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PACKRAT MIDDENS AND LATE HOLOCENE ENVIRONMENTAL CHANGE IN SOUTHWESTERN COLORADO

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ABSTRACT—Seventeen middens of the bushy-tailed packrat (*Neotoma cinerea*), ranging in age from 3450 ± 40 to 160 ± 50 radiocarbon years before present (B.P.), were collected in 1996 from the Upper Gunnison Basin, Colorado. Eight of these subfossil middens contained plant remains from species that no longer occur near the locations of the middens. Radiocarbon dates on conifer remains indicated shifts in forest communities in the late Holocene at 3320, 560, and 240 B.P. Past climates were cooler than today at 3320 B.P., when mixed lodgepole (*Pinus contorta*) and ponderosa pine (*P. ponderosa*) forest expanded to lower elevations in the basin. Conditions became warmer between 1500 to 950 B.P., with additional cooling from 660 to 170 B.P., corresponding with cooling periods in the 1300s and during the Little Ice Age (500–150 B.P. or 1500–1850 CE). These data indicated that the late Holocene of Colorado was marked by episodes of climate change that previously have not been identified in the paleoclimatic record.

RESUMEN—Diecisiete nidos del roedor *Neotoma cinerea* de entre 3450 ± 40 a 160 ± 50 años de radiocarbono antes del presente (A.P.), fueron recolectados del Upper Gunnison Basin, Colorado, en 1996. Ocho de estos nidos subfósiles contenían restos de plantas de especies actualmente inexistentes en los alrededores del área de donde se encontraron los nidos. Dataciones de radiocarbono en restos de coníferas indicaron variaciones en las comunidades de bosque correspondientes al Holoceno tardío en 3320, 560, y 240 A.P. Climas pasados fueron más fríos que hoy en 3320 A.P., cuando bosques mixtos de *Pinus contorta* y *P. ponderosa* se expandieron a elevaciones más bajas de la cuenca. Hubo un calentamiento entre 1500 a 950 años A.P., con un enfriamiento adicional de 660 a 170 años A.P., correspondiendo con periodos de enfriamiento en los años de 1300 y durante la Pequeña Edad de Hielo (550–150 A.P. o A.D. 1500–1850). Estos datos indicaron que el Holoceno tardío en Colorado estuvo marcado por episodios de cambio climático no identificados previamente en el registro paleoclimático.

The Upper Gunnison Basin in southwestern Colorado long has been recognized for its unusual ecological characteristics, including an absence of plant and animal taxa that should occur there, but do not (Woodbury et al., 1962; Barrell, 1969; Armstrong, 1972). For example, piñon pine (*Pinus edulis*) is rare, and ash (*Fraxinus*) and ground cherry (*Physalis*) are absent from the basin (Stiger, 2001). Vertebrates that occupy the same elevational ranges and habitats as those within the basin, but are absent there, include Woodhouse's toad (*Bufo woodhousei*), short-horned lizard (*Phrynosoma douglassii*), collared lizard (*Crotaphytus collaris*), western rattlesnake (*Crotalus viridis*), sagebrush vole (*Lemmiscus curtatus*), and thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*) (Hammerson, 1986; Fitzgerald et al., 1994). Fossil and archaeological evidence indicate that many of these species occurred in the basin during the late Pleistocene to middle Holocene (Emslie, 1986; Stiger, 2001), but have since become extirpated. Ecological isolation of extant species in the Upper Gunnison Basin also is apparent. Populations of the sage grouse (*Centrocercus urophasianus*), for example, have been isolated in this region apparently since the Pleistocene and are now considered to be a separate species, *C. gunnisoni*, distinguished genetically and behaviorally from pop-

