AN INVENTORY OF PACKRAT (*NEOTOMA* SPP.) MIDDENS IN NATIONAL PARK SERVICE AREAS

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Abstract—Packrat middens are important tools for reconstructing the paleoecology and climate of the late Pleistocene and Holocene of western North America. These collections of plant material, food waste, coprolites, bones, and other biological materials can be well-preserved in arid, protected settings such as caves and rock shelters, and document the environment within the builder's foraging range. Middens have been most widely utilized to illustrate climate through the environmental requirements of the plants preserved as inclusions, but have been used for a variety of other studies as well. These include the use of included pollen, arthropods, and vertebrate remains as climate proxies, the evolution and distribution of plant taxa, erosion rates, responses to grazing, megafaunal extinction and archaeology. Middens from many National Park System units have been important components of numerous midden studies. Thirty-three National Park System parks, monuments, and other areas in 11 states are currently known to contain packrat middens, with all but five known to have fossil middens. Among them are some of the best-known midden series in the nation, including those of Big Bend National Park, Chaco Culture National Historical Park, Death Valley National Park, Grand Canyon National Park and Organ Pipe Cactus National Monument. National Park System middens are important not only at the broad level of climate change research, but also at the park or monument level as tools for resource management, and have untapped potential as educational resources because of their "time capsule" properties.

BACKGROUND

Packrats (*Neotoma* spp.), also known as woodrats or trade rats, belong to the New World rat family Cricetidae. They are noted for their collecting and gathering behavior, primarily for food and den construction. Packrats are long-tailed rodents that weigh between 100 and 400 g (0.2 to 0.9 lb) as adults. The eyes and ears are large, and the limbs are adapted for grasping and climbing. They are found throughout much of North America and into Central America, from just south of the Arctic Circle to Nicaragua, and they inhabit a wide range of environments, from boreal woodlands to deserts (Vaughan, 1990). Numerous species have been assigned to the genus; Vaughan (1990) listed 21 extant species. Species of interest for the American Southwest, where most fossil middens have been found, include *N. albigula* (white-throated packrat), *N. cinerea* (bushy-tailed packrat), *N. devia* (western Arizona packrat), *N. lepida* (desert packrat), *N. mexicana* (Mexican packrat) and *N. stephensi* (Stephen's packrat). *Neotoma* appears in the fossil record during the middle Hemphillian, and all regional species were probably present by fifty thousand years ago, the age of the oldest fossil middens (Vaughan, 1990).

Packrats shelter in caves, crevices and dense vegetation. Most species collect nearby materials to build dens in these shelters. Den materials can include sticks and other plant fragments, dung and bones. Den size, structure and preferred materials vary by species and availability. Plants and other items incorporated into the middens are gathered within a radius of approximately 30 to 50 m (100 to 160 ft) from a den (Vaughan, 1990). A nest is associated with the den, but is not necessarily within it. The den serves many functions, including a protected haven from predators, food storage, and a means of temperature control, which permits the rodent to remain active throughout the year. Usually, a den will be occupied by a single packrat. A variety of other small vertebrates, such as other rodents, lizards and snakes, may also occupy dens (Vaughan, 1990). Packrats will take over abandoned dens, including those of different *Neotoma* species, and resulting changes in collected vegetation can potentially be mistaken for climate change (Dial and Czaplewski, 1990).

A midden is only one component of an active den. It is the primary area where the rodent excretes and a place where unused plant fragments accumulate (Dial and Czaplewski, 1990). Fossil middens are thought to typically represent waste materials that accumulated near passage entrances used by the packrat during house cleaning, but can encompass much larger areas of the den. Individual middens are thought to have been active over short periods of time, up to a few years. Reuse of a shelter can result in extensive sequences of accumulated plant and animal debris that may span thousands of years. Fossil middens frequently have mm-scale stratigraphic layers, which has led to the proposal that dens created at different times in the same location can "melt" over time into a single compound fossil midden (Spaulding et al., 1990).

Fossil middens are described as "resembling blocks of asphalt with the consistency and mass of an unfired adobe brick" (Spaulding et al., 1990) (Fig. 1). They can be distinguished from other accumulations, such as ringtail cat or porcupine middens, by several characteristics. These include the presence of non-woody fecal pellets of the appropriate size to have been produced by packrats; dark heavy urine stains or deposits; an abundance of sticks and other plant materials, bones and plant cuttings; and gnaw marks on plants and bones consistent with the dimensions of rat incisors (Finley, 1990). The composition of a fossil midden and how closely it reflects the vegetation present at the time it was formed depend on several factors: the dietary preferences of the packrat; the relationship of distance to a particular plant versus the preference of the packrat; compositional variation within a den; duration of deposition; and postdepositional history. Additionally, how an investigator translates the raw material of a midden into data is important (Spaulding et al., 1990).

Fossil middens are usually indurated by crystallized packrat urine, known as amberat (Spaulding et al., 1990). Induration by amberat improves midden survival, although there are examples of ancient unindurated middens (Spaulding et al., 1990). Induration can be rapid, occurring over months to years. An outer rind often forms on amberat-indurated middens and encases their contents. The rind has self-sealing properties: under humid conditions amberat rehydrates, becoming sticky

FIGURE 1. A fossil packrat midden in Capitol Reef National Park. Photo courtesy Kenneth Cole, Northern Arizona University.

and trapping additional dust and debris, which in turn block atmospheric moisture from reaching further into the amberat. Amberat has several other useful properties. Plant material saturated by amberat is protected from decay because the amberat essentially mummifies the material, like packing it in salt. Amberat also appears to prevent insect feeding and lichen growth. Additionally, its adhesive properties fix middens to rock walls. Thus, it is not uncommon to find "hanging" middens, the result of underlying rock shelves failing and leaving the middens behind. Hanging middens provide a method of measuring cliff retreat and exfoliation (Spaulding et al., 1990).

The formal study of fossil packrat middens began in the 1960s (Wells and Jorgensen, 1964). Since that time, middens have become one of the primary paleoecological proxies for the late Pleistocene and Holocene in much of the American West, recognized as excellent sources of plant macrofossils, pollen, arthropod and vertebrate body fossils, and rodent coprolites. Geographic coverage has focused on several areas: the Chihuahuan Desert of southeastern New Mexico and western Texas; the Colorado Plateau of northern Arizona, southwestern Colorado, northwestern New Mexico, and southern Utah; the Great Basin of Nevada and western Utah; the Mojave Desert of eastern California and southern Nevada; and the Sonoran Desert of southern Arizona. Middens are of particular interest in these desert regions because of the rarity of other paleoecologically-useful fossils, such as pollen from pluvial or other lake deposits. Fossil middens are typically used to reconstruct ancient floral assemblages, which are then used as proxies for the climate. For example, a midden may have fossils of conifer species, which are today only found at much higher elevations, or assemblages of plants that are adapted to greater humidity than currently present.

Although the packrat midden literature is dominated by paleoecological studies, many other avenues of research have been undertaken by workers. Studies following the distribution of a particular plant taxon through time are common (Lanner, 1974; Wells and Hunziker, 1976; Spaulding and Van Devender, 1977, 1980; Van Devender and Hawksworth, 1986; Van Devender et al., 1990; Lanner and Van Devender, 1998; Hunter et al., 2001). Various categories of fossils outside of plant macrofossils have also been studied, including pollen (Thompson, 1985; Davis and Anderson, 1987), arthropods (Hall et al., 1989, 1990; Elias and Van Devender, 1990, 1992; Elias et al., 1992), small vertebrates (Mead et al., 1983, 2003; Van Devender and Bradley, 1990; Van Devender et al., 1991), and rodent coprolites, which have been used to study rodent size and response to climate (Smith and Betancourt, 1998). At least one taxon has been named from midden fossils (the rabbitbrush *Chrysothamnus pulchelloides*, from a midden at Chaco Culture National Historical Park; Anderson, 1980). Middens have been used to study the rate of erosion in the Grand Canyon (Cole and Mayer, 1982), the extinction of ground sloths (Phillips, 1984), the disappearance of people from Chaco Canyon (Betancourt and Van Devender, 1981; Betancourt, 1990) and to provide points of comparison for resource management at Capitol Reef National Park (Cole and Henderson, 1993; Cole et al., 1997; Cole and Murray, 1999) and Glen Canyon National Recreation Area (Fisher et al., 2006, 2009). Middens have also been incorporated into cultural resource studies (Emslie et al., 1995). All of the above examples are taken from middens preserved within National Park System units.

