Impacts of the Little Ice Age on the vegetation of southern Nevada

Kimberly Lynn Hunter

University of Nevada, Las Vegas

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Impacts of the Little Ice Age on the vegetation of southern Nevada

Hunter, Kimberly Lynn, M.S.

University of Nevada, Las Vegas, 1991
IMPACTS OF THE LITTLE ICE AGE
ON THE VEGETATION OF SOUTHERN NEVADA

by

Kimberly L. Hunter

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science
in
Biological Sciences

Department of Biological Sciences
University of Nevada, Las Vegas
May 1991
The thesis of Kimberly L. Hunter for the degree of Master of Science in the Biological Sciences is approved.

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Examining Committee Member, Wesley Niles

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Graduate Dean, Ronald W. Smith

University of Nevada
Las Vegas, Nevada
May 1991
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ABSTRACT

Fossil woodrat middens from a wash near Searchlight Nevada were used to reconstruct the timing and magnitude of vegetation change using Larrea tridentata, Coleogyne ramosissima, and Yucca sp. The study revealed that Coleogyne appeared in the midden at 600 ± 50 yr B.P., and full Coleogyne community establishment occurred by 470 ± 60 yr B.P. The increase in Coleogyne was coincident with the climatic shifts during the Little Ice Age, 1250 A.D. to 1800 A.D., and was probably caused by increased precipitation.
ACKNOWLEDGEMENTS

I would like to thank Dr. Joseph R. McAuliffe for aid in conception and execution of this project, my committee members for invaluable editorial comments, and Tom and Becky Van Devender for identification of plant species at the site and for helpful discussions.

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I would especially like to thank my family. First, my loving husband, Richard, for his thoughtful discussions, field assistance, and for his encouragement. Second, to Elijah for his field assistance and patience. Finally, to my parents for constant encouragement.
INTRODUCTION

Little Ice Age

There has been rapid growth of information from various sources providing evidence for climatic change during a time period representing approximately the last 10,000 years of geologic history. These proxy climatic records are obtained with different methods depending on the area of concern. The data is obtained from tree rings, glacial deposits, pollen sequences, isotopic concentration of ice bodies, and fossil woodrat middens. These records indicate the Holocene has undergone significant climatic variability. Understanding the nature of Holocene climatic fluctuations is essential for refining our ability to predict future climatic change.

A recent time period in the Holocene that has received considerable interest is the Little Ice Age (Matthes 1939). The Little Ice Age culminated around AD 1550-1750 but apparently had a total range from the 14th to the late 19th century (Lamb 1966, 1982, Grove 1985). During this period lower temperatures occurred over most if not all of the globe. The documented global temperature decline had important consequences for the flora and fauna of Europe and North America (Grove 1988).

The lower temperatures were not sustained throughout the period. Temperature fluctuations consisted of
individual years and clusters of years during which weather conditions departed strongly from long term means. In Europe, conditions throughout the Little Ice Age led to the advance of mountain glaciers to more forward positions than those occupied for several centuries, or in some areas for millennia. Frontal lobes of glaciers then fluctuated about maximal positions until the warming phase in the decades around the turn of the twentieth century brought them back to where they had been in earlier warm periods of the Holocene (Grove 1988).

In Eastern North America, four Michigan lakes have illustrated a synchronous change over the last 2700 years (Bernarbo 1981). Pine pollen values increased between AD 1200 and 1450, while the highest values for spruce occurred between AD 1450 and 1650, beech declined from AD 1200 to 1600. These species shifts demonstrate that changing conditions may reorder relative dominance of different species in the community. However, the magnitude of the climatic change was insufficient to alter the total forest composition.

The documentation of the Little Ice Age in the western United States is less complete than that of Europe, but ample evidence exists showing regional cooling. Glaciers on Mt. Rainier have well-marked moraines which have been dated using Porter's (1981) lichenometric curve supplemented by tree-ring dating for the older moraines (Burbank 1981).
Periods of moraine stabilization, when ice fronts receded after readvances, were dated to 1519-28, 1552-76, 1613-24, 1640-66, 1691-5, 1720, and 1750 A.D. Benedict (1965, 1973) used lichenometric studies to date a moraine in the Colorado Front Range that experienced an ice advance about AD 1750, which was apparently greater than any other in the Holocene history of this region.

Although there are a few records from montane regions in the Western US, the records are very scant in lower elevations of the Southwest. One type of record documenting the Little Ice Age in the Southwest is lake level studies. Enzel et al. (1989) have reported that some time between 522 and 313 BP a substantial body of water covered the now desiccated Silver Lake Playa in the Mojave Desert. Mono Lake shorelin levels (Stine 1990), 380 km to the north, appear to correspond to the hydric episodes at the Silver Lake Playa. Stine (1990) has found a correspondence between the Mono curve and the record of DeVries type solar variations. DeVries effect are $^{14}$C variations correlated with variations in solar activity. This suggests that the climatic changes experienced at Mono Lake and other lakes of the western Great Basin may be related to such events as the Maunder minimum, one of the hypothesized causes of the Little Ice Age. The Maunder minimum was a prolonged period of diminished solar activity that provided the first well documented case of an inconstancy in solar output.
Other records in the Southwest come from chronostratigraphic data from Black Mesa, AZ (Karlstrom and Karlstrom 1986). During the Little Ice Age there was an aggradation of sediments. However, these conditions were punctuated by droughts, valley erosion, and the formation of weakly to moderately developed geosols and diastems.

