Mojave Desert. The chronology and extent of elevational shifts in plant species during the Little Ice Age documented by Cole and Webb (1985) is from the northwestern part of the Mojave Desert where summer precipitation is negligible. The Death Valley area typically receives less than one-sixth of total annual precipitation during summer months (Rowlands, 1980). In this paper, we add to the knowledge of vegetation changes in the Mojave Desert during the Little Ice Age through study of fossil woodrat middens located in the eastern part of the desert where substantially greater amounts of precipitation are received during the summer months.

STUDY SITE/METHODS

The study area was located on the alluvial piedmont to the east of Castle Peaks, 96.5 km south of Las Vegas, Nevada, and 13.7 km west-southwest of Searchlight, Nevada (35°28′N, 114°55′W; elevation 1220–1286 m) (Fig. 1). Average annual precipitation at Searchlight (elevation 1079 m) is 168 m (Turner, 1982); approximately 37% of this amount is received during July through September (Rowlands, 1980). The canyon wall consists of strongly cemented petrocalcic horizons (caliche); overhangs of the cemented horizons form shelters preserving scores of middens.

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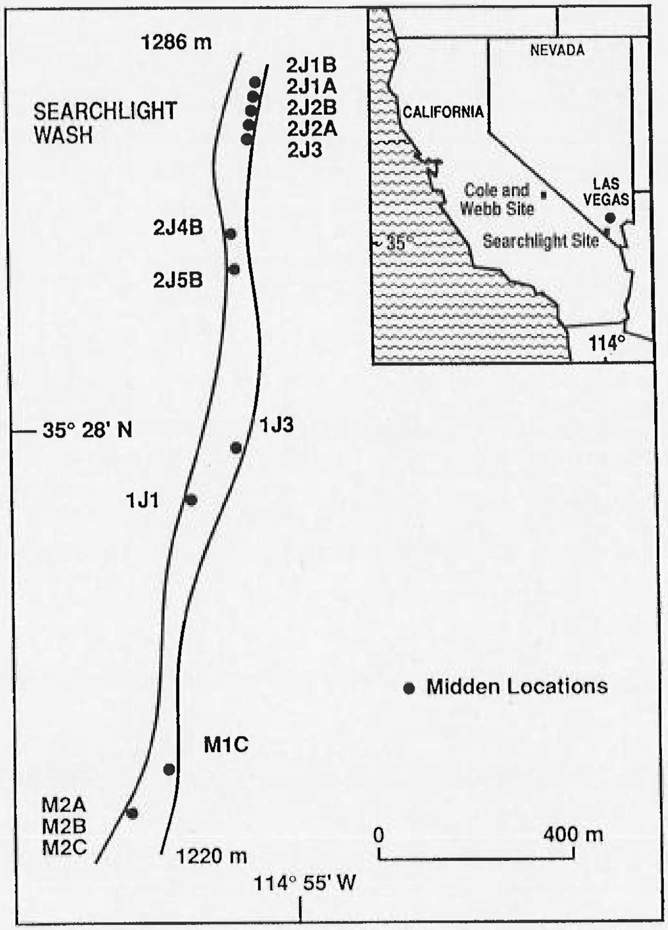

FIG. 1. Map showing location of the study site and the fossil middens along a wash near Searchlight, Nevada.

At present the site is at the interface between communities dominated by creosotebush (*Larrea tridentata*) and those dominated by blackbrush (*C. ramosissima*). This kind of interface exists along elevational gradients throughout much of the Mojave Desert, with creosotebush-dominated communities occupying lower, more arid elevations and blackbrush-dominated communities in more mesic, higher elevations (Bradley and Deacon, 1967).

Pleistocene alluvial fan surfaces above the canyon rim are dominated by blackbrush, whereas restricted deposits of more recent alluvium on the floor of the canyon are dominated by creosotebush. Areas of the piedmont below 1100 m are also dominated by creosotebush.

Creosotebush and blackbrush were chosen as the principal target species for the analysis of late Quaternary vegetation change because the site was positioned at the present interface of the two species distribution. In addition to these two shrub species, three *Yucca* species [Mojave Yucca (*Y. schidigera*), Joshua Tree (*Y. brevifolia*), and Banana Yucca (*Y. baccata*)] were also selected for study in middens because of this elevational pattern of distribution. Mojave Yucca occupies the lower, more-arid elevations, whereas Joshua Tree and Banana Yucca are restricted to slightly higher, more-mesic elevations (Yeaton *et al.*, 1985).