FOSSIL PACKRAT MIDDENS IN NATIONAL PARK SERVICE AREAS

Packrat middens have been documented within 33 parks, monuments and other areas managed by the National Park Service, in 11 states (Fig. 2). Units with fossil middens are for the most part within the five broad geographic areas mentioned above, but there are some outliers, such as Bighorn Canyon National Recreation Area on the Montana–Wyoming border and Jewel Cave National Monument in the Black Hills of South Dakota. For most of these units, at least one midden (often more) has been described in the literature. The U.S. Geological Survey and National Oceanic and Atmospheric Administration jointly maintain an online packrat midden database (http://esp.cr.usgs.gov/data/midden/) that includes many of the middens studied in NPS units. For these and other published packrat middens, this database provides extensive documentation, including coordinates, elevation, radiocarbon ages, key publications and lists of plants found in a given midden. This information will eventually be added to the *Neotoma* Paleoecology Database (http://www.neotomadb.org/index.php/) as well, which will permit investigation in concert with other Quaternary paleoecological proxies. Five of the 33 National Park System units described here are only known to have modern middens, or their midden records are presently undated: Craters of the Moon National Monument and Preserve; El Malpais National Monument; Gila Cliff Dwellings National Monument; Mesa Verde National Park; and Pipe Spring National Monument. It is possible that fossil middens will be found in at least some of these five units, and it is likely that fossil middens are present in other units as well. For example, fossil middens have been published from lower Kings Canyon just west of Sequoia and Kings Canyon National Parks (Cole, 1983), which suggests that this park is a promising location to survey for middens. Similarly, unstudied middens are known from areas along or near the eastern and southern boundaries of Zion National Park (D.B. Madsen, S.A. Elias, C. Weng, S.T. Jackson, R.S. Thompson and D. Rhode, unpubl. report for the National Park Service, 2002).

National Park System units have been preferred areas for midden research for several reasons, including their biodiversity, protected status, accessibility and the presence of an infrastructure for dissemination of results to the scientific and broader public (Holmgren et al., 2007). However, most investigations have been performed by individual researchers, with the result that although there is breadth of coverage, coordination has been lacking. Midden fossils are also dispersed through several institutions, generally at the home institution of a given investigator. Thus, there is a great deal of room for integration and coordination of research.

Ages and Dating

Radiocarbon ages in this document are present as radiocarbon years before present (14C yr BP). In instances where the radiocarbon age is less than 46,400 14C yr BP and a standard deviation was provided, the age was also converted to calendar years before present (denoted cal yr BP) using the online calibration Calib 6.0 (http://calib.qub.ac.uk/calib/). The late Pleistocene and Holocene have been subdivided differently by various researchers. The latest part of the Pleistocene is assigned to the Wisconsinan (or simply Wisconsin), after the Wisconsin glaciation. We use the following subdivisions following Spaulding et al. (1990). The middle Wisconsinan dates from about 65,000 to 22,600 14C yr BP, and the late Wisconsinan dates from about 22,600 to 10,000 14C yr BP, with the Last Glacial Maximum occurring at 18,000 14C yr BP, and the warming phase at the end of the Wisconsinan (latest Wisconsinan) dating from about 12,000 to 10,000 14C yr BP. The Holocene is subdivided into early (10,000 to 8,000 14C yr BP), middle (8,000 to 4,000 14C yr BP), and late (4,000 14C yr BP to the present).

Arches National Park (ARCH)

A number of middens are known from Bison Alcove at ARCH, at an elevation of 1,317 m (4,321 ft). Midden samples range in age from at least 20,050 ± 160 14C yr BP (23,490 to 24,390 cal yr BP) to modern (Smith and Betancourt, 1998). Bison remains in the alcove may derive from packrats taking small bones from the carcass of an animal killed or scavenged nearby by humans (Mead et al., 1991).

Sharpe (1993) analyzed 11 midden samples from the alcove. Seven of the samples were from full glacial or late glacial periods, 22,000 to 14,000 14C yr BP and 14,000 to 11,000 14C yr BP, respectively, with the rest from the last 2,700 14C yr BP. The gap is consistent with a decline in midden abundance seen elsewhere in the Southwest between 8,000 and 4,000 14C yr BP. Midden plant fossils suggest that more mesophytic vegetation dominated the Bison Alcove area between 20,000 and 12,500 14C yr BP. *Pinus flexilis* (limber pine) and *Pseudotsuga menziesii* (Douglas fir) were abundant, probably widely dispersed among a scrubby understory. These two taxa are no longer present at ARCH, being restricted to higher elevations (at least 208 m [682 ft) for Douglas fir and 513 m [1,683 ft] for limber pine). Similar late Pleistocene taxa have also been found at Cowboy Cave near Canyonlands National Park (CANY) and Bechan Cave in Glen Canyon National Recreation Area (GLCA). Modern vegetation was present near Bison Alcove before 2,660 14C yr BP, with conditions possibly slightly moister than present (Sharpe, 1993). Smith and Betancourt (1998) used packrat dung from 13 Bison Alcove middens, among other sites, to estimate the size of the packrats that produced them as a proxy for how the animals responded to climate

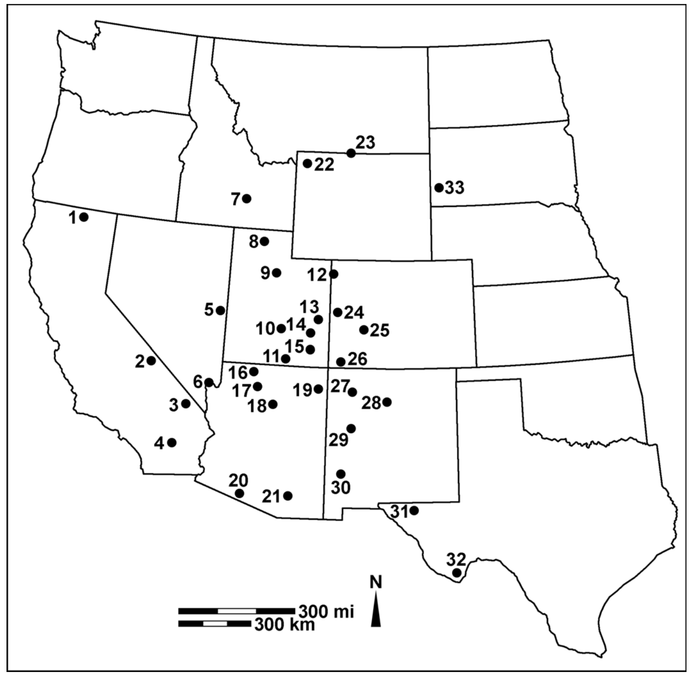

FIGURE 2. Map of National Park Service areas that have documented packrat middens. **1**, Lava Beds National Monument, California; **2**, Death Valley National Monument, California; **3**, Mohave National Preserve, California; **4**, Joshua Tree National Park, California; **5**, Great Basin National Park, Nevada; **6**, Lake Mead National Recreation Area, Arizona and Nevada; **7**, Craters of the Moon National Monument and Preserve, Idaho; **8**, Golden Spike National Historic Site, Utah; **9**, Timpanogos Cave National Monument, Utah; **10**, Capitol Reef National Park, Utah; **11**, Glen Canyon National Recreation Area, Arizona and Utah; **12**, Dinosaur National Monument, Colorado and Utah; **13**, Arches National Park, Utah; **14**, Canyonlands National Park, Utah; **15**, Natural Bridges National Monument, Utah; **16**, Pipe Spring National Monument, Arizona; **17**, Grand Canyon National Park, Arizona; **18**, Wupatki National Monument, Arizona; **19**, Canyon de Chelly National Monument, Arizona; **20**, Organ Pipe Cactus National Monument, Arizona; **21**, Saguaro National Park, Arizona; **22**, Yellowstone National Park, Wyoming; **23**, Bighorn Canyon National Recreation Area, Montana and Wyoming; **24**, Colorado National Monument, Colorado; **25**, Curecanti National Recreation Area, Colorado (equivocal; see text); **26**, Mesa Verde National Park, Colorado; **27**, Chaco Culture National Historical Park, New Mexico; **28**, Bandelier National Monument, New Mexico; **29**, El Malpais National Monument, New Mexico; **30**, Gila Cliff Dwellings National Monument, New Mexico; **31**, Guadalupe Mountains National Park, Texas; **32**, Big Bend National Park, Texas; **33**, Jewel Cave National Monument, South Dakota.

change. They found that the packrats were larger during the late Pleistocene and declined to modern sizes rapidly, by the early Holocene, concurrent with a warmer climate. The packrats' size changes were also more rapid than floral changes (Smith and Betancourt, 1998).