These records support the Little Ice Age as a global phenomenon. Lamb (1966) documented 50 yr mean annual temperature variations in central England using instrumental and historical data, which are similar to many other researchers' (LaMarche 1974, Dansgaard et al. 1971, Bernarbo 1981, Thompson et al. 1986, Koerner and Fisher 1990). These researchers document, to an extent, a range of temperatures fluctuating around 1.5° C, with a marked "Medieval" warmth between AD 1000 and 1300, and a cold "Little Ice Age" period from AD 1300 to 1850. The data of the various authors differs in the timing of the temperature maxima and minima which may be attributed to regional differences.

In comparison, there has been work done supporting the regional or hemispherical nature of the Little Ice Age. Morner (1987) stated that short-term climatic changes during the past 20,000 yr have had durations of about 50-150 yr. He concluded that changes were local or regional, but not global events. He also proposed a rotational-gravitational-oceanographic model as a possible causation mechanism.
Woodrats and Woodrat Middens

Woodrats, in the genus *Neotoma*, are medium-sized cricetid rodents which are scanisorial herbivores. The adult weight ranges from 95 g to 585 g. The genus has a wide distribution, with 21 species found from British Columbia to Central America. They inhabit the deserts, oak woodlands, and mixed chaparral communities from sea level to at least 3,350 m elevation (Cameron and Rainey 1972, Atsatt and Ingram 1983). All species of *Neotoma* share the trait of accumulating large amounts of plant material, either in massive stick-houses or in less structured middens within rock shelters (Finley 1958, Leskinen 1975, Wells 1976). The den of a woodrat contains a variety of functionally specific areas including food caches, nesting chambers, and trash middens. These trash middens also serve as sites for repeated urination and defecation (Finley 1958, Van Devender 1973, Spaulding et al. 1983, Finley 1990).

When woodrat middens are located in dry caves or rock shelters they may be preserved for tens of millennia by desiccation. The physical structure of the woodrats crystallized urine, called amberat, augments the middens' preservation. The hot dry desert air hardens woodrat middens through the quick release of its volatile uric vapors (Van Devender 1973). Amberat is hygroscopic and becomes a highly viscous fluid during periods of high
atmospheric humidity, which gives the midden a self-sealing capability (Spaulding 1981). Middens include various types of debris collected by the rat (leaves, twigs, seeds, spines, teeth, and bones) and woodrat fecal pellets, all sealed into a consolidated mass by solidified amberat. Woodrats characteristically have small home ranges and restricted movement. Woodrats forage within 50 m from the den, hence material preserved in middens provides an excellent representative sample of the local vegetation at the time of midden formation (Bleik and Schartz 1975, Van Devender and Spaulding 1979).

The study of fossil middens, pioneered by Philip V. Wells, permits the examination of fossil plant assemblages that have existed at local sites over the last 40,000 years (Wells and Jorgensen 1964, Wells 1976). The method has also been expanded by Van Devender (1977, 1987), Spaulding (1981, 1985), Cole (1981), and Van Devender and Spaulding (1979). Once collected and cleaned the entire assemblage can be radiocarbon dated, thus providing a species list and some information on relative abundance from a particular site and time.
Vegetational History of the Mojave Desert

Paleoecological studies of the Mojave Desert began in the first half of the twentieth century with detailed analyses of the contents of ground sloth dung excavated at Gypsum Cave, NV (Harrington 1933, Laudermilk and Munz 1934). Beginning in the early 1960's a rich paleoecologic record from fossil woodrat middens has been recovered from the region's limestone mountains (Wells and Jorgensen 1964, Mehringer and Ferguson 1969, Spaulding 1981, 1985).

A chronology for the Mojave Desert based on vegetational history has been proposed by Van Devender and Spaulding (1979). The following detailed chronology provides a view of local vegetational changes that took place as the ecosystems of the Mojave Desert developed.

Late Wisconsin/Early Holocene. The midden sequences for this time period have poor resolution. Vegetational change from pinyon-juniper (Pinus-Juniperus) woodland to desertscrub occurred more recently that 11.4 thousand years ago (ka) in some records, and before 11.7 ka in others (Spaulding 1985, Van Devender et al. 1985, Wells and Woodcock 1985). To add complexity to the record, in some lower elevations "glacial age desert scrub" assemblages were in place, yet these assemblages lacked major thermophiles (Spaulding 1990).

Early Holocene/Middle Holocene. Principal vegetational
changes seemed to have occurred between 8.5 and 8.4 ka, and they were more subtle than the vegetational change at the end of the Wisconsin. The immigration of desert thermophiles from their refugia was staggered. For example in Eureka Valley, arrival of Atriplex confertifolia was dated at 8.3 ka (Spaulding 1990).

**Middle Holocene/Late Holocene.** This boundary is not as clear as in other regions of the Southwest, possibly due to the shortage of records for the time period. However, there is a growing interest in the late Holocene due to concerns about future climatic change. Two notable records are present from this period. In the northern Mojave Desert (Eureka Valley, CA) Larrea tridentata arrived between 5.4 and 3.9 ka (Spaulding 1980). Further, Cole and Webb (1985) which recorded a downward shift of 50 to 100 m for Coleogyne ramosissima communities (in Greenwater Valley, CA) between 1435 and 1795 AD.

The vegetational history of the Mojave Desert is thus a complex record of ecological change through time, apparently in response to varying climatic shifts.
Research Objectives

My research objectives were to answer the following questions in relation to the flora during the Little Ice Age near Searchlight, Nevada.

(1) What is the history of occupancy of *Larrea tridentata*, *Coleogyne ramosissima*, *Yucca schidigera*, *Yucca brevifolia*, and *Yucca baccata* in this area?