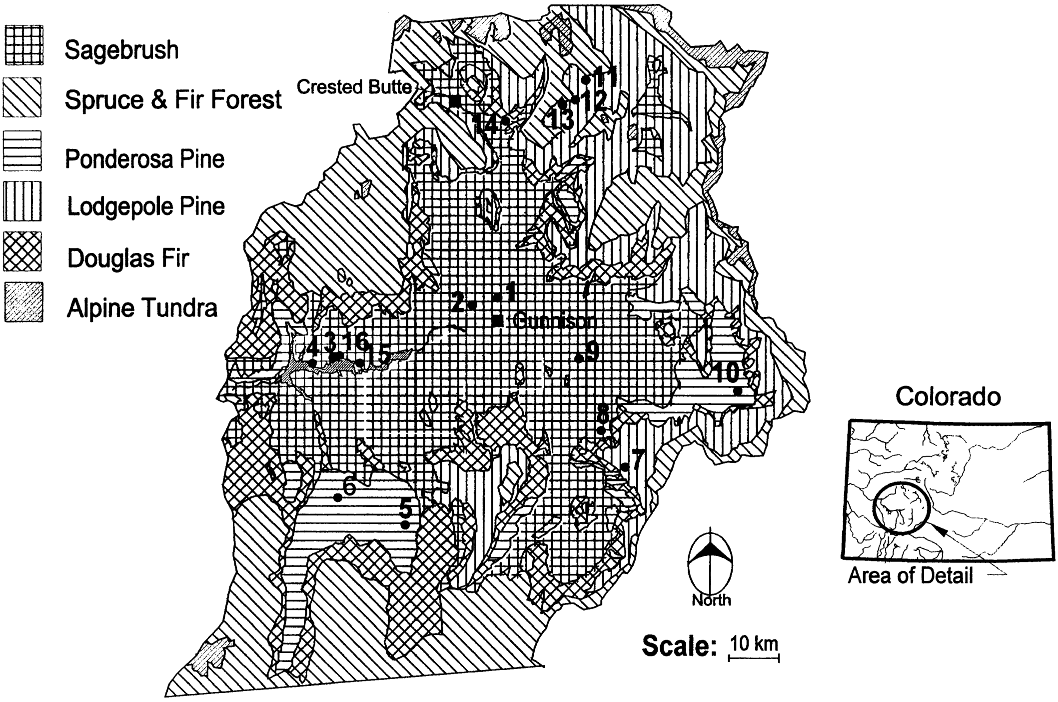

FIG. 1—Vegetation map of major forest communities in the Upper Gunnison Basin, Colorado, with the locations of 16 subfossil midden sites discussed in the text. Numbered locations match those for midden sites listed in Table 1.

ulations of sage grouse elsewhere in Colorado and the western United States (Young et al., 1994, 2000).

The development of these ecological anomalies, including local extirpations and isolation, probably has resulted from the unique topography and climate that characterize the Upper Gunnison Basin. Pleistocene and Holocene climatic change might have been important in altering the composition of basin communities to produce these modern assemblages, but few data have been gathered on this subject. Here, we examine subfossil macrobotanical remains from 17 middens of the bushy-tailed packrat (*Neotoma cinerea*) to reconstruct environmental changes in the late Holocene (last 3,000 years) in the Upper Gunnison Basin. Our data also are compared to other local and regional studies on climatic change in Colorado during the Holocene.

METHODS—*Study Area*—The Upper Gunnison Basin encompasses 11,000 km^2 in southwestern Colorado within the southern Rocky Mountains and on the eastern edge of the Colorado Plateau (Fig. 1). It has an elevational range of 2,200 to 4,300 m and no outlet lower than 2,650 m, except through the narrow gorge of the Black Canyon of the Gunnison to the west. This canyon, which includes a 20-km section that is over 700 m deep and only 400 m across at its narrowest point, acts as a filter for the movement of species in and out of the basin. No other large montane basin in Colorado is enclosed by similar geographic barriers, and it is this feature that we believe has caused the development of the unusual community and biogeographic patterns that exist there.