Bandelier National Monument (BAND)

Spaulding (unpubl. report for Los Alamos National Laboratory, 1992) reported on a packrat midden within BAND from Frijoles Canyon at an elevation of 1,933 m (6,342 ft), near where the Rito de los Frijoles enters the Rio Grande River. This midden dates to 3,195 ± 85 14C yr BP (3,680 to 3,290 cal yr BP).

Big Bend National Park (BIBE)

Big Bend National Park is one of the best-known sources of middens in the National Park System, with 40 published examples (Van Devender, 1990a) from several localities. A number of others have been described from just outside of the park, including from Maravillas Canyon and Terlingua. Rio Grande Village and Maravillas Canyon are among the best locations for studying vegetation change at the Pleistocene–Holocene boundary and early Holocene–middle Holocene transition (Van Devender et al., 1987).

Most described middens from the park come from a group of localities in the Rio Grande Village area of eastern BIBE (Van Devender, 1986a, b, 1990a), including Baby Vulture Den, Ernst Tinaja and Tunnel View (Elias and Van Devender, 1990). Elevations of these sites range from 600 to 835 m (1,970 to 2,740 ft). The middens span several tens of thousands of years. The oldest predate 40,000 14C yr BP, with one as old as 45,600 14C yr BP. More than a dozen were formed between approximately 26,500 and 14,100 14C yr BP, during the middle and late Wisconsinan. Another group covers the Pleistocene–Holocene transition, between approximately 11,800 and 7,900 14C yr BP. Finally, several date from the past few thousand years to about 600 years ago (Van Devender, 1990a). The middle Wisconsinan middens were possibly constructed in a juniper desert grassland setting. *Pinus remota* (papershell or Texas pinyon) appeared at the end of this period, and *Quercus hinckleyi* (Hinckley oak) joined the assemblage to form pinyon-juniper-oak woodlands during the late Wisconsinan (Van Devender, 1987a, 1990a). The plants in the woodland assemblage have moved to higher elevations or locations outside of BIBE since the late Wisconsinan. Among them, pinyon disappeared from the Rio Grande Village area between 11,500 and 10,500 14C yr BP, juniper disappeared between 9,870 and 8,980 14C yr BP while oak declined, and some associated desertscrub and grassland taxa are now typically found hundreds of meters higher in elevation (Van Devender, 1990a). The woodland taxa were completely gone by about 8,600 14C yr BP, and essentially modern desertscrub took over (Van Devender, 1977, 1990a), with the modern flora in place after 4,330 ± 110 14C yr BP (5,300 to 4,780 cal yr BP) (Van Devender et al., 1987).

Another group of middens has been described from Burro Mesa and Dagger Mountain (Wells, 1966, 1977; Van Devender, 1990a). Two middens were recovered from Burro Mesa from elevations of 1,200 to 1,210 m (3,940 to 3,970 ft), and date to >36,600 14C yr BP and 18,750 ± 360 14C yr BP (23,340 to 21,490 cal yr BP). Three middens were recovered from Dagger Mountain, from 850 to 880 m (2,790 to 2,890 ft). They date to >40,000 14C yr BP, 20,000 ± 390 14C yr BP (24,890 to 22,920 cal yr BP) and 16,250 ± 240 14C yr BP (19,950 to 18,850 cal yr BP) (Wells, 1966, 1977). Like the Rio Grande Village middens, the Burro Mesa and Dagger Mountain examples preserve vegetation no longer growing in the area (Wells, 1966, 1977; Van Devender and Spaulding, 1979; Van Devender, 1990a). These middens were dominated by papershell pinyon, juniper, and oak (Van Devender, 1990a). The records of these middens and those from Rio Grande Village show that the late Wisconsinan climate of the BIBE area was more equable, with mild and wetter winters, and cool summers. By 8,900 14C yr BP, the late Wisconsinan climate had been replaced by a climate similar to the modern (Van Devender et al., 1987).

Published BIBE midden fossils are not limited to plants. Arthropods have been described from a number of middens in the Rio Grande Village area (Elias and Van Devender, 1990, 1992). Like the plants, the arthropod assemblage has changed substantially over the past 45,000 years. A fauna of temperate-adapted arthropods was present in the BIBE area before 12,000 14C yr BP, when all but one of the temperate arthropod species disappeared. Xeric-adapted arthropods are not known until about 7,500 14C yr BP, but this could be an artifact of the fossil record (Elias and Van Devender, 1990, 1992). Vertebrates are known as well. For example, a Burro Mesa midden is associated with a shell of the tortoise *Gopherus* (Berger and Libby, 1966), and Van Devender and Bradley (1990) described mammal fossils from several Rio Grande Village middens, including bones of kangaroo rats, cotton rats, packrats, deer mice and rabbits.

Bighorn Canyon National Recreation Area (BICA)

Numerous middens have been described from BICA by Lyford and colleagues (Lyford, 2001; Lyford et al., 2002, 2003). These middens were found in an area extending from the east slope of East Pryor Mountain to southern Bighorn Canyon, in the Montana portion of BICA, at elevations of 1,275 to 1,590 m (4,180 to 5,215 ft) (Lyford et al., 2002). Lyford et al. (2002) reported on 53 middens from East Pryor Mountain. They obtained 40 dates from 34 middens; most dated from 6,800 cal yr BP to a few hundred years ago, with five dates from three middens between 12,300 and 10,400 cal yr BP, near the Pleistocene–Holocene boundary. Lyford et al. (2003) focused on Utah juniper distribution during the Holocene, using middens in Wyoming and adjacent areas of Montana and Utah. They sampled 37 middens from East Pryor Mountain, with ages ranging from 30,110 to 510 cal yr BP. BICA midden fossils show that *Juniperus communis* (common juniper), a cold/moist-adapted species, was present initially but disappeared by the middle Holocene, and the dominant juniper changed from *J. scopulorum* (Rocky Mountain juniper) to *J. osteosperma* (Utah juniper) by 4,630 ± 160 14C yr BP (5,660 to 4,860 cal yr BP) as part of a shift to more arid conditions (Lyford et al., 2002). Utah juniper reached East Pryor Mountain between 5,900 and 5,400 cal yr BP during this relatively dry period (Lyford et al., 2003). This was followed by a brief moister phase between 4,400 and 2,700 14C yr BP, as recorded by the appearance of limber pine (Lyford et al., 2002).

Canyon de Chelly National Monument (CACH)

Three middens have been published from CACH. Two are from Canyon del Muerto, and a multi-layer midden is known from Wide Rock Butte. They are of particular interest as points of comparison to the Dead Man Lake pollen record in the nearby Chuska Mountains (Betancourt, 1990). The Canyon del Muerto middens were found near the mouth of the canyon at an elevation of 1,700 m (5,580 ft). The older midden (CDM-1 or MUERTO1) dates to 11,900 ± 300 14C yr BP (14,870 to 13,180 cal yr BP), and the younger (CDM-2 or MUERTO2) is dated to 3,120 ± 110 14C yr BP (3,580 to 3,000 cal yr BP). Both plant macrofossils and pollen have been studied from these middens. The two have quite different assemblages; CDM-1 is dominated by Douglas fir needles, with over 2,300 needles recovered (Betancourt and Davis, 1984), while CDM-2 is instead dominated by parts of herbs and shrubs (Betancourt, 1990). The pollen record of CDM-1 is dominated by *Artemisia* (sagebrush) and pine but lacks oak, while CDM-2 pollen includes more oak than *Artemisia*. It also includes some evidence of human presence, such as pollen of the crop plant *Zea mays* (corn) (Betancourt and Davis, 1984; Betancourt, 1990). Today, the CDM-1 plant assemblage is found in riparian settings at elevations of 2,250 m (7,380 ft) and above in the Chuska Mountains (Betancourt, 1990). The large Wide Rock Butte midden was recovered from an elevation of 2,100 m (6,890 ft) and has four levels. Levels 4 and 2 have been dated, yielding ages of 6,210 ± 90 14C yr BP (7,320 to 6,880 cal BP) and 1,930 ± 80 14C yr BP (2,060 to

1,700 cal yr BP), respectively (Schmutz et al., 1976; Mead et al., 1978). Associated surface scatter is part of modern packrat activity (Schmutz et al., 1976).