(2) Are there competing hypotheses which could explain a change in the flora at this site?

(3) Is the procedure of woodrat midden analysis sensitive enough to pick up the pulse of the Little Ice Age?

(4) Do the middens near Searchlight, NV, provide evidence comparable to that from Greenwater Valley, CA (Cole and Webb 1985)?
METHODS AND MATERIALS

Site Description

The study site was a canyon incised by a wash to a maximum depth of 7 m in an alluvial fan near Searchlight, Nevada, (35°28'N, 114°55'W) was the site for the study of late Holocene vegetational distributions in the area. The canyon wall consisted of massive petrocalcic horizons (caliche); overhangs of caliche formed shelters preserving scores of middens.

The area is 96.5 km south of Las Vegas, Nevada. This site is at the interface between communities dominated by Larrea tridentata (Sesse & Moc. ex DC.) Cov. and those dominated by Coleogyne ramosissima Torr. The location of the site at this ecological boundary makes the site particularly valuable for detecting past changes.

There is a long-term weather station maintained within 5 km E-NE of the study area in Searchlight, NV. The temperature extremes recorded at Searchlight since 1959 were 41.7°C and -11.7 °C, which occurred in July and January, respectively.

Precipitation records averaged over a thirty year period are shown in Figure 1. This was calculated from NOAA (1989) data by correcting the total precipitation for 1989, for its departures from "normal" to back-calculate a thirty year mean precipitation. This area experiences both summer
Figure 1. Thirty year mean precipitation record in Searchlight, NV.
and winter rainfall (NOAA 1989). The average annual precipitation is 160 mm. Winter precipitation is a result of maritime polar air masses coming from the Pacific Ocean. Summer precipitation occurs when tropical air masses from either the Pacific Ocean and the Gulf of Mexico move northward into the area (Houghton et al. 1975).

Assumptions of Midden Analysis

In using fossil middens to assess paleoecological change, I made the following four assumptions:

(1) Fossil middens directly reflect the vegetation of past environments from the immediate area in which the fossil midden was collected.
(2) Woodrats sample most plant species within the rodent's home range. However, midden assemblages do not contain a complete inventory of plants growing around a site (Phillips 1977). (When interpreting the data it is important to keep this information in mind.)
(3) Diet is the governing mechanism in the collection of food items contained in the woodrat midden. Knowing the woodrat species and possible dietary preferences of this species may be critical to understanding the fossil record.
(4) One species of woodrat is responsible for the midden accumulation. For late Holocene studies this is probably
accurate, however, when dealing with longer periods of time
this assumption may be incorrect.

Woodrat Midden Analysis

A. Field Techniques

Initially, the canyon in Searchlight was marked with
aluminum tags to delineate a study area. The ends of the
wash were designated as East and West, and at 100 m
intervals an aluminum tag was nailed to the caliche
overhang. Fossil middens were selected on the basis of
degree of induration. The canyon experiences periodic
flooding and some middens become exposed due to cliff
retreat. Late Holocene middens are less indurated and any
exposure to the elements reduces the conglomerated nature of
the midden. Over 20 Neotoma middens were collected in the
canyon from 4000' to 4220' elevation. Twelve of these
middens were analyzed and dated.

Once a suitable midden was selected, a portion of the
midden was removed using a hammer and crow bar. The midden
was placed in a plastic bag with a site number, and wrapped
with masking tape. At the site of each removal a metal disc
with initials (JM) followed by a sequential numbered code was
nailed into the midden or the caliche overhang. This was
done so that other researchers could contact me in future
years about the site data. Then a comprehensive analysis was done on the site, including slope, aspect, relative age, and a sketch of the midden in place in the shelter of the area (Figure 2).

B. Laboratory Techniques

When the field wrapping was removed from the sample in the laboratory it was inspected for any layering. The external weathering rinds were removed with a hammer and chisel. If any layering or depositional discontinuities were present the various strata were separated and designated as subunits of the sample. Extreme caution was exercised when removing internal weathering rinds, so as to reduce contamination.

Once all weathering rinds were removed and the lab data sheet was processed (Figure 3), the middens were soaked in hot water to dissolve the cementing amberat. Samples were washed in water for 1 to 2 weeks. Once the mass began to disaggregate it was poured through a nested set of three sieves (200 mm, 1.651 mm, and .354 mm). This was done every 3-5 days. When the amberat was completely dissolved the entire wet mass was placed in the sieves and rinsed with water to remove the urine and fine particulate matter. The washed material was then placed in a drying oven. After drying the material was placed in the triad of sieves, in a
Figure 2. Actual field data sheet.
FIELD SHEET FOR MIDDEN COLLECTION

Midden No. Modern 2, 3 Location Searchlight, NV

Elevation_________ Slope_________ Aspect N facing, N side
Substrate Caliche _______ Collectors Reesbridge, McAlister

MIDDEN ATTRIBUTES:
Size: Height_________ Length_________ Horiz. Depth_________
Color_________ Consistency_________ Age (Old; Modern) Modern
Apparent macrofossils

For old middens:
I.D. No. of comparative modern midden 1 20 m from E-2
Distance; location of comparative modern midden

Sketch of midden

MODERN VEGETATION DATA:
Size & location of surveyed area
Total cover (%)_________
Percentage coverage of individual species:

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Figure 3. Laboratory data sheet.
MIDDLE ANALYSES

Midden No.__________________ Location__________________

Sketch of Midden Prior to Processing

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<th>WEIGHTS</th>
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<td></td>
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<tr>
<td>Subsample_</td>
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mechanical shaker and each size class of the dried material was stored in a different plastic bag with a paper label.