Also partly due to its topography, the Upper Gunnison Basin experiences a climate unlike other regions in Colorado. Winters often are extremely cold as cool air settles into the lower basin (the record minimum temperature is −43.9°C in December 1924), and the average annual temperature is 3.1°C (Western Regional Climate Center, http://www.wrcc.dri.edu). In addition, the area is drier than other regions at this elevation, with an annual average precipitation of 27 cm. For comparison, the state annual average temperature is 7°C and precipitation is 38 cm for montane shrublands at 1,675 to 2,600 m elevation (Fitzgerald et al., 1994). It is possible that these factors (temperature, moisture, topography), or interactions among them, have been responsible for the composition of plant communities that are dominated by sagebrush (*Artemisia*) at elevations from 2,800 to 3,100 m, a range where piñon-juniper forests prevail in areas outside of the basin. At elevations between 3,100 and 3,600 m, there are a variety of forests that include juniper (*Juniperus osteosperma*), aspen (*Populus tremuloides*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*P. contorta*), bristlecone pine (*P. aristata*), limber pine (*P. flexilis*), blue spruce (*Picea pungens*), Engelmann spruce (*P. engelmannii*), and Douglas-fir (*Pseudotsuga menziesii*); subalpine forests (3,600 to 4,200 m) are comprised primarily of Englemann spruce, limber pine, or bristlecone pine. Alpine vegetation occurs above 4,200 m. In addition, historical records indicate that the interior basin habitats have remained relatively unchanged and undisturbed since the area was first explored and surveyed by the United States government in 1853 (Beckwith, 1854).

Packrat middens have not been investigated as a source of paleoenvironmental information in the Upper Gunnison Basin. Only 1 species of *Neotoma*, the bushy-tailed packrat or woodrat (*N. cinerea*), occurs in the basin (Fitzgerald et al., 1994). Vertebrate fossils from Haystack and Cement Creek caves (Emslie, 1986, 2002) indicate that no other species of *Neotoma* has occurred in the Upper Gunnison Basin since the late Pleistocene. *Neotoma cinerea* inhabits cliffs, crevices, and caves, where its middens are most likely to be preserved over hundreds to thousands of years. In 1996, we surveyed areas with suitable habitat for *N. cinerea* and located 45 sites with preserved middens of various ages. Macroplant data from 17 of these middens from 16 locations are presented here.

Solidified middens were sampled by removing a small portion (300–1,000 g) with a rock hammer; none of the middens were stratified. We rinsed and soaked all samples in water to remove packrat urine and to extract clean plant remains for identification. After rinsing and drying, plant remains, including seeds, leaves, and twigs, and packrat feces, were sorted and identified from each midden. Weights of middens and of plants were not recorded because these data do not provide an accurate assessment of plant cover or density (Spaulding et al., 1990). Thus, only presence-absence of identified plant taxa from selected middens are presented here. All samples are housed at Western State College (WSC), Department of Anthropology, Gunnison, Colorado.

Conventional radiocarbon analyses were completed on 17 subfossil middens using a sample of 15 to 25 g of packrat feces to give an average age for the midden. Accelerator Mass Spectrometry (AMS) dating was completed on pine (*Pinus*) needles from 3 middens to obtain a specific age on trees no longer found in the area where the middens were collected. Because these latter dates differed from those on fecal pellets, we used the dates on single needles in our interpretations. Plant remains from the middens were identified using the collections at WSC, the Anasazi Heritage Center (Dolores, Colorado), and Northern Arizona University (Flagstaff). Voucher specimens of modern plants from 9 midden localities were collected, pressed, and curated into the herbarium collections at WSC. Vouchers of modern plants collected at the midden localities include 178 specimens representing at least 80 taxa. These specimens provide a permanent record of current plant communities at each locality for comparison to midden samples.

RESULTS—Conventional and AMS radiocarbon analyses of packrat feces and individual plant remains from 17 middens provided a range in age from 3450 to 160 B.P. (Table 1). AMS dates on individual plant remains differed from conventional dates on packrat feces from the same midden at 3 sites (RC 2, EIC 2, and RB 1; Table 1). Average conventional dates differed from AMS dates by 290, 390, and 1,910 y, respectively, from these middens.

