Reports

Holocene Vegetation in Chaco Canyon, New Mexico

Abstract. *Well-preserved plant remains in packrat middens chronicle vegetation change in Chaco Canyon over the past 11,000 years. Early Holocene evidence of communities dominated by Douglas fir, Rocky Mountain juniper, and limber pine in the San Juan Basin calls for revision of traditional constructs based on fossil pollen. Middle and late Holocene vegetation in the canyon was pinyon-juniper woodland up until Anasazi occupation between 1000 and 800 years ago. Instead of climate, Anasazi fuel needs may explain the drastic reduction of pinyon and juniper after 1230 years ago. The lack of pinyon-juniper recovery over the past millennium has implications for contemporary forest and range ecology.*

Destruction of vegetation by the Anasazi has been a ruling theory among Chaco Canyon archeologists since the turn of the century. These people used an estimated 100,000 ponderosa pine trees to construct 13 multistoried buildings and a host of smaller establishments that were occupied between 1000 and 800 years ago (*1*). The isolated snags and relict stands of ponderosa on the south side of Chaco Canyon are seen as remnants of a once extensive forest. In time, accelerated erosion due to deforestation presumably destroyed much of the agricultural land and the canyon was abandoned. Only recently have there been attempts to document changes in local vegetation. Hall (*2*) describes a Holocene pollen stratigraphy from local alluvial sediments and infers little or no change in vegetation during the past 7000 years. However, alluvial processes integrating pollen from a wide source area may not produce records sufficiently sensitive to changes in local plant communities. We use plant macrofossils in packrat middens to reconstruct past vegetation in Chaco Canyon. Packrats (*Neotoma*) gather plant materials mostly from within 30 m of their dens. Our midden record from the more xeric, north side of the canyon displays significant changes over the past 11,000 years.

Dark, shiny masses of organic residue in caves of the Southwest were first recognized in 1874 by a geologist with the Wheeler Survey (*3*), but the paleoecological worth of the material went unnoticed until the early 1960's (*4*). In protected perch areas, crystallization of packrat urine through desiccation cements waste debris containing plant fragments, animal bones, fecal pellets, dust, and pollen. In the laboratory, indurated samples are disaggregated in water, wet-screened through a 20-mesh soil sieve, and dried in an oven. The organic residue is sieved into size classes, sorted by hand, and compared with reference collections. A radiocarbon date obtained from a bulk sample of one species is usually applied to the entire assemblage. Middens from different exposures and elevations allow use of traditional ecological methods in sampling across topographic gradients. At Chaco Canyon and similar archeological settings, packrat middens can measure resource availability and extent of human impact on the prehistoric landscape.

Chaco Canyon is in San Juan County, northwestern New Mexico (107°54′W, 36°02′N), and occupies a 32-km stretch in the upper reaches of Chaco Wash. The canyon, formed by erosion during the mid-Pleistocene, cuts through upper Cretaceous sandstones, which dip slightly to the north. Elevations on the north side range from 1860 to 2010 m, while the southern escarpment rises up to 2165 m on Chacra Mesa. The canyon alluvium, from 0.5 to 1.0 km wide and up to 30 m deep, is dissected by an ephemeral channel initiated in the late 1800's. Local climate is characteristic of the cold and dry Great Basin Desert on the Colorado plateaus. Mean annual rainfall is 220 mm, with 40 percent resulting from the summer influx of monsoon air from the gulfs of Mexico and California. During winter, moist polar Pacific air from the northwest occasionally reaches the area. Extreme drought is common during the early part of the growing season, from late April to early July. Mean annual temperature is 10.7°C, with a July mean of 27.4°C and a January mean of −2°C. Local vegetation represents a gradient from pinyon-juniper woodland on Chacra Mesa to a mix of Great Basin desert scrub and grassland over most of the canyon. Dominant woodland elements include Colorado pinyon (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*). Pinyon seldom grows below 1980 m, but scattered junipers are found at lower elevations. Ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*) occur only sporadically on the crest and at the heads of the deeper reentrants on Chacra Mesa.

Four separate localities along a 10-km transect on the north side of the canyon yielded 22 packrat middens that were

Table 1. Radiocarbon dates from fossil packrat middens, Chaco Canyon, New Mexico. Species codes for material dated are: Jumo, *Juniperus monosperma*; Jusc, *Juniperus scopulorum*; Pied, *Pinus edulis*; Psme, *Pseudotsuga menziesii*; and Epto, *Ephedra torreyana*.