A small portion of the matrix was then poured on a white enameled tray subdivided into separate 7.6 X 7.6 cm squares drawn in indelible ink. The small squares facilitated systematic sorting and searching for particular species. The target species and Hymenoclea salsola macrofossils were sorted out and stored in plastic bags. The fossil and modern floras were identified through the use of Kearney and Peebles 1960, and Munz 1974.

C. Quantification of Plant Macrofossils

The number of macrofossils representing each target species were counted and divided by the weight (kg) of the subsample. This figure represented the concentration of the target species per kilogram of amberat (Cole 1981). Concentration values ranged from 0 to almost 1,000 fragments per kilogram. In order to reduce this large range, the common logarithm of the concentration values was used as a quantitative index of fossil abundance in each sample. This quotient produced a value that can be thought of in terms of relative numbers of plant parts, which has become an accepted practice for quantifying midden data (Van Devender 1985). This allows for the comparison of data from different researchers, since concentration can be easily
calculated from log data. This method, although not perfect, is considered to be superior to simple presence-absence lists.

**Distribution of Modern Plants**

The late Holocene distributions of plants are meaningless without a detailed knowledge of modern plant distributions. In order to resolve this problem, estimates of abundance and cover in circular plots were taken for every midden that was sampled. For each sampled location, a species list was produced from an area of 30 m from the fossil midden. This area was designed to approximate the area in which a woodrat would be effectively collecting.

To obtain this information a new semiquantitative method was utilized. The log-series survey method is a technique that allows rapid, independent estimates of abundance and cover, Appendix 1 (McAuliffe 1990). An optical rangefinder was used to determine the boundaries of circular plots, and the numbers of individuals of each species were estimated and assigned to logarithmic abundance classes. These classes were equal to the logarithm base 2 of actual abundances. For each species, median canopy cover per individual was estimated on the basis of average canopy diameters. Thus, each species was assigned to a logarithmic canopy cover class, equivalent to the logarithm base 2 of
actual cover. Total cover per species per plot can then be expressed on a logarithmic scale by the simple addition of logarithmic abundance and cover classes.
RESULTS

Modern Vegetation

The floristic composition of the modern vegetation at the Searchlight site is complex (Table 1). Vegetation in the vicinity of the study area consisted of two distinct assemblages: one in the wash and the other on the wash rim. A Sorensen Index of Similarity (Mueller-Dombois and Ellenberg 1974) was calculated and the two communities were 64% similar. The plant species found in each community were basically analogous, yet there were drastic differences as seen in Tables 2, 3, 4 and 5. One of the differences easily observable was the dominance of Coleogyne ramosissima on the wash rim, while on the wash floor Larrea tridentata, Eriogonum fasciculatum, Ambrosia eriocentra, and Chrysothamnus nauseosus were prevalent. The important target species were Coleogyne and Larrea, so it is important that their distributions were relatively spatially separate.

To determine if the two populations of Coleogyne in the wash and rim were identical the Mann - Whitney Test was performed (Kvanli 1988). The hypothesis that the populations were identical was rejected ($p < 0.001$), indicating that the sites differed mainly because Coleogyne dominated the wash rim and was virtually absent from the wash floor (Figure 4). The same test was conducted on the Larrea assemblages in the wash and on the rim. The results
<table>
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<td>Catclaw Acacia</td>
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<td><em>Allionia incarnata</em></td>
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<tr>
<td><em>Amaranthus fimbriatus</em></td>
<td></td>
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<tr>
<td><em>Ambrosia eriocephala</em></td>
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<td><em>Astragalus sp</em></td>
<td></td>
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<td><em>Brickellia desertorum</em></td>
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Table 2. Log Abundance Class Designations for Individual Species in the Wash Valley, Using Four Plots.

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See Appendix 1
Table 3. Log Abundance Class Designations for Individual Species on the Wash Rim, four sites.

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See Appendix 1
Table 4. Log Canopy Cover Class Designations for Individual Species in the Wash Valley, Using Four Plots.

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See Appendix 1
Table 5. Log Canopy Cover Class Designations for Individual Species on the Wash Rim, four sites.

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See Appendix 1
Figure 4. Frequency distribution of *Coleogyne* in the wash and rim. Mann-Whitney Test was performed comparing the two populations. (See Appendix 1)
Coleogyne - Wash

\[ p < 0.001 \]

Coleogyne - Rim

Log Survey Score - Abundance
were similar and the hypothesis of identical populations was rejected (p<0.002) (Figure 5). Although Larrea was present in both the wash and on the wash rim, the abundances were significantly different.

**Modern Middens**

Modern middens were collected to determine target species concentrations. Each modern midden that was collected was located near a fossil midden used in this study. Only five modern middens were used due to the close proximity of several fossil middens. These middens were not indurated, yet possessed a thin layer of amberat.

The concentrations of Coleogyne, Larrea, and Yucca in the modern middens are recorded in Table 6. This illustrated that the plant species composition in the modern middens was very similar.

The five middens were also analyzed in order to test the woodrats' selectivity in representing the target species. Figure 6 compares the relative cover and the relative weight of the target species, and illustrates that Larrea was over-sampled by woodrats, while Coleogyne and Yucca were under-sampled.