Only 7 of the 17 middens included plant taxa no longer found in the immediate vicinity (>100 m) of the midden, and only species identified from these middens plus IC 5 are presented here (Table 2). Five middens contained needles of conifers (>1 km) or other plants (>50 m) that no longer occur in the midden area. RC 2 and WHC 1 had abundant needles of ponderosa pine and lodgepole pine, neither of which occurs near these middens today. Both sites have modern vegetation dominated by sagebrush and a few scattered trees of juniper and Douglas-fir. Although isolated stands of ponderosa pine occur within 1 km of RC 2, the nearest lodgepole pines occur approximately 15 km to the north at an elevation of 3,100 m (Fig. 1). DP 1 and LC 1B also contained needles of ponderosa pine, which is represented by isolated trees or small stands in the general region of these sites. The fifth midden, RB 1, had needles of both bristlecone and limber pine and, although limber pine occurs within 100 m of the midden site, no bristlecone are near this area today.

DISCUSSION—Previous investigations on the environmental history of plant communities over the last 10,000 years in the Upper Gunnison Basin have included analyses of strati-

TABLE 1—Conventional and accelerator mass spectrometry (AMS) radiocarbon dates (± *SD*) from packrat middens collected in the Upper Gunnison Basin, Colorado. Numbers refer to site locations in Fig. 1.

Sampling site (Type)	Elevation (m)	Age (years B.P.)	Laboratory number	Material analyzed
1. Lost Canyon Site 1b (LC 1B)	2,491	1580 ± 50	Beta-98905	packrat feces
2. Palisades Site 2 (PAL 2)	2,438	950 ± 60	Beta-98906	packrat feces
3. Red Creek Site 2 (RC 2)*	2,432	3030 ± 70	Beta-98231	packrat feces
		3320 ± 60	CAMS-33963	*Pinus contorta* needle
4. Dillon Pinnacles Site 1 (DP 1)	2,515	1790 ± 50	Beta-98228	packrat feces
5. Cebolla Creek Site 4 (CC 4)	2,760	480 ± 60	Beta-98903	packrat feces
6. Indian Creek Site 4 (IC 4)	2,560	1660 ± 60	Beta-98904	packrat feces
Indian Creek Site 5 (IC 5)	2,560	2660 ± 50	Beta-96228	packrat feces
7. Mill Creek Cave (MCC 2)	3,048	660 ± 60	Beta-87715	packrat feces
8. Singing Antelope Cave (SAC 1)	2,804	300 ± 70	Beta-87716	packrat feces
9. Parlin Flats Sites 4c (PF 4c)	2,636	450 ± 60	Beta-96230	packrat feces
10. East Indian Creek Site 2 (EIC 2)	2,839	170 ± 50	Beta-98229	packrat feces
		560 ± 60	CAMS-33962	*Pinus aristata* needle
11. Rocky Brook Site 1 (RB 1)	3,170	2150 ± 60	Beta-98907	packrat feces
		240 ± 60	CAMS-33964	*P. aristata* needle
12. Ute Gulch Site 1 (UG 1)	3,048	2410 ± 60	Beta-98908	packrat feces
13. Deadman Gulch Site 2 (DG 2)	3,020	1580 ± 50	Beta-98227	packrat feces
14. Cement Creek Cave (CCC 1)	2,975	160 ± 50	Beta-96227	packrat feces
15. West of Haystack Cave (WHC 1)	2,450	3180 ± 40	Beta-124334	*P. contorta* needle
		3450 ± 40	Beta-124335	*P. ponderosa* needle
16. Two Ravens Cave 2 (TRC 2)	2,487	300 ± 60	Beta-87712	packrat feces