Site	Elevation (m)	Age (years B.P.)	Sample	Material dated
Atlatl Cave 3	1910	9460 ± 160	A-2116	Psme wood fragments
Atlatl Cave 3	1910	10500 ± 250	A-2411	Jumo twigs
Atlatl Cave 4A	1910	5550 ± 130	A-2115	Jumo twigs
Atlatl Cave 4B	1910	10030 ± 150	A-2123	Jusc twigs
Atlatl Cave 4B	1910	10600 ± 200	A-2139	Psme wood fragment
Casa Chiquita 1A	1865	2360 ± 70	A-2138	Jumo twigs
Casa Chiquita 1B	1865	3940 ± 110	A-2129	Pied wood fragment
Casa Chiquita 2	1865	4780 ± 90	A-2124	Jumo twigs
Casa Chiquita 3	1865	1970 ± 100	A-2125	Miscellaneous twigs
Casa Chiquita 4	1860	4920 ± 110	A-2126	Miscellaneous twigs
Casa Chiquita 5	1860	1610 ± 90	A-2127	*Neotoma* fecal pellets
Gallo Wash 1	1896	2810 ± 90	A-1839	Jumo twigs
Gallo Wash 2	1908	4480 ± 90	A-1833	Jumo twigs and seeds
Gallo Wash 3	1908	460 ± 190	A-1837	Epto twigs
Gallo Wash 4	1908	1940 ± 150	A-1834	Jumo twigs and seeds
Gallo Wash 5	1921	2070 ± 90	A-1840	Jumo twigs
Gallo Wash 6	1896	2820 ± 300	A-1838	*Lepus* fecal pellets
Gallo Wash 7	1945	2160 ± 80	A-2109	Jumo twigs and seeds
Mockingbird Canyon 1	1930	1990 ± 90	A-2110	Jumo twigs
Mockingbird Canyon 2	1930	1910 ± 90	A-2111	Jumo twigs
Mockingbird Canyon 3	1935	3270 ± 90	A-2112	Pied needles
Mockingbird Canyon 4	1935	1230 ± 60	A-2113	*Neotoma* fecal pellets
Mockingbird Canyon 5	1935	1860 ± 120	A-2114	Jumo twigs
Werito's Rincon 2	1900	1780 ± 110	A-2128	Jumo twigs

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dated from 10,600 to 460 years before the present (B.P.) (Table 1). The midden sites range in elevation from 1860 to 1945 m, well below the local distribution of pinyon and on slopes presently occupied by Great Basin desert scrub. The quality of coverage in the time series varies, with the majority of the samples clustering between 5550 and 1230 years B.P. The gap in the record between 9460 and 5550 years B.P. is due to inadequate sampling. Middens may be scarce in the past millennium because of reduced packrat densities with intense human predation and habitat disturbance. The youngest midden (460 years B.P.) postdates prehistoric abandonment but is slightly older than historic arrival of the Navajo who now occupy the area. Each midden assemblage contains 10 to 33 species, with a total of 78 plant taxa, or 25 percent of the modern flora represented (Fig. 1).

Two middens are of early Holocene age (10,600 to 9460 years B.P.) and contain evidence of communities dominated by Douglas fir, Rocky Mountain juniper (*Juniperus scopulorum*), and limber pine (*Pinus* cf. *flexilis*). Isolated Douglas firs are still found on Chacra Mesa 20 to 25 km to the east. Rocky Mountain juniper, absent from the lowlands of the San Juan Basin, grows best where mean July temperatures range from 15.5° to 23.0°C, well below the norm at Chaco (*5*). Its distribution coincides with areas where mean annual rainfall ranges between 381 and 631 mm, well above what the canyon receives today (*5*). The nearest population of limber pine is in the San Juan Mountains (180 km northeast), though it was abundant in the nearby Chuska Mountains (60 to 80 km west) during the late Pleistocene (*6*). A single needle from one assemblage suggests that spruce (*Picea* sp.) was present but not common. Both ponderosa pine and pinyon are conspicuously absent from the early Holocene assemblages.

Four middle Holocene samples (5550 to 4480 years B.P.) record pinyon-juniper woodland, which contrasts with the more mesic forest communities of the early Holocene. The exact timing of this shift is not known. One midden (5550 years B.P.) from a protected alcove contains small amounts of Douglas fir and ponderosa pine with abundant pinyon and juniper. All of the samples younger than 5550 years B.P. contain the more xeric-adapted one-seed juniper, suggesting a substantial decrease in effective moisture beginning in the middle Holocene. Several herbs that respond primarily to summer precipitation appear for the first time.