Cover was estimated prior to analysis of the midden contents. Log total cover was backtransformed to the corresponding arithmetic midpoints representing approximate
Figure 5. Frequency distribution of Larrea in the wash and rim. Mann-Whitney Test was performed comparing the two populations. (See Appendix 1)
Larrea — Wash

\[ p < 0.0022 \]

Larrea — Rim

Log Survey Score — Abundance
Figure 6. Woodrats' selectivity in representing target species.
Table 6. Target species contained in modern middens

Target Species Concentration\(^1\)

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coleogyne ramosissima</td>
<td>2.72</td>
<td>2.22</td>
<td>2.47</td>
<td>2.79</td>
<td>3.12</td>
</tr>
<tr>
<td>Larrea tridentata</td>
<td>3.18</td>
<td>3.50</td>
<td>2.68</td>
<td>3.64</td>
<td>2.88</td>
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<tr>
<td>Yucca sp.</td>
<td>2.04</td>
<td>2.31</td>
<td>2.43</td>
<td>1.98</td>
<td>2.59</td>
</tr>
</tbody>
</table>

\(^1\) Concentration is log base 10 of plant fragments per kilogram of midden matrix
total cover. These cover estimates were then summed for the
three species, then percentages were calculated using only
the target species. Relative weight was calculated by
summing the weights of all target species, then the
percentage of each species was determined.

Fossil Middens

Fecal pellets from thirteen middens or subsamples were
radiocarbon dated from the Searchlight site (Tables 7 and
8). The earliest midden samples were from one large midden,
5-MAR-1989-2 (M2), from the easternmost portion of the wash.
This midden was relatively exposed to the environment and
was experiencing degradation. Coleogyne was not present in
subsamples M2A, M2B, and M2C. Based on this absence, I
conclude that Coleogyne was not in the foraging range of the
woodrat in the earlier time periods, 1050 ± 60 yr B.P.

The middens that followed in chronological sequence
were 2J1B and 2J1A which were located at the western extreme
of the site (Figure 7). These middens were also devoid of
Coleogyne, but at a younger age of 890 ± 80 yr B.P.

Coleogyne appeared in the record at 600 ± 50 yr B.P.
(Figure 8). However, in the same midden Larrea was absent.
Coleogyne was also found in 2J2B at 590 ± 50 yr B.P. These
middens were found at the western end of the wash system.
At site M1C, Coleogyne was not present in the midden record
Figure 7. Fossil midden location along the wash and concentrations of target species in each midden.
Figure 8. Comparison of macrofossil concentration of Coleogyne and Larrea with an A.D. timescale.
TABLE 7. Woodrat midden samples and radiocarbon dates.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Radiocarbon Date</th>
<th>Lab No.</th>
<th>Material Dated</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-MAR-89-1.C</td>
<td>520 +/- 50</td>
<td>Beta-31980</td>
<td>Fecal pellets</td>
</tr>
<tr>
<td>5-MAR-89-2.A</td>
<td>970 +/- 70</td>
<td>Beta-31981</td>
<td>Fecal pellets</td>
</tr>
<tr>
<td>5-MAR-89-2.B</td>
<td>1040 +/- 70</td>
<td>Beta-38134</td>
<td>Fecal pellets</td>
</tr>
<tr>
<td>5-MAR-89-2.C</td>
<td>1050 +/- 60</td>
<td>Beta-31982</td>
<td>Fecal pellets</td>
</tr>
<tr>
<td>1-JUL-89-1</td>
<td>160 +/- 80</td>
<td>Beta-33918</td>
<td>Fecal pellets</td>
</tr>
<tr>
<td>1-JUL-89-3</td>
<td>150 +/- 70</td>
<td>Beta-36656</td>
<td>Fecal pellets</td>
</tr>
<tr>
<td>2-JUL-89-1.A</td>
<td>840 +/- 60</td>
<td>Beta-38135</td>
<td>Fecal pellets</td>
</tr>
<tr>
<td>2-JUL-89-1.B</td>
<td>890 +/- 80</td>
<td>Beta-33919</td>
<td>Fecal pellets</td>
</tr>
<tr>
<td>2-JUL-89-2.A</td>
<td>470 +/- 60</td>
<td>Beta-36306</td>
<td>Fecal pellets</td>
</tr>
<tr>
<td>2-JUL-89-2.B</td>
<td>590 +/- 50</td>
<td>Beta-38136</td>
<td>Fecal pellets</td>
</tr>
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<td>2-JUL-89-3</td>
<td>600 +/- 50</td>
<td>Beta-38137</td>
<td>Fecal pellets</td>
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<tr>
<td>2-JUL-89-4.B</td>
<td>450 +/- 80</td>
<td>Beta-36657</td>
<td>Fecal pellets</td>
</tr>
<tr>
<td>2-JUL-89-5.B</td>
<td>230 +/- 60</td>
<td>Beta-33920</td>
<td>Fecal pellets</td>
</tr>
</tbody>
</table>

1 Units are $^{14}$C yr B.P. ± SD since 1950
Table 8. Target species found in middens

**Macrofossil Concentration**

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>M2C</th>
<th>M2B</th>
<th>M2A</th>
<th>2J1B</th>
<th>2J1A</th>
<th>2J3</th>
<th>2J2B</th>
<th>M1C</th>
<th>2J2A</th>
<th>2J4B</th>
<th>2J5B</th>
<th>1J1</th>
<th>1J3</th>
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<tbody>
<tr>
<td><strong>Coleogyne ramosissima</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.68</td>
<td>2.93</td>
<td>2.72</td>
<td>2.51</td>
<td>3.45</td>
<td>1.61</td>
<td>2.28</td>
<td></td>
</tr>
<tr>
<td><strong>Larrea tridentata</strong></td>
<td>1.50</td>
<td>3.12</td>
<td>4.40</td>
<td>2.66</td>
<td>2.73</td>
<td>3.07</td>
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<td>3.56</td>
<td>2.55</td>
<td>2.34</td>
<td></td>
</tr>
<tr>
<td><strong>Yucca sp.</strong></td>
<td>2.84</td>
<td>2.39</td>
<td>2.45</td>
<td>2.63</td>
<td>2.53</td>
<td>3.54</td>
<td>2.93</td>
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<td>2.92</td>
<td>2.65</td>
<td>2.90</td>
<td>2.84</td>
<td>2.46</td>
</tr>
</tbody>
</table>