graphic sediments (Andrews et al., 1975), fossil pollen (Andrews et al., 1975; Markgraf and Scott, 1981; Fall, 1985, 1997*a*, 1997*b*), and plant macrofossils (Andrews et al., 1975; Carrara et al., 1984). The pollen record at high elevations indicates that the period 11000 to 5000 B.P. was characterized by upward expansion of subalpine forests during a warm, dry period, followed by cooler conditions and retraction of subalpine forests from 4000 to 3000 B.P. (Markgraf and Scott, 1981; Fall, 1985). In addition, piñon trees (*P. edulis*) were notably absent throughout the basin except for a few isolated trees or small stands that have been recolonizing the area in recent years; juniper occurs in numerous areas. Based on archaeological and palynological evidence, piñon trees were present in the basin from about 8000 to 3000 B.P. before becoming extirpated, perhaps due to climatic change (Stiger, 2001). These records support the northern, postglacial expansion of piñon into Colorado from desert lowlands to the south described by Betancourt et al. (1991). Modern communities and environmental conditions seem to have developed by 2000–1500 B.P.

Fall (1997*a*, 1997*b*) recently refined these interpretations. For example, macrofossil concentrations (needles, cones, and seeds per 100 cm^3 of sediment) of *Picea engelmannii* from a dated sequence of pond sediments spanning the Holocene reflect episodes of climate change and subalpine forest movements in the higher elevations of the Upper Gunnison Basin (Fall, 1997*a*). Fall concluded that the period from 9000 to 4000 B.P. had 1.6°C warmer mean annual temperatures, thereby allowing subalpine forests to extend up to 270 m higher than today. Moreover, she hypothesized that from 9000 to 2600 B.P. there was increased effective moisture (8 to 11 cm or 11 to 16% more precipitation per year than at present). Beginning at 4000 B.P., a cooling period lowered upper timberline by 100 to 200 m and caused a gradual decrease in effective moisture (Fall, 1997*a*). After 2000 B.P., modern communities had become established in the Upper Gunnison Basin and have remained essentially unchanged since that time.

Information obtained from ancient packrat middens collected in the Upper Gunnison Basin indicated the expansion of coniferous for-

TABLE 2—Macroplant taxa identified from 8 packrat middens located throughout the Upper Gunnison Basin, Colorado. Midden acronyms refer to those listed in Table 1. An asterisk (*) indicates those taxa that no longer occur within at least 50 m of midden location.

Taxon	RC-2	DP-1	WHC-1	IC-4	IC-5	LC-1B	RB-1	UG-1
Common juniper (*Juniperus communis*)							X	X
Rocky Mountain juniper (*J. scopulorum*)	X	X	X*	X	X	X		
Bristlecone pine (*Pinus aristata*)							X*	
Limber pine (*P. flexilis*)							X*	
Ponderosa pine (*P. ponderosa*)	X*	X*	X*	X	X	X*		
Lodgepole pine (*P. contorta*)	X*		X*					
Pine (*Pinus*)			X*					
Blue spruce (*Picea pungens*)						X*	X	X
Douglas-fir (*Pseudotsuga menzeisii*)	X	X			X	X	X	
Quaking aspen (*Populus tremuloides*)					X			
Cottonwood (*Populus*)	X			X			X	X
Willow (*Salix*)					X			
Gambel's oak (*Quercus gambelii*)	X							
Doorweed (*Polygonum* cf. *aviculare*)			X*					
Doorweed (*Polygonum* cf. *scandens*)						X		
Chenopodiaceae/Amaranthaceae			X	X	X			X
Greasewood (*Atriplex*)							X	X
Nyctaginaceae		X						
Baneberry					X	X	X	
Barberry (*Berberis repens*)					X		X	
Gooseberry (*Ribes* cf. *inerme*)								X
Serviceberry (*Amelanchier* cf. *alnifolia*)		X						
Mountain-mahogany (*Cercocarpus montanus*)			X*					
Cinquefoil (*Potentilla tridentata*)				X				
Bitterbrush (*Purshia tridentata*)	X		X*					
Rose (*Rosa woodsii*)					X		X	X
Skunkbrush (*Rhus trilobata*)	X	X	X	X	X	X		
Cactus (*Opuntia*)		X				X		
Ball cactus (*Coryphantha vivipara*)		X	X*		X			
Cactus (*Opuntia*)			X*					
Dogwood (*Cornus* cf. *stolonifera*)				X*				
Stoneseed (*Lithospermum*)			X*					
Thistle (*Circium*)		X				X		
Big sagebrush (*Artemisia tridentata*)		X	X		X			
Rabbit brush (*Ericameria viscidiflora*)			X*			X		
Asteraceae	X							
Wheatgrass (*Agropyron repens*)					X			
Ricegrass (*Oryzopsis hymenoides*)	X	X	X	X	X			
Mannagrass (*Glyceria striata*)					X			
Bluestem (*Andropogon gerardi*)								X*
Spanish bayonet (*Yucca glauca*)			X			X		
Yucca (*Yucca*)	X	X						