Canyonlands National Park (CANY)

Middens have been described from several localities within CANY (Elias et al., 1992; Anderson et al., 2000; Coats et al., 2008). The Cowboy Cave area just west of CANY is also a prolific source of middens (McVickar, 1991). Elias et al. (1992) described arthropods from three middens found at elevations of 1,505 to 1,755 m (4,940 to 5,760 ft) in Salt Creek Canyon. Multiple taxa of beetles as well as an ant and a lepidopteran were found in them. The three middens cover a wide time span, with dates of 27,660 ± 340 14C yr BP (32,790 to 31,270 cal yr BP), 6,980 ± 120 14C yr BP (8,010 to 7,610 cal yr BP), and 3,830 ± 70 14C yr BP (4,420 to 4,080 cal yr BP) (Elias et al., 1992).

Anderson et al. (2000) briefly reported on middens from three CANY localities: Island-in-the-Sky (1,340 to 1,400 m [4,390 to 4,590 ft]), with middens dating to between 35,400 and 400 cal yr BP; Salt Creek Canyon (1,490 to 1,830 m [4,890 to 6,000 ft]), with middens from between 39,900 cal yr BP and the present; and The Maze, with middens from between 800 cal yr BP and the present. Coats et al. (2008) reported on 27 middens from Salt Creek Canyon, with ages from over 38,000 14C yr BP to essentially the present. They also added White Rim as a locality, with 12 middens dated between >48,000 and 380 14C yr BP from elevations of 1,340 to 1,400 m (4,390 to 4,590 ft). The Salt Creek Canyon record shows increased quantities of fossils from mesophytic taxa such as Rocky Mountain juniper, Douglas fir, and limber pine during the late middle Wisconsinan to the end of the Wisconsinan, approximately 35,000 to 10,000 14C yr BP, with the Holocene floral assemblage composed of xerophytic taxa and immigrants, which appear in increasing abundances over the Holocene (Coats et al., 2008). Essentially modern vegetation was established at Salt Creek Canyon by about 9,500 cal yr BP (Anderson et al. 2000).

Capitol Reef National Park (CARE)

Twenty-two packrat middens have been described from CARE, mostly from locations on Hall's Canyon in southern CARE and Hartnet Draw in northern CARE (K.L. Cole, unpubl. report for CARE, 1992; Cole et al., 1997; Cole and Murray, 1999). The majority of these postdate 1400 AD, but ten are older. The oldest two date to >39,600 14C yr BP and 28,050 ± 2,600 14C yr BP (38,560 to 27,570 cal yr BP), three are dated to between 7,010 and 3,615 14C yr BP, and five others were constructed between 3,000 and 600 years ago. Additionally, numerous fossil middens are present along the Fremont River between park headquarters and Deep Creek, but they are difficult to access, and only one has been dated (Cole and Murray, 1999). Comparing midden plant assemblages predating grazing activities to assemblages from more recent middens has been a common topic of study (Cole and Henderson, 1993; Cole et al., 1997; Cole and Murray, 1999). The park's midden record indicates that vegetation change over the past 150 years has been more extensive than any period during the previous 5,000 years, probably due to sheep grazing, which began during the 19th century. Many plants that are eaten by large herbivores have declined in abundance, while plants typical of overgrazed lands have increased in abundance. Pinyon appears to be in recovery now that sheep have been removed (Cole and Murray, 1999). Other fossils in the middens include pollen, invertebrate fossils, bones and packrat droppings (Cole et al., 1997; Cole and Murray, 1999).

Chaco Culture National Historical Park (CHCU)

CHCU is a prolific source of middens; the USGS/NOAA database has records for 55 published middens from nine sites, and Betancourt (1990) mentioned the presence of more than 300 in Chaco Canyon containing needles of the now much less abundant *Pinus edulis* (Colorado pinyon). The primary references are Betancourt and Van Devender (unpubl. report for the Southwest Cultural Resources Center, National Park Service, 1980, 1981), Betancourt et al. (1983), Hall (1988), Betancourt (1990), and Long et al. (1990). Midden sites have been found at elevations of 1,860 to 2,020 m (6,100 to 6,630 ft) between Chacra Mesa and the mouth of the canyon (Betancourt, 1990). The great majority of the dated middens are younger than 5,550 14C yr BP (Betancourt and Van Devender, 1981). Five are older (USGS/NOAA, no date), with the oldest being two middens dated to 10,600 ± 200 14C yr BP (12,930 to 11,820 cal yr BP) and 10,500 ± 250 14C yr BP (12,880 to 11,590 cal yr BP) (Betancourt and Van Devender, 1981).

The local climate had already shifted from glacial to postglacial by the time the oldest known middens of the park were active (Hall, 1988). The oldest middens indicate open woodlands composed primarily of limber pine and Rocky Mountain juniper, with Douglas fir and spruce present but apparently restricted in distribution (Betancourt, 1990); Hall (1988) proposed a desert shrub grassland interpretation based on pollen, with the conifers as possible relicts. By 8,300 14C yr BP, limber pine and spruce had disappeared, and *Pinus ponderosa* (Ponderosa pine), Colorado pinyon, and *Juniperus monosperma* (one-seed juniper) had appeared. Rocky Mountain juniper disappeared by 7,900 14C yr BP, and Ponderosa pine and Douglas fir by 2,200 14C yr BP, leaving Colorado pinyon and one-seed juniper as the main conifers. These two taxa suffered dramatic reductions between 1,200 and 500 14C yr BP (Betancourt, 1990). It has been proposed that they were harvested for fuel during the Ancestral Puebloan presence at Chaco Canyon, leading to their decline (Betancourt and Van Devender, 1981; Betancourt, 1990). Pollen from middens and other sources at CHCU indicates that the climate became warmer and drier before 5,800 14C yr BP, and then more like the present around 1,000 years ago (Hall, 1988).

An extinct species of rabbitbrush has been named from a CHCU midden: *Chrysothamnus pulchelloides* (Anderson, 1980). The type material came from a Mockingbird Canyon midden dated to 1,910 ± 90 14C yr BP (2,060 to 1,690 cal yr BP). As of its description, this species records the only known Holocene plant extinction in the Southwest. Its extinction may be related to human activities (Anderson, 1980).

Colorado National Monument (COLM)

COLM has packrat middens, but they are largely unpublished. Middens were first reported from the Rimrock Drive area during 1994 (K. Trujillo, M. Imhof and Z. Walke, unpubl. report for COLM, 2004). Anderson et al. (2000) mentioned the presence of an unspecified number of middens. They were found at elevations ranging from 1,890 to 2,140 m (6,200 to 7,020 ft), and range in age from 8,500 cal yr BP to modern (Anderson et al., 2000). Scott et al. (1999) noted the presence of numerous packrat middens under overhangs at COLM, and a 2004 paleontological survey of the monument observed middens in Monument Canyon, the Squaw Fingers and Ute Canyon. The 2004 examples may be significantly older than the Holocene middens (K. Trujillo, M. Imhof and Z. Walke, unpubl. report for COLM, 2004).

Craters of the Moon National Monument and Preserve (CRMO)

Packrat middens have been found within lava tubes at CRMO. They have yielded fossils, including the bones of microtine rodents (Santucci et al., 2001).

Curecanti National Recreation Area (CURE)

The presence or absence of packrat middens within CURE is equivocal. Anderson et al. (2000) noted the presence of at least one midden in the Black Canyon of the Gunnison, dating to between 6,000 and 5,500 cal yr BP. The USGS/NOAA database has a record for one midden from the Black Canyon of the Gunnison sourced to Anderson et al. (2000), with coordinates that place it within CURE. It is not clear how precise these coordinates are or what their source is, because no coordinates are included in Anderson et al. (2000). Because of this uncertainty, it is possible that this midden derives instead from a non-National Park System area along the canyon. Emslie et al. (2005) published a study of 17 middens from the upper Gunnison Basin, including four examples apparently either within or immediately adjacent to CURE. These middens are all fairly young, postdating 3,500 14C yr BP, and are of interest because of their high elevations. Approximate coordinates for the four examples (S. Emslie, personal commun., 2011) place two of them just inside CURE boundaries and two just outside.

Death Valley National Park (DEVA)

Death Valley National Park has a number of documented middens, with 26 described in the literature: 14 from Greenwater Valley, nine from the Panamint Range and one each from the floor of the valley, Pyramid Peak in the Funeral Range and Titus Canyon. These middens span elevations from below sea level to 1,280 m (4,200 ft), and range in age from 41,300 14C yr BP to the present. Numerous middens are known from the immediate vicinity of DEVA as well (W.G. Spaulding, unpubl. report for the California Bureau of Land Management, 1980; Spaulding, 1990; Thompson, 1990; Koehler et al., 2005), which provide complimentary data to the DEVA middens.