**Midden Age**

<table>
<thead>
<tr>
<th></th>
<th>1050</th>
<th>1040</th>
<th>970</th>
<th>890</th>
<th>840</th>
<th>600</th>
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<th>520</th>
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<td>+/-50</td>
<td>+/-60</td>
<td>+/-60</td>
<td>+/-80</td>
<td>+/-60</td>
<td>+/-70</td>
</tr>
</tbody>
</table>

**Aspect**

|       | S   | S   | S   | N   | N   | N   | N   | N   | N   | S   | S   | S   | N   |

1 Concentration is log base 10 of plant fragments per kilogram washed midden matrix
2 Units are $^{14}$C yr. B.P. +/- SD
at 520 ± 50 yr B.P. This site was found at the eastern end of the wash, Figure 7, which presents an anomaly.

In the following five middens (2J2A, 2J4B, 2J5B, 1J1, and 1J3) all three of the target species were present. The radiocarbon dates ranged from 470 ± 80 to 150 ± 70 yr B.P.

To see if these results statistically indicated a pattern of systematic increase in Coleogyne, the Cox and Stuart (Conover 1971) test for trend was performed. The hypothesis that the occurrence of Coleogyne over time in the midden samples was random was rejected (p < 0.031) and I conclude that the midden samples record a systematic, non-random appearance of Coleogyne after 520 B.P.
DISCUSSION

The data shown in Table 8 indicate a change in the vegetation at the Searchlight site coincident with the onset of the Little Ice Age. Before this hypothesis can be accepted it is necessary to critically analyze alternative hypotheses. At the conception of the project three hypotheses were proposed: 1) catastrophic floods in the wash; 2) human disturbance; and 3) the climatic change associated with the Little Ice Age.

The catastrophic flooding concept was proposed because the site was in a canyon system incised by a major wash. It seemed very plausible that any discrepancy found 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 then be eventually replaced by dominant shrubs. The weedy species that may be an indicator of flooding is *Hymenoclea salsola* (cheeseweed). *Hymenoclea* has been documented to be a rapid colonizer in the Mojave Desert (Webb et al. 1987), and has a very distinctive fruit that would allow easy identification in midden materials. No *Hymenoclea* fruits were present in the middens, thus this hypothesis was rejected.

The human disturbance hypothesis was proposed due to the charred nature of one on the middens. It has been shown
that the cultural activities of man have had profound influences on the structure and composition of modern local vegetation (Betancourt and Van Devender 1981, Van Devender 1985). If human activity were to decimate or increase the population of a plant species certain conditions would have to exist. First, there would have to be a significant population inhabiting the immediate area. Secondly, the plant would have to serve a function for it to be removed or cultivated. It has not been documented that a large population lived in Searchlight during the time in question. Also, Coleogyne as a food source is questionable due to its production of few large seeds, and I am not aware of other uses for the plant. This hypothesis therefore does not seem plausible. One burnt midden was observed that was charred; this condition may have been due to the method used of capturing woodrats as a food source by hunter gatherers.

Critical examination of the previous two hypotheses have led to their rejection. The climatic change of the Little Ice Age seems to be the most reasonable hypothesis to explain the observed vegetational change over time.

The hypothesized causes of the Little Ice Age have traditionally been attributed to three factors. They include: 1) increased volcanic activity 2) large scale ocean-atmospheric interaction and 3) the Maunder minimum of solar activity (Schuurmans 1981). Currently researchers have been examining sunspot cycles and auroral activity to
determine solar activity and how that effects climate (Holdsworth 1990, Silverman 1990).

Coleogyne appeared in the midden record at 600 ± 50 yr B.P., and full Coleogyne community establishment appeared to occur by 470 ± 60 yr B.P. These dates fall into the proposed timing of the Little Ice Age as determined by Lamb (1966). Not only do they correspond to the Little Ice Age, but they correspond to other work conducted in the Southwest.

Similar work with Coleogyne/Larrea was documented by Cole and Webb (1985). Their work was done in the northern Mojave Desert and illustrated a 50 to 100 m downward shift for Coleogyne between 1435 and 1795 A.D. This corresponds closely to my data. Outside the midden literature lake level studies have provided support to the data found in Searchlight. Enzel et al. (1989) have documented a hydric episode between 522 and 313 B.P. in the now desiccated Silver Lake Playa in the Mojave Desert. Mono Lake, 380 km to the north of Silver Lake Playa, also exhibited a wet period at 300 yr B.P. These studies, taken together, indicate a clear climatic shift in the Southwest that corresponds with the timing of the Little Ice Age.
Minor Irregularities in the Midden Record

Vegetational data obtained from fossil middens indicate that late Holocene plant communities were less stable than is usually proposed (Cole 1981). The data in Table 8 documents that Coleogyne was absent from the study site locale, and appeared in the midden at 600 ± 50 yr B.P., or approximately 1350 A.D. However, the same midden was devoid of Larrea. Before the presence of Coleogyne can be interpreted, the absence of Larrea must be explained.