Fifteen middens demonstrate the persistence of pinyon-juniper woodland into the late Holocene (3940 to 1230 years

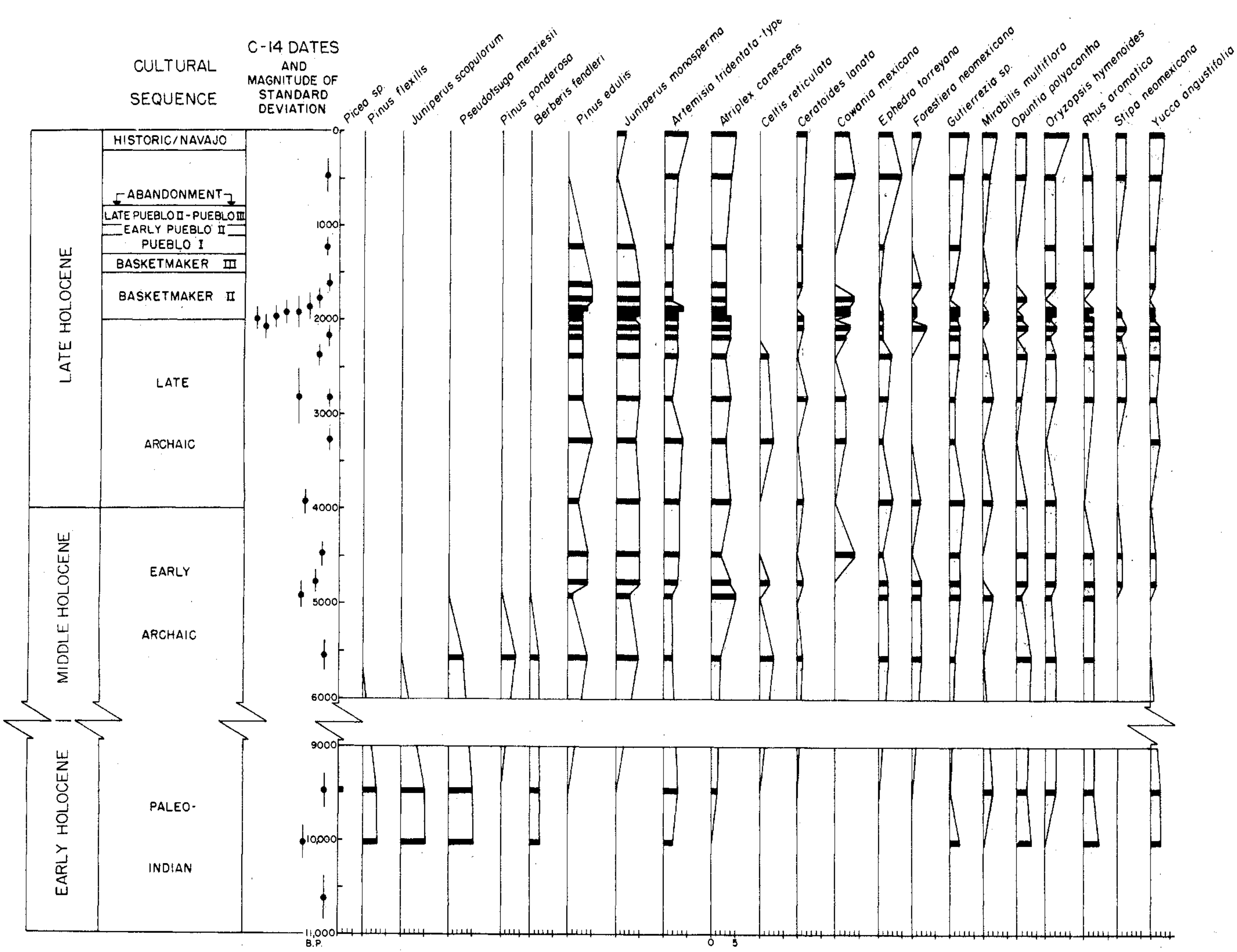

Fig. 1. Time sequence of relative abundances of 22 perennial species in fossil packrat middens from Chaco Canyon, New Mexico. Relative abundance (on a scale of 1 to 5) is an internal ranking used because the original mass and number of identifiable specimens per kilogram vary. To assign values, all specimens are counted except one or two dominants which are estimated. An approximation of modern abundances (the uppermost set of bars on the graph) was obtained from similar rankings given to percentages of sites at which each taxa is found today. Sample points are connected to accentuate differences between samples and not to imply a continuous record. Variability in the sequence may be due partly to site differences within the overall data set.

B.P.). In the field, we examined a number of active packrat dens in close proximity to the midden localities. Small traces of juniper occur only where isolated trees grow at present within 30 m of the dens. We failed to find pinyon remains in any modern deposits. Our youngest sample (460 years B.P.) lacks remains of pinyon and juniper and contains material that most closely resembles the modern flora. Some 87 percent of the perennial species in the midden today occur within 30 m of the site; the mean for all late Holocene samples was 40 percent. Four-winged saltbush (*Atriplex canescens*), cliffrose (*Cowania mexicana*), and Mormon tea (*Ephedra torreyana*) are codominants in this assemblage. Relative abundances for four-winged saltbush and Mormon tea vary inversely with pinyon and juniper values throughout the sequence. Some herbaceous species in late Holocene middens, such as trailing four-o'clock (*Alliona incarnata*), spiderling (*Boerhavia* sp.), bugseed (*Corispermum* sp.), and summer poppy (*Kallstroemia* sp.), no longer occur in Chaco Canyon and may represent local extinctions. These plants may have declined because of Navajo grazing practices, an idea suggested for the Colorado plateaus and the central Rio Grande Valley (*7*).