Cole and Webb (1985) described the Greenwater Valley middens. These specimens were collected from a hill near the abandoned Greenwater settlement. Elevations range from 1,340 to 1,410 m (4,400 to 4,630 ft). Except for a single Pleistocene example dated to 41,300 ± 1,500 14C yr BP (47,650 to 42,500 cal yr BP), they date to between 2,235 ± 35 14C yr BP (2,280 to 2,150 cal yr BP) and the present. Cole and Webb found that *Coleogyne ramosissima* (blackbrush) spread to lower elevations in the last few hundred years, which could indicate increasing winter precipitation. The downward shift in elevation of blackbrush is consistent with other records of cooler and wetter climates beginning a few hundred years ago (Cole and Webb, 1985). The Panamint Range middens were described by Wells and Woodcock (1985). Most were from elevations of 775 m (2,540 ft) or 425 m (1,390 ft). Dates range from 19,550 ± 650 14C yr BP (24,920 to 21,740 cal yr BP) to 900 ± 130 14C yr BP (1,070 to 640 cal yr BP), with the majority dating to the latest Pleistocene and the Pleistocene–Holocene boundary.

Of the other middens, the Pyramid Peak midden was the first published example from DEVA. It was found at 1,280 m (4,200 ft) and dates to 11,600 ± 160 14C yr BP (13,790 to 13,160 cal yr BP) (Berger et al., 1965; Wells and Berger, 1969). It included abundant fossils of Utah juniper; the plant fossils in this midden indicate upward displacement in elevation of 610 m (2,000 ft) and lateral displacement of 80 km (50 miles) since the midden was active (Berger et al., 1965). The valley floor midden, from near Bennett's Well, has the lowest elevation of any midden recorded in the USGS/NOAA database: -73 m (-240 ft). It dates to 990 ± 110 14C yr BP (1,100 to 690 cal yr BP) and contains fossils of plants present in the vicinity today (Buckley and Willis, 1969; Wells and Hunziker, 1976). The Titus Canyon midden was found at an elevation of 1,130 m (3,710 ft) and dates to 9,680 ± 300 14C yr BP (12,030 to 10,240 cal yr BP). It represents a juniper-Joshua tree community (Van Devender, 1977).

The midden record of DEVA indicates that during the Pleistocene, the region was less arid and more equable. Woodland zones were lower in elevation by 1,200 to 1,500 m (3,940 to 4,920 ft), perhaps as low as 450 m (1,480 ft), there was three to four times the modern precipitation, and summers were between 8 and 14 °C (14 to 25 °F) cooler. Woodlands were dominated by Utah juniper. Instead of the creosote (*Larrea tridentata*)-white bursage (*Ambrosia dumosa*) scrub found today in the Mojave Desert below woodlands, there was semidesert vegetation of *Yucca whipplei* (chaparral yucca), *Y. brevifolia* (Joshua tree), *Atriplex confertifolia* (shadscale) and *Opuntia basilaris* (beavertail cactus). Climate shifted to a state similar to the present in lower elevations between 11,000 and 10,200 14C yr BP. Concurrently, the woodland and semidesert ecozones moved higher in elevation, with semidesert species persisting until at least 9,000 14C yr BP (Wells and Woodcock, 1985; Woodcock, 1986). At 775 m, the change from woodland to hyperarid desert occurred between 13,000 and 9,000 14C yr BP, with at least three transitional stages involving semidesert components (Wells and Woodcock, 1985).

Dinosaur National Monument (DINO)

Five middens have been described from Sand Canyon Alcove in the Colorado section of DINO (Sharpe, 1991, 2000, 2002; Anderson et al., 2000). Numerous middens were found in this alcove at an approximate elevation of 1,920 m (6,300 ft). Of the five sampled middens, one was modern, and the other four yielded dates of 9,870 ± 80 14C yr BP (11,620 to 11,160 cal yr BP), 9,050 ± 120 14C yr BP (10,510 to 9,780 cal yr BP), 8,460 ± 100 14C yr BP (9,630 to 9,230 cal yr BP) and 3,000 ± 100 14C yr BP (3,400 to 2,920 cal yr BP) (Sharpe, 1991, 2002). Sharpe (2002) found that the location underwent a transition from a cool mesophytic community to a more xerophytic and warmer-adapted community between the construction of the 9,050 14C yr BP and 8,460 14C yr BP middens. Blue spruce (*Picea pungens*), limber pine, and common juniper (*Juniperus communis*) are not found after the 9,050 14C yr BP midden, and the former two taxa are not present at DINO today, indicating vertical displacement of at least 215 m (705 ft) below present. Mesophytic shrubs are also only found in the two older middens. The modern pinyon-juniper woodland was present before the construction of the 3,000 14C yr BP midden. The floral assemblage indicates that since the 9,870 14C yr BP midden was built, the January temperature has increased by 1 to 3 °C, the July temperature has increased by 3 to 10 °C, the January precipitation has decreased by half, and the July precipitation has decreased by two-thirds (Sharpe, 2002).

El Malpais National Monument (ELMA)

Undated and unstudied packrat middens are known from lava caves within ELMA (Rogers and Mosch, 1997; Tweet et al., 2009).

Gila Cliff Dwellings National Monument (GICL)

Undated and unstudied packrat middens are known from alcoves at GICL (NPS, 2008; Tweet et al., 2008).

Glen Canyon National Recreation Area (GLCA)

Ten fossil packrat middens have been described in detail from GLCA (Betancourt, 1990; Elias et al., 1992). Betancourt (1990) described seven middens from Long Canyon Cave, from an elevation of 1,390 m (4,560 ft) in central GLCA. These middens range in age from 17,400 to 2,400 14C yr BP. The oldest midden is unique as the only glacial-period midden from above 1,000 m (3,300 ft) in the Southwest without conifer fossils. The sequence shows that mesophytic plants disappeared from the area between 14,900 and 9,500 14C yr BP, replaced by more drought-tolerant forms. The Long Canyon Cave sequence is also a useful series to compare to GLCA's mammoth dung deposits, which formed between 12,900 and 11,700 14C yr BP (Betancourt, 1990). Elias et al. (1992) described insect fossils from three other middens at GLCA, finding multiple beetle taxa and a reduviid (assassin bugs, thread-legged bugs and wheel bugs). Two of these middens date to between 2,000 and 1,000 14C yr BP, while the third dates to 8,640 ± 140 14C yr BP (10,160 to 9,420 cal yr BP).

Fisher et al. (2006, 2009) described a series of 27 middens collected from five locations at GLCA. Pollen and plant macrofossils from these middens, all younger than 1,000 years old, were used to study the impact of grazing at the recreation area. After accounting for substantial inter-site variability, the authors found that middens from grazed areas contained fewer taxa than middens from ungrazed areas (particularly native grasses, herbs and shrubs), and that middens from grazed areas had more homogeneous floras (Fisher et al., 2006, 2009). Palatable plants are also more common in middens from ungrazed areas. Insect remains, bones and fecal pellets were found in the middens as well, but are undescribed (Fisher et al., 2006).

Other fossil middens are known from GLCA, but are undescribed. Fisher et al. (2006, 2009) also collected 14 middens between 1,000 and 17,000 years old, but did not describe them because these samples were beyond the scope of their study. They are to be described in the future (Fisher et al., 2009). Some undescribed GLCA middens, in alcoves high in the Navajo Sandstone, are too old for radiocarbon dating (H.G. McDonald and V.L. Santucci, unpubl. report for GLCA, 2000), which makes them of particular interest. Mead and Agenbroad (1992) noted the presence of a midden at Hooper's Hollow. Middens are common on ledges in Cove Canyon (H.G. McDonald and V.L. Santucci, unpubl. report for GLCA, 2000).

Golden Spike National Historic Site (GOSP)

Rhode (2000; personal commun., 2010) described two middens from GOSP as part of a larger study on the Bonneville Basin. One dates to 3,670 ± 50 14C yr BP (4,100 to 3,870 cal yr BP) and the other dates to 3,110 ± 50 14C yr BP (3,420 to 3,210 cal yr BP); both are from an elevation of 1,495 m (4,900 ft). Most of the plant taxa from the middens were shrubs, forbs, succulents and grasses, with Utah juniper as the only identified tree taxon; today the juniper is only found at higher elevations. A National Park Service geological resources inventory workshop also noted the presence of packrat middens from an undisclosed cave locality within GOSP (NPS, 1999), which may be a reference to Rhode's middens.