Fossil middens were selected on the basis of degree of induration; the extent of induration of midden deposits generally increases with age, providing that the deposits are completely sheltered from the elements. More than 20 *Neotoma* middens were collected in the canyon. Data collected at the site included dimensions of each midden, aspect, and distance from midden to wash floor and rim of the canyon. External weathering rinds were removed from individual middens in the laboratory with a hammer and chisel. Extreme caution was exercised when removing internal weathering rinds in order to reduce contamination (Spaulding *et al.*, 1990). The middens were soaked in hot water to dissolve the cementing amberat and then were washed, dried, and sorted. Fecal pellets from 13 middens or subsamples were then radiocarbon dated.

Active middens were collected to determine current target species concentrations. A midden was considered active on the basis of the abundance of fresh plant material collected and incorporated by a resident woodrat. Each modern midden that was collected was located within a few meters of a fossil midden used in this study. Only five active middens were used due to the close proximity of several fossil middens. The active middens were not indurated. The flora of fossil and active middens were identified according to the keys found in Kearney and Peebles (1960) and Munz (1974).

To quantify the abundance of target species in the midden samples the number of macrofossils of each species was counted and divided by the weight (kg) of the washed and dried subsample. This figure represented the concentration of the target species per kilogram of washed midden matrix (Cole and Webb, 1985). Concentration values ranged from 0 to >1000 fragments per kilogram. This large range was reduced by taking the common logarithms of the concentration values. This quotient produced a value that can be thought of in terms of relative numbers of plant parts and has been used as a measure by other investigators of fossil woodrat middens (Van Devender, 1987; Cole and Webb, 1985).

The density and canopy cover of perennial plants was estimated within circular plots centered on each midden. For each sampled location, a species list was produced from the area of a 30-m-radius circle centered at the fossil midden. This area represents the approximate area over which a woodrat collects materials (Finley, 1958, 1990). Cover and density of the various plant species was collected using the log-series survey method, yielding estimates of both vegetation parameters on a log base 2 (geometric) scale (McAuliffe, 1990).

RESULTS

Vegetation in the vicinity of the study area consists of two distinct assemblages. The Pleistocene alluvial fan surfaces above the canyon rim were dominated by blackbrush, while on the terrace within the canyon creosotebush, *Eriogonum fasciculatum, Ambrosia eriocentra,* and *Chrysothamnus nauseosus* were prevalent (Table 1). The important target species were blackbrush and creosotebush, so it is significant that densities of the two were different in the wash and on the terrace.

The plant species composition in the modern middens was very similar (Table 2). This indicates that all the target species were sampled. The concentrations of the three target *Yucca* species have been summed due to our inability to distinguish seeds or fragments of leaf tissues of the species.

The earliest midden samples were subsamples collected from one large midden (M2), containing three distinguishable strata (M2A, M2B, M2C) separated by distinct weathering rinds. M2 is located in the eastern portion of the study area. Blackbrush was not present in subsamples older than 600 yr B.P. (Table 3, Fig. 2). Based on this absence, we conclude that blackbrush was not in the foraging range of the woodrat in the earlier period, between 1050 ± 60 and 600 ± 50 yr B.P.

The middens that followed in chronological sequence were located at the western, higher elevational area of the site. These middens are also devoid of blackbrush, but have a younger age of 890 ± 80 and 840 ± 60 yr B.P. (samples 2J1B, 2J1A).

Blackbrush appeared in the record at 600 ± 50 yr B.P. (sample 2J3). However, in the same midden creosotebush was absent. Blackbrush was also found in middens from the western end of the wash system. Blackbrush was not present in the midden record at 520 ± 50 yr B.P. This site was found at the eastern end of the wash, which presents an anomaly.

In the youngest five middens all three of the target species were present. The radiocarbon dates range from 470 ± 80 to 150 ± 70 yr B.P.

The hypothesis that the occurrence of blackbrush over time in the midden samples was random was rejected (Cox and Stuart test for trend; $P < 0.031$; Conover, 1971) and we conclude that the midden samples record a systematic, nonrandom appearance of blackbrush between 840 and 600 yr B.P.