I have developed two possible hypotheses to explain the absence of Larrea in the 2J3 midden: 1) Larrea was not present at the location 2) a frost was able to kill the Larrea individuals and 3) there was a sampling discrepancy. The Larrea population in the wash is made up of a few, very large, long-lived individuals. These individuals occupy positions very close to the wash wall. It is hypothesized that this location enabled the plants to survive any catastrophic flood that may have occurred in the wash. Thus, it is very unlikely that Larrea was not present at the site.

Beatley (1974) attributed low minimum air temperatures due to temperature inversions as the primary cause of the absence of Larrea in the closed basin of Frenchman Flat on the Nevada Test Site (NTS). This was the proposed limiting condition of Larrea at lower elevations. However, the upper
distributional limit was due to increased moisture. The Searchlight site appeared to be at the upper limits of Larrea. Increased moisture prevented Larrea from reproducing at higher elevations at the NTS. An inability to reproduce for a few years would not affect the population of such a long-lived plant. The concept of frost kill is not a very feasible explanation for the absence of Larrea in the midden, as the species that occurred in the wash were plants that were intolerant of freezing. Thus, if Larrea was frost killed the other species in the wash would be also killed.

The third hypothesis for the absence of Larrea was a sampling problem. If Larrea were outside the foraging range of the packrat, it would not be represented in the midden. Since the distribution of Larrea in the wash floor is patchy it would be plausible to expect at least one midden not to contain creosote bush. Thus, the sampling hypothesis appears to best explain the absence of Larrea in midden 2J3.

Table 8 displays another discrepancy, and that is the absence of Coleogyne at 520 ± 50 yr. B.P. M1C is located at the extreme eastern end of the wash with the lowest elevation (4000') at the site, while the first midden to possess Coleogyne was located at the extreme western portion of the wash (4220'), Figure 5. The distance between these to middens was approximately 1.4 km. I have developed two hypotheses to interpret the absence of blackbrush in this
midden: 1) the change is an artifact of the verticle
position of the midden in the caliche wall or 2)
vegetational inertia.

The vertical positions of the dated middens are shown
in Table 9. The absence of Coleogyne in midden M1C could be
explained by where the woodrats were actually foraging. If
the rats were foraging only in the wash it is possible that
the Coleogyne assemblage would be entirely unsampled in the
midden record. Midden M1C is located in the middle of the
caliche wall (Table 9). Theoretically, the rodent has a 50-
50 chance of sampling the wash or the rim. However, when
comparing the vertical locations to other middens 200 cm
does not pose a formidable barrier to the rodent. For
example, midden 2J4B, 2J5B, and 1J1 were between 260 and 300
cm below the wash rim, yet all contained Coleogyne (Table
9). Thus, the hypothesis is rejected.

Vegetational inertia is simply the potential lag time
in vegetational response to climatic change (Thompson 1990).
A sudden climatic change may not be represented in the
midden record because of slow migration rates for some
plants. Therefore, a climatic shift must be severe enough to
dislocate the original vegetation before the invading type
can become dominant.

In the case of the Searchlight site the absence of
Coleogyne from the M1C midden may represent a less drastic
form of vegetational inertia. Since Coleogyne was present
Table 9. Vertical position of middens in wash wall

<table>
<thead>
<tr>
<th>Location</th>
<th>M2C</th>
<th>M2B</th>
<th>M2A</th>
<th>2J1B</th>
<th>2J1A</th>
<th>2J3</th>
<th>2J2B</th>
<th>M1C</th>
<th>2J2A</th>
<th>2J4B</th>
<th>2J5B</th>
<th>1J1</th>
<th>1J3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above Wash Floor</td>
<td>1.54</td>
<td>1.54</td>
<td>1.54</td>
<td>5.50</td>
<td>5.50</td>
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<td>600</td>
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<td>E</td>
<td>E</td>
<td>W</td>
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<td>E</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>E</td>
</tr>
</tbody>
</table>

1 Distance in meters
2 Units are ¹⁴C yr. B.P. +/- SD
at the upper end of the wash it is plausible to conclude that blackbrush had invaded the site locale. Thus, Coleogyne was only 1 km from M1C. It is possible to conceive that in approximately 80 years the vegetational lag time of Coleogyne had not allowed the population to reach the eastern end of the site. This hypothesis is supported by work done on the autecology of Coleogyne, which documents the slow rate of change in blackbrush communities. In historical photographs taken over a 78 year period, Coleogyne individuals changed the least of any other species and individuals appeared virtually identical (Webb et al. 1987). Also, 37 years after a burn Coleogyne showed no signs of recovery (Callison et al. 1985). The vegetational inertia model provides a reasonable explanation for the absence of Coleogyne in midden M1C.

Implications of Vegetation Change

Coleogyne ramosissima is the dominant perennial on more than one million hectares in Utah, along the Colorado River drainage, and in several adjacent enclosed basins of the Great Basin-Mojave Desert Transition (Figure 9, Bowns and West 1976). Beatley (1976) has documented Coleogyne occurring often in nearly pure stands on upper bajadas of closed basins or over the floors of open basins at middle elevations in the Mojave Desert.
Figure 9. Distribution of Coleogyne (Bowns and West 1976).
Coleogyne was absent from the midden record for approximately 400 years. So the natural questions to ask are: Where did blackbrush migrate from and how did this movement occur? To answer this it is necessary to look at the autecology of Coleogyne ramosissima.