Grand Canyon National Park (GRCA)

The approximately 150 described packrat middens from GRCA are the most for any National Park System unit, and the park's midden record has both great depth and breadth. The Grand Canyon is 400 km (250 miles) long (Cole, 1990a), and elevations of midden sites within GRCA range from 440 m (1,440 ft) (Mead et al., 1978) to 2,200 m (7,220 ft) (Cole, 1990a), by far the greatest midden elevation range for any unit of the National Park System. GRCA middens have been dated from 46,370 ± 3,270 14C yr BP (Coats, 1997, 1998) to less than a thousand years old (Cole, 1981, 1990a). GRCA's geography gives it a complex biogeographical history, which can be studied through its middens. The park's modern vegetation includes elements of the Colorado Plateau, Great Basin, Mojave Desert and Sonoran Desert, as well as unique plant associations (Cole, 1990a). Important references for GRCA middens include: Wells (1976); Van Devender and Mead (1976); Phillips (1977, 1984); Van Devender (1977); Van Devender et al. (1977a, 1987); Mead et al. (1978, 2003); Van Devender and Spaulding (1979); Cole (1981, 1982, 1985, 1990a, 1990b); Mead and Phillips (1981); Cole and Mayer (1982); Mead (1981, 1983); Spaulding et al. (1983); Emslie (1988); Betancourt (1990); Dryer (1994); Emslie et al. (1995); Coats (1997); Anderson et al. (2000); Thompson and Anderson (2000); Kenworthy et al. (2004); Cole and Arundel (2005); and Coats et al. (2008).

Numerous midden sites have been described from GRCA; 30 sites are listed in the USGS/NOAA midden database. Most localities have fewer than six described middens, but some areas have numerous samples. For example, 26 middens were described from one area by Phillips (1977). Many of the localities are in cave sites, which also often include a variety of other fossils, particularly bones and mammal dung (Emslie, 1987, 1988; Mead and Agenbroad, 1992; Emslie et al., 1995; Spamer, 1992; Kenworthy et al., 2004). Plant fossils from middens dating approximately to the extinction of *Nothrotheriops shastensis*, the Shasta ground sloth (approximately 12,000 to 10,000 14C yr BP), help illustrate a setting that appears to have been climatically and floristically favorable to the animal's continued existence (Phillips, 1984).

Some midden sites also contain archeological material, such as cairns and split-twine figurines. Middens have been incorporated into the cultural resources in some cases, with multiple examples of cairns constructed wholly or partially from midden fragments. These midden cairns are associated with fossil material of the extinct mountain goat *Oreamnos harringtoni*, and the midden pieces selected for cairns often include visible fragments of mountain goat bones or dung. The cairns are part of cultural activities that occurred in the area between approximately 4,390 and 3,700 14C yr BP. It is thought that the people responsible for the cairns and figurines were making ceremonial visits to the remote locations, possibly as part of a hunting ritual. They may have recognized that the goat fossils belonged to animals that were no longer present. The Grand Canyon cultural/fossil sites are rare examples of artifacts deliberately associated with fossil resources; it is more common for fossils to be taken to cultural sites (Emslie et al., 1995).

The midden record indicates that the Grand Canyon had two major types of vegetation associations during the late Wisconsinan. At elevations between 450 and 1,450 m (1,475 to 4,755 ft), the dominant association was juniper and desertscrub; juniper is now present 800 to 1,000 m (2,625 to 3,280 ft) higher. From 1,450 to 2,200 m (4,755 to 7,220 ft), mixed-conifer forests were dominant, with quantities of Douglas fir, limber pine, Engelmann spruce (*Picea engelmannii*), white fir (*Abies concolor*), common juniper, and mountain lover (*Pachystima myrsinites*). Only Douglas fir and white fir are still found in significant numbers in the canyon, although now limited to higher elevations than the midden records (720 to 800 m [2,360 to 2,625 ft] higher). Elevation shifts of the vegetation zones were not simple vertical translations of entire plant communities. Much of the upward elevational shifting occurred between about 11,000 and 8,000 14C yr BP. Unique assemblages were present during the Early Holocene as these shifts were happening. The late Wisconsinan climate was cooler and wetter; by the Early Holocene, the summer temperature was similar to the modern, but with greater precipitation. The middle Holocene climate was slightly warmer and drier (Cole, 1990a).

Great Basin National Park (GRBA)

Great Basin National Park is within the Snake Range region, an area with numerous published packrat middens. The USGS/NOAA database has records for 57 middens in the Snake Range, of which four appear to be within or immediately adjacent to GRBA. The four middens designated Wells #12, #14, #15 and #16 derive from a location that is approximately on the eastern border of GRBA, shared with a section of the Humboldt–Toiyabe National Forest. These middens have been described by Thompson (1984, 1990) and Wells (1983). All four middens come from an elevation of 2,040 m (6,690 ft). Their ages are clustered between 11,895 ± 270 14C yr BP (14,630 to 13,190 cal yr BP) and 11,035 ± 250 14C yr BP (13,410 to 12,520 cal yr BP) (Wells, 1983). Within the larger Snake Range midden series, these middens are among a group of middens of late glacial age (14,000 to 10,000 14C yr BP), which record part of the shift to the modern vegetation in the region (Thompson, 1990).

Guadalupe Mountains National Park (GUMO)

Five middens from three locations have been described from GUMO. They are part of a larger midden series from the Guadalupe Mountains. Two groups of two were found in east-central GUMO. The first pair was found at an elevation of approximately 1,500 m (4,920 ft). One is probably very young, based on its inclusions (Van Devender et al., 1977b). The other has been dated to 12,040 ± 210 14C yr BP (14,650 to 13,410 cal yr BP) (Mead et al., 1978). Its source vegetation was a pinyon-juniper woodland (Van Devender and Spaulding, 1979; Van Devender et al., 1979). The other pair was found a short distance to the north, at an elevation of 2,000 m (6,560 ft) (Mead et al., 1978). They are roughly the same age. One dates to 13,060 ± 280 14C yr BP (16,820 to 14,790 cal yr BP), and the other, an unindurated midden, dates to 13,000 ± 730 14C yr BP (17,450 to 13,490 cal yr BP). These two middens were dated from fossils of spruce (*Picea* sp.), which no longer grows in the area (Mead et al., 1978). Dwarf juniper is also present in the other pair of middens, but absent from the local modern vegetation (Spaulding, 1984). The middens and megafaunal dung from the caves show that the initial mixed conifer forest of spruce, dwarf juniper, Douglas fir, and southwestern white pine was replaced by a juniper grassland after 11,500 14C yr BP (Van Devender et al., 1977b; Van Devender and Spaulding, 1979). Today the area supports desert scrub (Van Devender et al., 1979). Finally, an undated midden has been described from northeast GUMO, at an elevation of 1,610 m (5,280 ft). It includes young, unconsolidated midden material dominated by pieces of *Quercus grisea* (gray oak), *Celtis reticulata* (hackberry) and *Nolina microcarpa* (sacahuista), as well as pollen and abundant packrat dung (Wells, 1976).

Jewel Cave National Monument (JECA)

Cave fill at JECA has yielded a variety of fossils, including packrat middens. The middens are abundant, and there is even a cave within the monument named "Midden Cave" (B. Schubert, B. Agenbroad and L. Agenbroad, unpubl. report for JECA, 1995; Santucci et al., 2001). The ages of these fossils are not known, but it is thought that most are from the late Pleistocene or Holocene (Santucci et al., 2001). They represent the northeasternmost packrat middens known from a National Park System area at this time.

Joshua Tree National Park (JOTR)

JOTR middens have been mentioned in several documents (Lanner, 1974; Lanner and Van Devender, 1998; Arundel, 2000), but have only been extensively published since 2007 (Holmgren et al., 2007, 2010). Holmgren et al. (2010) collected more than 100 middens from a number of sites at JOTR. Elevations ranged from 930 to 1,357 m (3,051 to 4,452 ft). Thirty-eight middens were dated, with ages ranging from more than 47,200 14C yr BP to 1,225 ± 15 14C yr BP (1,236 to 1,073 cal yr BP), although only four were older than 10,000 14C yr BP. Unlike some National Park System areas in this report, the JOTR middens show a stable floral assemblage for the late Pleistocene and Holocene, with few immigrant taxa during the late Pleistocene and early establishment of the modern flora. The few extralocal plant taxa that were found suggest contradictory climate states for the late Pleistocene. The record also indicates that vegetation changes due to the appearance of invasive species in recent decades are not comparable with vegetation changes during the rest of the Holocene (Holmgren et al., 2010).