Tree density in the former woodland cannot be estimated precisely from the midden record, but a general scenario can be suggested. The understory in the fossil assemblages is more like modern desert scrub communities than the understory of the Chacra Mesa woodland. Gambel oak (*Quercus gambelli*) and squaw currant (*Ribes inebrians*), common woodland associates on the Mesa, are missing from the record. On the north side of the canyon, we envision a patchwork of desert scrub and grassland with scattered junipers on exposed hillsides and pinyon-juniper stands on cliffsides and sandy outcrops. Limited stands of ponderosa pine may have occupied favorable sites on the canyon's south side and Chacra Mesa, but we cannot infer this from our data.

The biogeography of past conifer forests in the Southwest is poorly understood. Some authors (*8*) have characterized late Pleistocene climate over much of the Southwest as cloudy with heavy winter precipitation and cool summers. Modern disjunct populations of bristlecone pine (*Pinus aristata*), limber pine, and spruce on the highest mountains in the Southwest suggest that late Pleistocene vegetation zones were depressed enough to create lowland corridors (*9*). Fossil pollen spectra from highland lakes have been used to project ponderosa pine forest or pinyon-juniper woodland across the San Juan Basin (*5, 10*). Our midden record, however, suggests that early Holocene plant communities in Chaco Canyon are relicts of more extensive late Pleistocene forests dominated by Douglas fir, limber pine, and spruce. Interpretation of the fossil pollen record may be in error because of uniformitarian assumptions based on modern phytogeography, and the difficulty in distinguishing between fossil pollen grains of the various pines in the region. The absence of ponderosa pine remains in late Pleistocene middens east of the Sierra Nevada and early Holocene middens at Chaco suggests that this pine did not reach its maximum distribution until the middle Holocene. Establishment of the northern ranges of pinyons, rarely found in Pleistocene middens north of 36° latitude, may also be a Holocene event. Regeneration of ponderosa pine is sporadic because favorable distribution of summer rainfall must coincide with a productive seed year. Once established, ponderosa seedlings can withstand drought and survive at altitudes below the limits of other conifers. We propose that warmer global temperatures and the shift northward of the summer monsoon culminating in the middle Holocene produced the conditions necessary for expansion of ponderosa pine into its present range. Spring drought and midsummer thunderstorms increased the frequency of lighting fires, favoring ponderosa over the more fire-sensitive conifers.

At Chaco Canyon, we find it difficult to explain drastic reduction of pinyon and juniper after 1230 years B.P. through climatic change alone. Regional climatic variability inferred for the last 1200 years (*11*) is probably within the range of climatic extremes that occurred between 5550 and 1230 years B.P., when woodland prevailed at the midden sites. A climatic model advanced to explain drastic changes in prehistoric demography and settlement pattern on the Colorado Plateaus (*11*) fails to consider the self-limiting consequences of human impact in heavily populated areas. Although climatic change may partially explain abandonment of Chaco about 800 years ago, the resident population probably exceeded local carrying capacity even in times of optimal weather. An extensive road network connected Chaco with procurement areas of outlying communities, but resources close at hand were fully exploited. Although our present data are insufficient to establish the exact timing of woodland reduction, we postulate that marginal stands of pinyon and juniper could not withstand the relentless woodcutting needed to meet fuel demands of a growing population over the span of two centuries. Depletion of fuelwood and other local resources probably intensified the reliance on commodity imports from peripheral communities. The resulting political and economic instability may partly explain eventual migration of Chacoan peoples to the northern Rio Grande and elsewhere after 800 years B.P.

From the lack of pinyon-juniper recovery over the past millennium, resource managers and range ecologists may find some traditional assumptions doubtful. Primarily, southwestern vegetation just before Anglo-European settlement may not have been as pristine as it is often described. Current efforts to improve forage and water yield through pinyon-juniper eradication are partly legitimized by the assumption that the woodland expanded historically at the expense of marginal grasslands. Where large prehistoric populations once congregated, this "invasion" may reflect slow recovery of the woodland subsequent to human impact. If accurate, our prehistoric analog suggests that rising public consumption of marginal pinyon and juniper for domestic fuel may be irreversible in the time tables of contemporary forest and range policy.

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