TABLE 1

Log Density Class Designations ($\log_2 N$) for the Dominant Perennials in the Wash Valley and on the Wash Rim, Using Four-Plots

	Sites			
Dominant perennials	1J12	1J34	2J123	2J34
Wash valley				
Larrea tridentata	4	2	2	3
Eriogonum fasiculatum	3	3	4	2
Ambrosia eriocentra	2	4	2	2
Chrysothamnus nauseosus	1	3	5	2
Wash rim				
Coleogyne ramossissma	9	9	9	8
Eriogonum fasiculatum	5	5	3	3
Hilaria rigida	5	5	5	1

Note. Data taken from 30-m radius circular plots.

TABLE 2

Target Species Concentration in Modern Middens[a]

Plant species	1	2	3	4	5
Coleogyne ramosissima	2.72	2.22	2.47	2.79	3.12
Larrea tridentata	3.18	3.50	2.68	3.64	2.88
Yucca sp.	2.04	2.31	2.43	1.98	2.59

[a] Concentration is log base 10 of plant fragments per kg of midden matrix.

DISCUSSION

Three hypotheses were considered to account for the pattern of vegetational change recorded in the fossil midden.

Hypothesis 1: Catastrophic Floods in the Wash

The possible impacts of catastrophic flooding were proposed because the site is in a canyon system incised by a major wash. It seemed plausible that variability in the midden record could be explained by species being removed due to the scouring effect of high water flows. If this occurred, "weedy" species would invade the wash floor first and then eventually be replaced by dominant shrubs. A local species that invades disturbed areas is *Hymenoclea salsola* (cheesebush) (Webb *et al.*, 1987); it has a very distinctive fruit allowing easy identification in midden materials. However, no cheesebush fruit were present in the middens, and so this hypothesis was rejected. In addition, the presence of extremely large creosotebush plants on the terrace above the wash floor indicates lack of flows strong enough to remove these older plants. The generally high abundance of creosotebush throughout the entire midden sequence also argues against the complete and catastrophic removal of vegetation on the canyon floor during the 1050-yr period of the record.

Hypothesis 2: Vertical Position of Midden on Canyon Wall and Proximity to Vegetation

An alternative hypothesis is that the vertical location of the middens within the wall of the wash would affect the foraging patterns of the woodrat. The vertical heights of

TABLE 3
Target Species Concentration in Fossil Middens[a]

Plant species	M2C	M2B	M2A	2J1B	2J1A	2J3	2J2B	M1C	2J2A	2J4B	2J5B	1J1	1J3
Coleogyne ramosissima	—	—	—	—	—	1.68	2.93	—	2.72	2.51	3.45	1.61	2.28
Larrea tridentata	1.50	3.12	4.40	2.66	2.73	—	3.07	3.12	3.15	4.20	3.56	2.55	2.34
Yucca sp.	2.84	2.39	2.45	2.63	2.53	3.54	2.93	2.39	2.92	2.65	2.90	2.84	2.46
Midden age[b]	1050 ± 60	1040 ± 70	970 ± 70	890 ± 80	840 ± 60	600 ± 50	590 ± 50	520 ± 50	470 ± 60	450 ± 80	230 ± 60	160 ± 80	150 ± 70
Aspect	S	S	S	N	N	N	N	N	N	S	S	S	N

[a] Concentration is log base 10 of plant fragments per kg washed midden matrix.
[b] Units are ^{14}C yr B.P. ± 1σ.

each fossil midden are found in Table 4. The absence of blackbrush in midden M1C could be explained by where the woodrats were actually foraging. If the rats were foraging only in the wash floor it is possible that blackbrush would be absent. Midden M1C is located in the middle of the caliche wall, 2 m from both the wash floor and canyon rim. When comparing the vertical locations to other middens, 2 m does not appear to pose a formidable barrier to the rodent. For example, middens 2J4B, 2J5B, and 1J1 were between 2.6 and 3.0 m below the canyon rim, yet all contained blackbrush. In addition the three oldest midden subsamples (M2C, M2B, M2A; Table 3) were located at the minimum distance recorded between any of the middens and the canyon rim, yet these oldest middens lacked blackbrush. Therefore, we rejected the hypothesis that the pattern of appearance of blackbrush in the midden record is an artifact due to the vertical positioning of the middens.