Lake Mead National Recreation Area (LAME)

A handful of middens has been described from three general areas at LAME: the Black Mountains of Arizona, Iceberg Canyon on the north side of Lake Mead in Nevada and the Newberry Mountains of southern Nevada. The middens of the Newberry Mountains are by far the best known. Leskinen (1975) noted the presence of 30 middens in a study area of about 0.8 km^2 (0.3 $miles^2$) with an elevation of 850 m (2,790 ft). Four dates have been published for middens from the general Newberry Mountains area: 15,000 ± 1,600 14C yr BP (21,610 to 13,620 cal yr BP) (Mead et al., 1978), 13,380 ± 300 14C yr BP (16,980 to 15,150 cal yr BP) (Leskinen, 1975), 12,625 ± 150 14C yr BP (15,510 to 14,140 cal yr BP) (Wells, 1983) and 9,500 ± 240 14C yr BP (11,410 to 10,190 cal yr BP) (Leskinen, 1975). Additionally, two middens have been described from Sacatone Wash in the Newberry Mountains, from an elevation of 730 m (2,400 ft). These middens date to 19,620 ± 600 14C yr BP (23,930 to 22,660 cal yr BP) and 9,490 ± 150 14C yr BP (11,210 to 10,390 cal yr BP). They have fossils of *Pinus monophylla* (single-leaf pinyon) and the oak species *Quercus dunnii*, representing the first reports of late Pleistocene oaks in the Mojave Desert (Leskinen, 1975). The Newberry Mountains sites indicate pinyon-juniper woodlands were present during the late Wisconsinan (Leskinen, 1975; Van Devender et al., 1987). Wells (1983) found the principal conifer of the 19,620 and 12,625 14C yr BP middens to be Utah juniper, with smaller amounts of Colorado pinyon. Juniper disappeared from the Newberry Mountains after the formation of the youngest dated midden (Leskinen, 1975; Van Devender et al., 1987).

The other published midden localities of LAME have only been discussed briefly. One midden from an elevation of 548 m (1,798 ft) in the Black Mountains has been dated to 11,525 ± 150 14C yr BP (13,720 to 13,120 cal yr BP). Utah juniper dominates the conifer fossils from this midden (Wells, 1983). Jass (1999) noted the presence of middens in a cave in the Black Mountains. Finally, a midden from an elevation of 425 m (1,390 ft) in Iceberg Canyon has been dated to 11,010 ± 400 14C yr BP (13,750 to 11,820 cal yr BP) (Mead et al., 1978). It contained abundant juniper twigs (Phillips, 1984).

Lava Beds National Monument (LABE)

Middens have been found in the lava tubes and rock shelters of LABE, and several have been described by Mehringer and Wigand (1984, 1987). In both publications, the focus was on prehistoric distribution of western juniper (*Juniperus occidentalis*). Seven middens have been sampled and dated; all date to the last few thousand years, with a range of 5,265 ± 75 14C yr BP (6,210 to 5,910 cal yr BP) to 1,260 ± 80 14C yr BP (1,310 to 1,050 cal yr BP). Aside from juniper, the middens have yielded a variety of fossils of trees, forbs, grasses, and mosses (Mehringer and Wigand, 1987).

Mesa Verde National Park (MEVE)

Recent packrat middens are present at MEVE. Samples of some are preserved in park collections by 29 specimens that have been dated to 100 ± 50 years ago (G. Cox, personal commun., 2009). They are otherwise unpublished.

Mojave National Preserve (MOJA)

Several late Pleistocene-age middens have been described from Clark Mountain in the northernmost part of MOJA. Additionally, two mid-Holocene middens have been briefly described from an area of the Mescal Mountains just outside of the preserve (Koehler et al., 2005). Three of the Clark Mountain middens came from a single rock shelter at 1,910 m (6,270 ft). They date to 28,720 ± 1,800 14C yr BP (36,740 to 29,750 cal yr BP), 23,600 ± 980 14C yr BP (30,390 to 25,940 cal yr BP) and 12,460 ± 190 14C yr BP (15,200 to 13,930 cal yr BP) (Mehringer and Ferguson, 1969). A fourth midden was collected at 2,100 m (6,890 ft) and dates to 19,900 ± 1,500 14C yr BP (27,690 to 20,280 cal yr BP) (Spaulding, 1977). The two oldest middens were mostly constructed of needles from limber pine and *Pinus longaeva* (intermountain bristlecone pine; originally identified as *P. aristata* [Rocky Mountain bristlecone] but identified as *P. longaeva* in more recent references), with lesser quantities of white fir and Utah juniper fossils. The assemblages from these middens indicate that interpluvials of the Pleistocene were not as hot and/or dry as those of the present (Mehringer and Ferguson, 1969). The 2,100 m midden also included bristlecone and limber pine needles (Spaulding, 1977). The youngest midden (12,460 14C yr BP) was dominated by fossils of Utah juniper and single-leaf pinyon, with lesser amounts of white fir and limber pine. Characteristics of the pinyon wood indicate that conditions were moister at the rock shelter at that time than at present anywhere on Clark Mountain. Bristlecone and limber pine are no longer found on Clark Mountain, and white fir is only present in a protected isolated stand; all three were living at lower elevations during the periods when the published middens were being formed (Mehringer and Ferguson, 1969). The assemblages show overlap of pinyon-juniper woodland with limber pine and white fir during late glacial times, followed by takeover by pinyon-juniper woodland before the beginning of the Holocene (Wells, 1983).

Natural Bridges National Monument (NABR)

Numerous packrat middens are known from a large, flat-floored rock shelter at NABR, along with bones and dung of the extinct mountain goat *Oreamnos harringtoni*. The middens include both indurated and unconsolidated examples. At least two layers rich in *Oreamnos* dung and three primary layers of packrat middens are present in the rock shelter, in a roughly 100 cm (40 in) thick stratigraphic column that took over 30,000 years to form. Midden material in the layers has been dated to 21,330 ± 240 14C yr BP (26,200 to 24,880 cal yr BP) and 9,660 ± 160 14C yr BP (11,410 to 10,510 cal yr BP), but at least some undated material is older. Plant macrofossils include several species that no longer grow nearby, such as Engelmann spruce, limber pine, and Douglas fir (Mead et al., 1987). The middens also include unspecified skeletal remains (Mead et al., 1987).

Organ Pipe Cactus National Monument (ORPI)

The Ajo Range and the Puerto Blanco Mountains in east-central ORPI are important locations for fossil packrat midden studies. Eleven middens have been described from the Ajo Range (seven from Alamo Canyon and four from Montezuma's Head), and 21 from the Puerto Blanco Mountains (ten from Ajo Loop, seven from Twin Peaks, and four from Cholla Pass) (USGS/NOAA, no date). Plant macrofossils (Van Devender, 1977, 1982, 1987b, 1990b; Spaulding, 1983; Van Devender et al., 1990), pollen (Davis and Anderson, 1987; Davis, 1990), arthropods (Hall et al., 1989, 1990), and vertebrates (Mead et al., 1983; Van Devender et al., 1991) have been described from these middens, providing a detailed picture of the vegetation, climate and terrestrial microfauna present in ORPI over approximately the last 35,000 years.

The seven middens from Alamo Canyon in the Ajo Range were collected from elevations of 855 to 915 m (2,805 to 3,000 ft). The three oldest middens have dates ranging from 32,000 ± 4,400 14C yr BP (44,560 to 28,010 cal yr BP) to 14,500 ± 300 14C yr BP (18,170 to 16,960 cal yr BP). They are interpreted as representing a pinyon-juniper-oak woodland paleoenvironment (Van Devender et al., 1991). The other four middens span the Holocene. They form a sequence from juniper-oak woodland paleoenvironments to oak-juniper chaparral to Sonoran desertscrub/chaparral in the most recent (Van Devender et al., 1991). Aside from plant remains, fossils of toads, snakes, lizards, birds, shrews and rodents have been described from some of these middens (Van Devender et al., 1991). The presence of an anguid lizard in one is notable because anguids are not found in ORPI today (P. Holm, personal commun., 2008). The four middens from Montezuma's Head in the Ajo Range were collected from an elevation of 975 m (3,200 ft). They range in age from 21,840 ± 650 14C yr BP (27,900 to 24,550 cal yr BP) to 13,500 ± 390 14C yr BP (17,460 to 15,080 cal yr BP). They are interpreted as representing a pinyon-juniper-oak woodland paleoenvironment. Lizard, bird, shrew, rodent and rabbit fossils have been described from them (Van Devender et al., 1991).