ests at 3450 to 3180 B.P. to lower elevations in the central basin. This interpretation was based on the abundance of needles of ponderosa pine and lodgepole pine in the middens at RC 2 and WHC 1 (Table 2). The latter pine is a fire-adapted species and, while it can grow at elevations up to 3,500 m in the southern Rocky Mountains (Benedict, 1991), the lowest elevation at which it occurs in Colorado is approximately 2,300 m. The abundance of needles suggests that cooler temperatures, moister conditions, or both occurred in the Upper Gunnison Basin at 3450 to 3180 B.P.

Although Fall (1997*a*) found evidence for a cooler period in the Upper Gunnison Basin beginning at 4000 B.P. that caused a downward shift in subalpine forests, we suggest that this cooling period extended until at least 3180 B.P. and that lodgepole pine forests shifted downward by as much as 600 to 700 m, where it intermixed with ponderosa pine. These results agree with a more regional paleoclimatic pattern for southwestern Colorado based on pollen records from the La Plata Mountains (Petersen and Mehringer, 1976; Petersen, 1988). These studies identified a cooling period and lowering of timberline from 4000 to 2500 B.P. In addition, although Fall (1997*a*) found evidence for an increase in effective moisture in the basin from 9000 to 2000 B.P., we suggest that drier conditions began slightly earlier (or by 3320 B.P.), increasing fire intensities and facilitating expansion of lodgepole pine forests.

The period from approximately 3000 to 1500 B.P. seems to have been relatively stable climatically with conditions similar to those at present. Plant remains from middens dating to this period show few differences from the communities at those localities today (IC 4 and 5, UG 1, LC 1B; Table 2). After this period of climatic stability, bristlecone pine and limber pine forests moved into lower elevations at approximately 240 and 560 B.P. (RB 1 and EIC 2) in the northern and eastern edges of the Upper Gunnison Basin, respectively (Tables 1 and 2). These species prefer cool, dry environments, and their expansion into these areas correlates with global cooling events in the late 1300s and between 1500–1850 CE (the Little Ice Age; Grove, 1988). RB 1 had the greatest discrepancy in conventional versus AMS radiocarbon dates (1,910 y; Table 1), suggesting that the subfossil pellets might be mixed from different ages. The date of a single needle of *Pinus aristata* from this midden was considered more reliable. Additional radiocarbon dates are needed on this site to evaluate this discrepancy.

Our study demonstrates that Holocene packrat middens can provide useful paleoenvironmental information in montane environments. The absence of middens older than approximately 3400 B.P., despite extensive surveys throughout the Upper Gunnison Basin, might be due to preservational factors in this montane region. A survey of 1,113 radiocarbon dates on all middens collected in the western United States indicated that no middens older than 10000 B.P. had been dated above 2,500 m elevation, and that 90% were from samples found between 300 and 2,200 m (Webb and Betancourt, 1990); the lowest elevation in the Upper Gunnison Basin is approximately 2,200 m. Here, high-elevation middens have provided new information on the distribution of coniferous forests in relation to climate change over the past 3,400 years.

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