Hypothesis 3: Climatic Change Associated with the Little Ice Age

With the critical examination and rejection of the previous two hypotheses, we conclude that climatic change of the Little Ice Age is the most plausible explanation for the observed vegetational change over time. Blackbrush appeared in the midden record at 600 ± 50 yr B.P., and full blackbrush community establishment appears to have

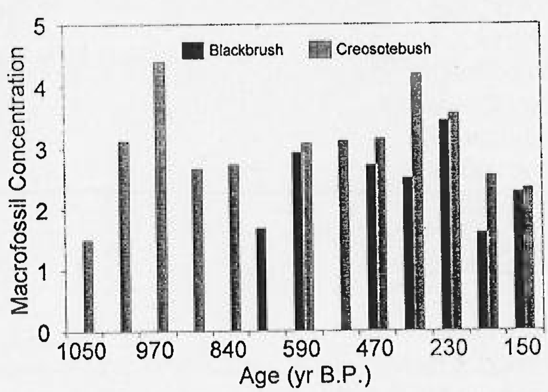

FIG. 2. Graphical representation of the macrofossil concentration (log of plant fragments/kg of midden matrix) of the target species.

occurred by 470 ± 60 yr B.P. These dates fall within the Little Ice Age, and they agree with other findings in the American Southwest.

REGIONAL EVIDENCE OF CLIMATIC CHANGE

Similar work with blackbrush and creosotebush was documented by Cole and Webb (1985). Their work was done in the northern Mojave Desert and suggested a 50- to 100-m downward shift of blackbrush between 1435 and 1795 A.D. This value corresponds closely to our data, which implies a 100-m downward shift of blackbrush between 1050 and 1410 A.D. Studies of lake stands in the playas of the Mojave Desert support the interpretation of the Searchlight data. Enzel *et al.* (1989) documented a high-lake episode 390 ± 90 yr B.P. in the now-desiccated Silver Lake Playa in the Mojave Desert. Mono Lake, 380 km north of Silver Lake Playa, also exhibited a wet period at about 300 yr B.P. Autoecological studies of blackbrush have shown that 180 mm of precipitation is needed to provide full establishment, but generally the values exceed 270 mm (Beatley, 1975; Bowns and West, 1976).

The importance of precipitation to blackbrush is indicated by shifts in the elevational distribution of this shrub in different parts of the Mojave Desert. The vicinity of Searchlight, Nevada, represents one of the least xeric parts of the Mojave Desert and scattered blackbrush can be found as low as 1080 m in this area. To the northwest, in the more-arid region around Death Valley, California, blackbrush is absent below 1350 m in the Greenwater Range (Cole and Webb, 1985) and also is absent below 1400 m on the west slopes of the Panamint Range (J. McAuliffe, personal observations, 1992), indicating that current geographic variation in precipitation exerts a major control on the lower elevational limits of the distribution of blackbrush.

The above studies suggest that increased precipitation is the primary climatic factor that would have allowed blackbrush to expand downslope. The downward shift in the distribution of blackbrush in the eastern Mojave Desert where substantial summer precipitation is received is similar to changes in blackbrush distributions in north-

TABLE 4
Vertical Position of Fossil Middens in the Wash Wall[a]

Location	M2C	M2B	M2A	2J1B	2J1A	2J3	2J2B	M1C	2J2A	2J4B	2J5B	1J1	1J3
Above wash floor	1.54	1.54	1.54	5.50	5.50	5.20	5.00	2.00	6.00	3.50	4.00	3.00	0.50
Below wash rim	0.94	0.94	0.94	1.20	1.10	1.50	1.00	2.00	1.00	2.75	3.00	2.60	1.05
Midden age[b]	1050 ± 60	1040 ± 70	970 ± 70	890 ± 80	840 ± 60	600 ± 50	590 ± 50	520 ± 50	470 ± 60	450 ± 80	230 ± 60	160 ± 80	150 ± 70
Relative position	E	E	E	W	W	W	W	E	W	W	W	E	E

[a] Distance in m.
[b] Units are ^{14}C yr B.P. ± 1σ.

western Mojave Desert (Cole and Webb, 1985) where summer precipitation is almost entirely lacking.

Major hydrologic fluctuations throughout the Mojave Desert region during the Late Quaternary including lake-level changes (Enzel *et al.*, 1989) and extreme flood events (Ely *et al.*, 1993) have similarly been linked to variation in winter, frontal precipitation, especially anomalous ENSO (El Niño-Southern Oscillation) patterns leading to greatly enhanced winter precipitation. The similar behavior of blackbrush during the Late Quaternary on opposite sides of the Mojave Desert suggests that major vegetation changes occurred primarily in response to variation in winter precipitation and were insensitive to the summer precipitation signal.

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