The ten middens from Ajo Loop in the Puerto Blanco Mountains were found at elevations of 535 to 550 m (1,755 to 1,805 ft). They range in age from 7,970 ± 130 14C yr BP (9,140 to 8,520 cal yr BP) to the present. The two oldest, predating 7,500 14C yr BP, are interpreted as representing a cool Sonoran desertscrub paleoenvironment, and the eight younger middens are described as representing a subtropical Sonoran setting (Van Devender et al., 1991). Grasses (Van Devender et al., 1990), arthropods (including beetles, ants, antlions, burrowing bugs, kissing bugs, soldier flies, millipedes and scorpions; Hall et al., 1990), and vertebrates (including snakes, lizards and rodents; Van Devender et al., 1991) have been described from Ajo Loop middens.

The seven middens from Twin Peaks in the Puerto Blanco Mountains were collected at elevations of 550 to 580 m (1,805 to 1,900 ft). They range in age from 14,120 ± 260 14C yr BP (17,870 to 16,770 cal yr BP) to 1,910 ± 50 14C yr BP (1,950 to 1,720 cal yr BP). The oldest midden is thought to represent a juniper-Joshua tree woodland paleoenvironment, with progressively younger middens representing juniper/Sonoran desertscrub, cool Sonoran desertscrub and subtropical Sonoran desertscrub paleoenvironments (Van Devender et al., 1991). Grasses (Van Devender et al., 1990), arthropods (including beetles, cicadas, ants, silkmoths, soldier flies, orthopterans, millipedes, isopods and scorpions; Hall et al., 1990) and vertebrates (including lizards, shrews, rodents, and rabbits; Van Devender et al., 1991) have been described from Twin Peaks middens.

Finally, the four middens from Cholla Pass in the Puerto Blanco Mountains were collected at elevations of 590 to 605 m (1,935 to 1,985 ft). Three date from 10,540 ± 250 14C yr BP (12,940 to 11,600 cal yr BP) to 8,790 ± 210 14C yr BP (10,400 to 9,430 cal yr BP), and one is much younger, from 3,440 ± 90 14C yr BP (3,920 to 3,470 cal yr BP). The three older middens are interpreted as coming from a juniper/Sonoran desertscrub paleoenvironment, while the youngest is described as representing a subtropical Sonoran desertscrub paleoenvironment (Van Devender et al., 1991). Grasses (Van Devender et al., 1990), arthropods (including beetles, ants, antlions, burrowing bugs, soldier flies, millipedes, scorpions and false scorpions; Hall et al., 1990), and vertebrates (including lizards, birds and rabbits; Van Devender et al., 1991) have been described from Cholla Pass middens.

Pipe Spring National Monument (PISP)

Modern midden material was recovered from Pipe Spring National Monument in 1995 (J. Leasor, personal commun., 2011).

Saguaro National Park (SAGU)

Packrat middens are known from SAGU (D. Swann, personal commun., 2008), but the only published example is a midden designated Tucson Mountains #3 (TM3) (Van Devender, 1973; Mead et al., 1978), which would be within current SAGU West boundaries if found today. It was found in the vicinity of Picture Rocks Pass (T.R. Van Devender, personal commun., 2008), at an elevation of 740 m (2,430 ft) and dates to 21,000 ± 700 yr BP (27,020 to 23,340 cal yr BP) (Mead et al., 1978). Its fossils are dominated by *Aplopappus cuneatus* (wedgeleaf), followed by *Juniperus*, *Agave* and *Opuntia chlorotica* (dollarjoint prickly pear) (USGS/NOAA no date). TM3 is described as coming from a pinyon-juniper-oak woodland paleoenvironment (T.R. Van Devender, personal commun., 2008).

Timpanogos Cave National Monument (TICA)

A number of bones have been found at TICA associated with packrat middens (George, 1999; Santucci et al., 2001; Santucci and Kirkland, 2010). Several sites were discovered in the early to middle 1990s during cave surveying and fill removal. Most of the specimens are mammal bones, particularly from rodent and small carnivorans, but a snake mandible and bird bones were recovered as well. The specimens are thought to date to the Holocene (George, 1999).

Wupatki National Monument (WUPA)

WUPA middens have been described in several publications (Cinnamon, 1988; Cinnamon and Hevly, 1988; Betancourt, 1990; Lanner and Van Devender, 1998; Ironside, 2006; Ironside et al., 2007). Twenty-two middens have been described from the monument: thirteen from Cedar Canyon, five from Box Canyon and four from sites in the Doney Mountain Monocline. Fifteen are younger than 1,000 14C yr BP. Of the other seven, three came from an elevation of 1,550 m (5,085 ft) on Cedar Canyon and date to between 2,000 and 1,000 14C yr BP. The other four date to between 13,670 ± 110 14C yr BP (17,060 to 16,510 cal yr BP) and 10,890 ± 680 14C yr BP (14,240 to 10,590 cal yr BP), and were recovered from the Doney Mountain Monocline at elevations of 1,500 to 1,530 m (4,920 to 5,020 ft) (Cinnamon, 1988; Betancourt, 1990). These middens were dominated by Colorado pinyon and Rocky Mountain juniper (Betancourt, 1990). Of the middens younger than 2,000 14C yr BP, Cinnamon (1988) and Betancourt (1990) note a gap of 800 years at the same time WUPA had intensive human occupation, which they suggest may be due to human predation on packrats.

Yellowstone National Park (YELL)

Lamar Cave formed in Eocene volcaniclastics in northeastern YELL.

It contains Holocene fossiliferous deposits from an elevation of 1,835 m (6,020 ft) (Hadly 1996). The Lamar Cave fossil deposits are a combination of packrat midden and carnivore den materials (Hadly, 1999; McGill et al., 2005). They have yielded abundant bones from fish, amphibians, reptiles, birds and mammals, with deposition beginning around 3,000 14C yr BP and continuing to the present. Unlike other middens, the Lamar Cave deposits have been of interest for their mammal fossils, not their plant fossils. The mammals found at the cave indicate that the local climate was cooler and moister before about 1,200 years ago (Hadly, 1996). Other publications that discuss Lamar Cave fossils include Steele and Hadly (2002, 2003) and Porder et al. (2003).

IMPLICATIONS AND FUTURE WORK

Fossil packrat middens are widely distributed in National Park System units and can be applied to a number of questions. They are one of the most important paleoclimate proxies in western North America. Their records of local biotic responses to the surroundings make them useful for land management purposes, not only for forecasting responses to climate change, but also responses to other disturbances, such as how a landscape will change after pasturing is prohibited. Additionally, middens offer valuable paleontological snapshots, which can be applied to studies of dispersal and evolution.

Going forward, there is still a great deal of work that can be done using National Park Service middens. Further surveys of the areas discussed above and other units in the same areas will expand the National Park Service's midden record. Outside of plant macrofossils and pollen, many of the fossils contained in middens have received relatively little attention to date; fossil categories with potential include arthropods, microvertebrate remains and the copious coprolites of the rodents themselves, which are all often mentioned as present, but unstudied. Middens also have much untapped potential as educational tools: their fossils can directly illustrate vanished ecological settings for park visitors and their unusual genesis can be used to attract attention in a visitor center. At this time, Arches National Park and Organ Pipe Cactus National Monument have exhibits about packrat middens in their visitor centers. Other avenues for future work could include a cross-park initiative to further research (which as noted has typically been done by individual researchers), perhaps incorporating a centralized archive to ensure standards of curation and access. It is hoped that this document will increase awareness of fossil packrat middens in the National Park System and their utility for climate studies, land management and paleontology.

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NOTE ADDED IN PROOF

City of Rocks National Reserve (CIRO)

Recent fieldwork found a packrat midden dating back to at least the Pleistocene/Holocene boundary. The midden record of this Idaho reserve is being used in conjunction with charcoal to detail its Holocene climate and fire history (Weppner et al., 2010).

Grand Canyon - Parashant National Monunment (PARA)

Undescribed packrat middens have been found in this Arizona monument (Covington, 2003).

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