When examining the autecology of plant species three parameters are focused on: 1) soil characteristics 2) temperature regimes and 3) precipitation limits. Beatley (1976) has documented that Coleogyne is found on Precambrian granite, on Paleozoic limestone, and on Quaternary alluvium. It also occurs on soils that range in pH from 7.8 to 8.0 with maximum soil development (Bowns and West 1976). This information is vital in determining the distribution of an organism, but is not as important when considering distributional changes on a smaller scale. Soil formation occurs over long periods of time and thus is not a factor in this study.

Temperature regimes could limit the distribution of Coleogyne, but they would have to be out of the range of associated species. At the Searchlight site Larrea is in association with Coleogyne. It has been documented that the minimum and maximum temperatures experienced by Coleogyne are well within the range of Larrea communities (Beatley 1974, 1975, Bown and West 1976). Therefore, there must be another factor that is limiting.

Coleogyne has been documented to reach its best
development when mean rainfall is in excess of 200 mm (Beatley 1975). Bowns and West (1976) have shown precipitation data for a 23 yr period in Coleogyne communities to have a mean of 274 mm. Larrea, and many other Mojave Desert species associated with it do not occur where the mean rainfall exceeds 180 mm (Beatley 1974).

Precipitation seems to be the factor that distinguishes between Coleogyne and Larrea communities. Coleogyne may become competitively dominant with increased moisture.

It seems clear that increased precipitation was the precursor to the movement of Coleogyne to the study site. Currently, annual precipitation is 160 mm. It is possible to estimate the amount of precipitation to be at least 200 mm. However, the other outstanding question is when did the rainfall occur? Enzel et al. (1989) have examined the modern Mojave River watershed. The Mojave River flow is the result of intensive winter storms in the San Bernardino Mountains. To have accumulation at Silver Lake, the terminus of the Mojave River, the average monthly precipitation would have to be exceeded by two standard deviations. They propose the increased rainfall was a response to an anomalous low which was caused by a shift of the central North Pacific winter low. This would have caused stronger storms to progress farther south than normal (Enzel et al. 1989).

These events can be used as analogues for conditions
during the Holocene. This is possible because the main features of atmospheric circulation have remained fairly constant for the past 10,000 yrs (Wendland 1989). Also, it has been documented that above-average precipitation would be needed in successive years, the first for seed production and the second for establishment of long-lived plants (McPherson and Wright 1990). Since Silver Lake and Searchlight are so near it seems probable that the timing of the rainfall was in winter. Yet, the physiological ecology of Coleogyne has not been considered.

Ehleringer and Cook (1990) have shown that hydrogen isotope ratios of stem waters are a reliable indicator of the water source being used by the plant. They have documented that long-lived plants are more water-use efficient, and that these plants utilize water stored deep within the soil profile. Such water is recharged primarily by winter rainfall. Since Coleogyne is a long-lived perennial it seems logical to conclude that it is using winter rainfall which corresponds to Enzel et al. (1989).

It is incorrect to ignore summer rainfall for it appears to play an important role in promoting the establishment of perennials (Ehleringer and Cook 1990). However, Coleogyne seeds may germinate only after unusual early spring rains (Beatley 1974), usually in rodent caches (Bowns and West 1976). Summer rains do not seem to have great impact on Coleogyne, yet it may be a secondary
CONCLUSIONS

An increase in precipitation seems to have allowed Coleogyne to occupy this wash in Searchlight. When the rainfall occurred is subject to interpretation, and may be under the control of many factors. However, it seems logical to conclude that the vegetational changes present in the Searchlight middens are due to the direct influence of climatic shifts during the Little Ice Age.
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Appendix 1

Scale for logarithmic density classes

<table>
<thead>
<tr>
<th>Midpoint of arithmetic interval (N)</th>
<th>Arithmetic density interval</th>
<th>Logarithmic density class (log₂N)</th>
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<td>-1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
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<td>2</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>3 - 5</td>
<td>2</td>
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<tr>
<td>8</td>
<td>6 - 11</td>
<td>3</td>
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<tr>
<td>16</td>
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<td>192 - 383</td>
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</tr>
<tr>
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<td>384 - 767</td>
<td>9</td>
</tr>
</tbody>
</table>

Scale for logarithmic canopy cover classes

<table>
<thead>
<tr>
<th>Midpoint of canopy cover interval (m²)</th>
<th>Range of canopy diameters (m)</th>
<th>Logarithmic canopy cover class (log₂M + 10)</th>
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<tbody>
<tr>
<td>0.002</td>
<td>0 &lt; x &lt; 0.06</td>
<td>1</td>
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<tr>
<td>0.004</td>
<td>0.06 - 0.09</td>
<td>2</td>
</tr>
<tr>
<td>0.008</td>
<td>0.09 - 0.12</td>
<td>3</td>
</tr>
<tr>
<td>0.016</td>
<td>0.12 - 0.17</td>
<td>4</td>
</tr>
<tr>
<td>0.031</td>
<td>0.17 - 0.25</td>
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</tr>
<tr>
<td>0.063</td>
<td>0.25 - 0.35</td>
<td>6</td>
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<tr>
<td>0.125</td>
<td>0.35 - 0.49</td>
<td>7</td>
</tr>
<tr>
<td>0.25</td>
<td>0.49 - 0.69</td>
<td>8</td>
</tr>
<tr>
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<td>0.69 - 0.98</td>
<td>9</td>
</tr>
<tr>
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<td>0.98 - 1.4</td>
<td>10</td>
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<tr>
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<td>1.4 - 2.0</td>
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<tr>
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<td>2.0 - 2.8</td>
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<td>3.9 - 5.5</td>
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<td>32</td>
<td>5.5 - 7.8</td>
<td>15</td>
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(From McAuliffe 1990)